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Craig T. Christy

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Craig T. Christy

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Usually, authors include a page to thank people for contributions to getting a project done.

I'd like to thank the United States Selective Service System for providing the motivation that made me stay in school in hopes of avoiding the draft and thus complete an engineering degree in four years.

I passed the Engineers in Training exam in the spring.  
I received my draft notice the following November.

I served for two and a half years.

Oh, well.

Craig T. Christy, P.E.  
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# INTRODUCTION

1

Not included on the CD-ROM

## ENGINEERING with the SPREADSHEET

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A B C D E F G H I J K L

### INTRODUCTION

The text of this manual has been assembled in Microsoft's Excel spreadsheet program.

This manual and CD-ROM are intended for use by professional engineers and college students alike. Examples include fundamental concepts and complex designs.

The spreadsheet is becoming an essential engineering tool. It allows the user to create consistent calculations and presentations and reduce the time spent on both routine and complex calculations. This manual puts you in touch with many of the tools you need to do your work.

row 20

You, as an engineer, must understand the calculations you produce. Computer program answers and choices from tables are good if documentation is provided. "Black box" and table answers without documentation don't demonstrate professional understanding. What's more, codes can be interpreted in different ways by other engineers and building officials. This requires the ability to adjust the program or spreadsheet templates to meet these varied requirements. Also, no program or template will answer all of the possible combinations of inputs and required outputs.

row 30

Stated another way, due diligence is required. There is no such thing as "engineering-in-a-can" -- blind faith in computer solutions does not serve as due diligence.

The templates on the CD-ROM are completely open to your view and can be modified to suit your needs. Put your own logo in place of the "Consulting Company" logo, but please leave the *Engineering with the Spreadsheet* title and the **Copyright 2006 American Society of Civil Engineers** somewhere in the header.

The templates are yours to use and may be issued to the Building Department and other authorities, customers, and interested parties but may not be repackaged and resold. If you use a template as part of another, new application that you intend to sell, be sure to leave an appropriate attribution next to the parts of the template you have adapted and contact ASCE to make any other arrangements to assure that you stay within the law.

row 40

This book was started twenty years ago as a means of keeping notes for using Lotus 1-2-3.

These notes evolved into a manual for short seminars and then as a 400 level class at Portland State University entitled "Engineering with the Spreadsheet." Over the years, more and more material was created for a host of engineering projects. Some of that material has been edited for this manual and the included CD-ROM.

row 50



# INTRODUCTION

Not included on the CD-ROM

# 1

## ENGINEERING with the SPREADSHEET

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A B C D E F G H I J K L

### INTRODUCTION -- Continued

We start out with how to use the spreadsheet as engineers. That's a few of the basics. The last chapter in this section is "Takedown." This is used at the beginning of class to make sure that everyone is on the same page. Many inexperienced users who come to class will get out a calculator to do work that should be done by the spreadsheet.

Advanced applications start with the "Regression Analysis" chapter. This chapter was created to help me with beginning statistics and back up some testing that I was doing on shear walls for a customer. This is the stuff that we were supposed to learn in college -- but didn't.

row 60

The "Pole" chapter begins the process of addressing the issues of presentation as do all of the design templates. It is important to present calculations that can be reviewed by someone else. This entails an audit trail that is visible on the printed calculation and documentation. Pictures and diagrams are a big help. Range name your variables for reviewing the template itself. You can use the spreadsheet's drawing tools to highlight information, draw arrows from a cell to dependent cells, create diagrams, and so on.

There are complete calculation sets in the manual which start with the cover page and table of contents followed by calculations for seismic, wind loads and the actual design from the top of the structure to the anchor bolts and soils. I feel that this is rarely done in engineering textbooks because any calculation set will contain errors and debatable philosophical issues. If you ask five engineers to design something a little out of the ordinary, you'll get seven answers. Engineering is as much an art as it is a science.

row 70

Finally, the manual contains a comprehensive collection of concrete design templates. The manual is setup so that examples are complete and you can follow the entire design process.

The templates use Imperial input and output units. The American Concrete Institute (ACI) and the International Building Code (IBC) use Imperial units. The IBC follows Imperial units with SI (System Internationale) units, the ACI does not. Word on the street has it that even Europe is having difficulty with SI units. The old meters-kilograms-seconds (mks) system is much easier to handle and less error prone. If the elites had let well enough alone, we might be using the mks system by now. The "Units" chapter contains conversions for Imperial to mks and SI and, conversely, SI to Imperial and mks. Unit conversions are presented as active formulas rather than tables which can be more easily misinterpreted.

row 80

Many of the templates contain formulas with numbers and units and with formulas comprised of units only. This is unit analysis which is vital to understanding the design and getting the right answer.

row 90



# INTRODUCTION

# 1

Not included on the CD-ROM

## ENGINEERING with the SPREADSHEET

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A B C D E F G H I J K L

### SOME HISTORY

In the beginning, in the land of WA there was Bill Gates and Michael Allen and a host of few. They struck a deal with the giant IBM and a "hacker" who had an operating system that operated with the Intel chip sets of the day. They bought the operating system and named it QDOS (quick and dirty operating system).

**fool proof** nothing is so foolproof that some talented fool can't make a mess of it

anything that can go wrong will go wrong -- so design accordingly

IBM's first attempt at a personal computer didn't work out. Management turned the project over to a "skunk works" that came up with the first usable IBM PC. The leader died in an airline crash coming into Dallas, Texas. I met and shook the left hand of one of the survivors (also with IBM) of that mishap -- his badly burned right hand held a beer.

**hacker** in the "old days" (1980) a hacker was someone who banged out code for whatever purpose. I was considered a hacker because I used the spreadsheet and other applications to do engineering. Now the term "hacker" has a bad connotation.

Mich Kapor sat down next to Dan Bricklin on another airliner. Dan Bricklin had created VisiCalc for the APPLE Computer, Altos, and others. It was on Dan Bricklin's electronic spreadsheet that I first learned the power of this medium. I still have books and programs bearing his name in my library.

**WA** Washington State

Mitch Kapor started the LOTUS company in the land of MA. Lotus started out with a staff of about 50. Lotus created a spreadsheet that worked with QDOS on the IBM PC.

**MA** Massachusetts State

**OR** Oregon State

QDOS and Lotus helped IBM launch the personal computer revolution in the early '80's. Lotus brought out the LOTUS 1-2-3 spreadsheet. This was good -- especially the release 2 version. MICROSOFT kept growing through various means. Eventually, Microsoft brought out EXCEL in direct competition with LOTUS. We now have EXCEL.

row 120

This manual was originally based upon Lotus 1-2-3. It was meant to be generic. This revised manual will, hopefully, be generic also. Its principles should transcend all sorts of software.

This manual (and disk) are aimed at presentation as much as analytical capability. Your spreadsheet template can be complete and accurate but, if it looks ugly, people will not read it. However, if both the template and the printed document use diagrams, pictures, and an audit trail, people will take your spreadsheet presentation seriously and use it. That's the whole point.

row 130



**NOTES**

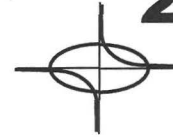
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A B C D E F G H I J K L M N

This section of the page is a large grid intended for taking notes. The grid is composed of vertical and horizontal lines forming small squares. On the right side of the grid, row numbers 20, 30, 40, 50, and 60 are printed. A small black dot is located in the upper left quadrant of the grid, specifically at the intersection of column F and row 20.

**PART 1:**  
**A FEW OF**  
**THE BASICS**





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\_2 Tips.xls

**USING THIS BOOK AND CD**

If you have a question or comment, e-mail to: [ice-or.com](mailto:ice-or.com) website: <http://www.ice-or.com>  
Send your spreadsheet if that will help. This is much faster and easier to understand than a phone conversation. We can always talk later.

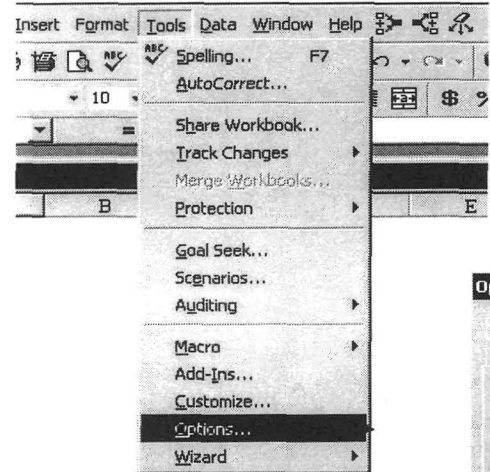
Make an **ARCHIVE COPY** of your disk before using it **OR**, copy your disk onto your hard drive and then archive the original disk.

A spreadsheet template is not meant to be tight code. The spreadsheet gives us the opportunity to provide a clear audit trail and uncomplicated code.

row 20

Keep file naming consistent. Develop your own standard format based upon date performed, job #, and etcetera, so that files will be easy to find in the future. For example, saving a job on September 15, 1997 might be given the name: MY091597file or MY 091597 file.

Explore the graphing features in the demonstration files. Graphics are an excellent troubleshooting tool. Excel allows you to locate your graph adjacent to your calculations.



row 30

Templates may be set to a recalculation mode through the Excel Tools menu. When using manual recalculation, press the [F9] key to recalculate.

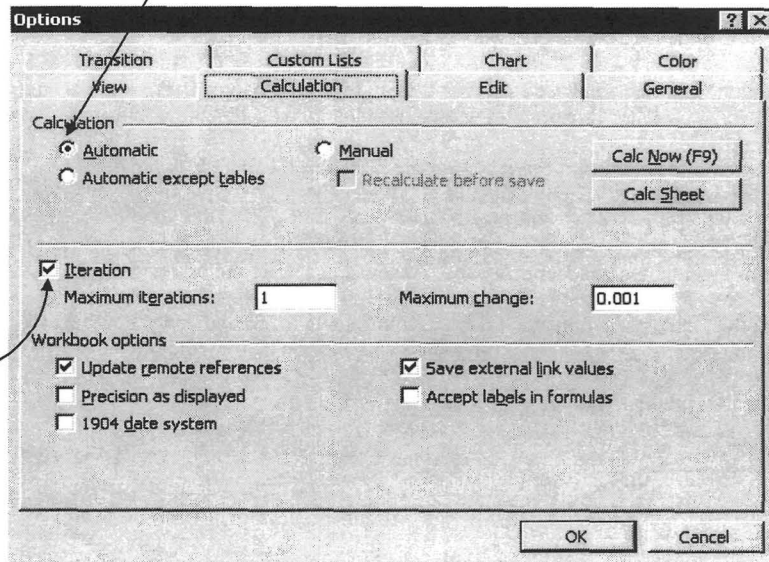


Figure 2-1 The Tools drop down menu.

You may also set the calculation mode to iteration. This is important for some templates.

Figure 2-2 The Options menu.

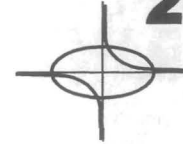
When doing an example, make sure that the input values in your template completely match the values in the figures, otherwise your answer may differ from the manual's.

Use the spreadsheet as a calculator. With practice, this becomes faster and more reliable than using the hand-held calculator.

row 70



TIPS



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A B C D E F G H I J K L M N  
USING THIS BOOK AND CD -- Continued

Using a ZIP file makes life a bit easier in that, when you need several files from a CD-ROM, you can copy and unzip a directory to hard disk without having to set each file from Read Only to Archive status in the file Properties menu.

HIJAAK PRO by QUARTERDECK was used to "screen capture" images like the one above. Other images were created with AutoCAD and then copy-clipped into the spreadsheet. Still, other images and diagrams were made with native Excel drawing tools. Some screen captures were made with the [Print Screen] key located on your keyboard.

row 80

A collection of print density arrangements are used in this manual. All sheets use a 9 or 10 line header which repeats with each printed page.

Each page is approximately 50, 60, 70, or 80 lines deep. The 80 line format most closely represents the old 132 characters per line format with lines and columns spaced at multiples of 1/8 inch. This gets a little small to read and fax but it is the easiest module to create.

All sheets are labeled at 10 row intervals. This helps in organizing work and with phone conversations. People rapidly adapt to using row numbers instead of page numbers or, where row numbers are duplicated because of using other templates, then use a page number or file name with a row number.

row 90

The black bar at the top of the sheet names the module below and sometimes contains other information. Row numbers may be included in this bar or just above it. Black bars within the page usually terminate at column G or H.

Also, in the repeated header, the columns are labeled. Almost all of ICE's templates use columns A through N. It just seems to work better that way.

The repeating header should also contain the time, date, and filename. These are real time savers when you need to find a file to reuse or determine which is the most recent and (probably) valid calculation.

row 100

Include some type of graphic symbol in the header to identify the module or project. Engineers, in particular, really appreciate this.

Write VOID in red pencil on discarded calculations and throw them into a box for safe keeping. Use a red pencil because it can be erased if necessary. You must use white-out or a large white label with red ink.

The spreadsheet template is meant to be easy for anyone to follow and verify. For that reason, information is arranged in columns. The column arrangement may include logic matrices.

row 110

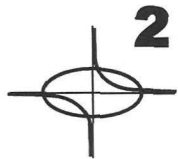
The standard template layout is:

label	variable	unit	explanation	notes and documentation
m		3 unitless	slope	reference the books you use by chapter and page number
X		1 in	measurement along the X-axis	
b		6 in	Y intercept at X = 0	reference codes by code number and date
Y		9 in	$m * X + b$ $3 * 1 \text{ in} + 6 \text{ in}$	explain the meaning of labels m slope of a straight line
Y		9 in		

row 120

Figure 2-3 Our standard template layout for ease of use.

row 130



Christy  
09:27  
07/03/06

ENGINEERING with the SPREADSHEET

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\_2 Tips.xls

A B C D E F G H I J K L M N

**USING THIS BOOK AND CD -- Continued**

Or highlight and make notes by hand -- which is probably the best way to draw someone's eye to your conclusion.

Also, a few hand written comments and parallel calculations in the notes column G through N will demonstrate to others that you actually did the work.

row 140

**Cautions**

Don't move an input value into another input cell. Instead, copy the input to another location with the spreadsheet Copy Paste commands -- [Ctrl] [c] and [Ctrl] [v] are the keyboard shortcut commands.

Putting labels instead of values or formulas into numerical cells returns a 0 (zero) value. Dividing by a label will yield a #NAME? flag in the template. Dividing by 0 yields a #DIV/0! flag.

Move an entire template to another template with the Cut and Paste commands. This preserves your absolute references.

row 150

Check your input and results with graphing.

Do the math in your head.

Anyone of questionable ability can alter the template. It is not compiled programming code. Results can be tampered with.

Try to keep all columns the same width. Format the entire sheet as 10 point Arial font vertically centered in the cell(s).

row 160

Avoid complicated sheet formatting -- complication will always come back to bite you.

Use a space between math operators and the variables or numbers in your presentation. For example:

$$(5 * 2 + 3) * m / b$$

When displaying an equation as active numbers in a text/formula string, the ^ symbol and traditional spreadsheet math characters must be used because nothing can be formatted in a formula string. However, the Symbols Chapter does have characters that are useful in formula strings. Look through the templates for examples.

row 170

**Using Textbook Examples**

Textbooks and references are often compiled by typists who don't understand the material and arranged and typeset by people who can't possibly be expected to know much about what they are working with or their audience. For this reason, figures and diagrams are located away from the text and the text has subtle errors. Examples are often broken up over several pages and mixed in with other examples. Examples are provided without values and units that help to explain the meaning of those values.

row 180

The copy machine has been readily available to most of us for the last 30 years. To create a preliminary template layout, copy the parts of the text or reference book you need and then cut and paste the examples into an orderly, modular format. Regular cellophane tape and copy paper works well. Don't use old printouts because you may not know which side, at a glance, has your information.

Code books usually present the principle formulas first followed by the supporting values and formulas. Spreadsheet modules are typically laid out so that each successive formula builds on the previous formulas. In this way, each formula references inputs and formulas above it and not below -- this works well for an audit trail and troubleshooting.

row 190



A B C D E F G H I J K L M N  
**ADJUSTING EXCEL FOR EASE OF USE**

There are a lot of things about *Lotus 1-2-3* that were easier to use than Excel fresh out of the box.

For math intensive work, you can set some of the Excel operating parameters to work like 1-2-3. This manual is based upon using the Transition formula evaluation and Transition formula entry features.

In the Excel Tools menu, be sure to enable:

- Transition navigation keys
- Transition formula evaluation
- Transition formula entry

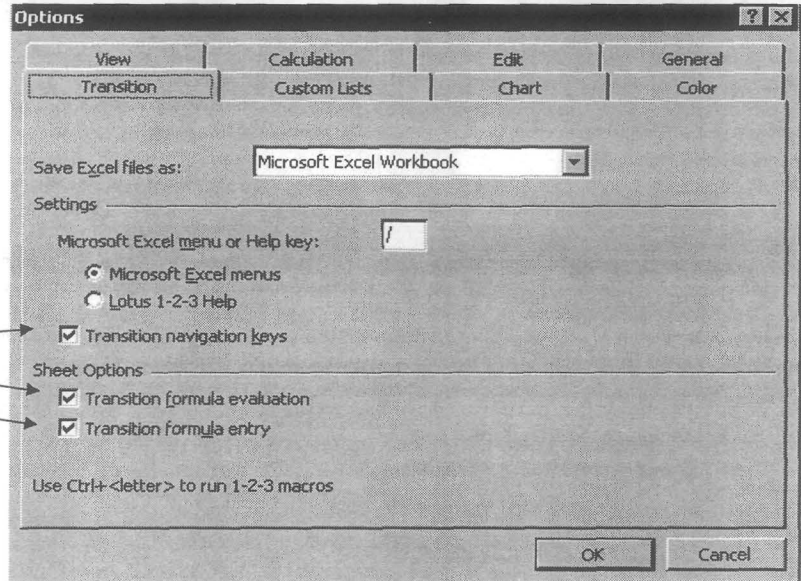


Figure 2-4 The Options menu with "Transition" choices.

- Edit directly in cell
- Allow cell drag and drop
- Alert before overwriting cells

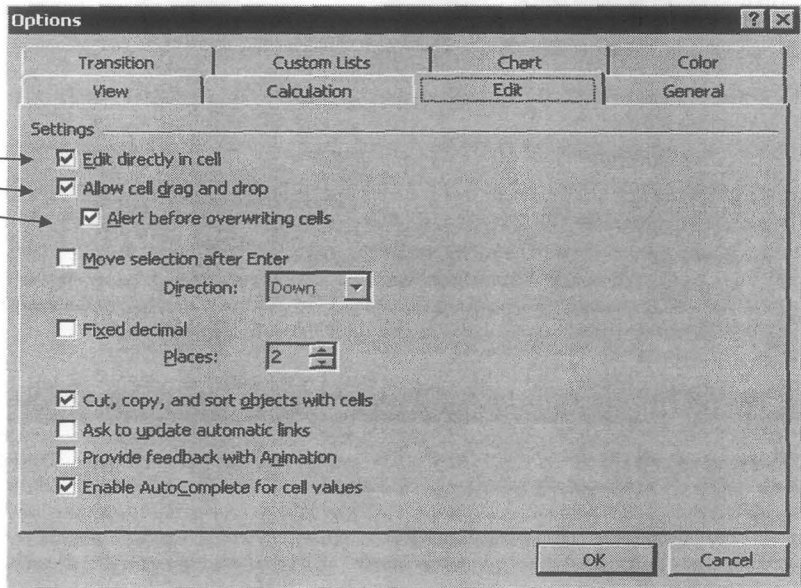


Figure 2-5 Check off "Edit" in the Options menu.



A B C D E F G H I J K L M N  
**PRINTING A DIRECTORY**

**Method 1**

Bring up your **Windows Start** menu and select **Accessories** and then **Command Prompt**.

**Command Prompt** brings up what is essentially an old fashioned **DOS** window.

Type in **cd** which is the DOS command for "change directory." Type in the appropriate directory name.

In this case, the directory name is **#SES**. The **#** puts the directory name close to the top of the directories list. **SES** stands for *Science and Engineering with the Spreadsheet* -- the name of the manual in the early '80's.

Type in **dir > directory** where **dir** is a DOS command, space, greater than sign, space, and some type of file name such as "directory."

Then hit the **[Enter]** key.

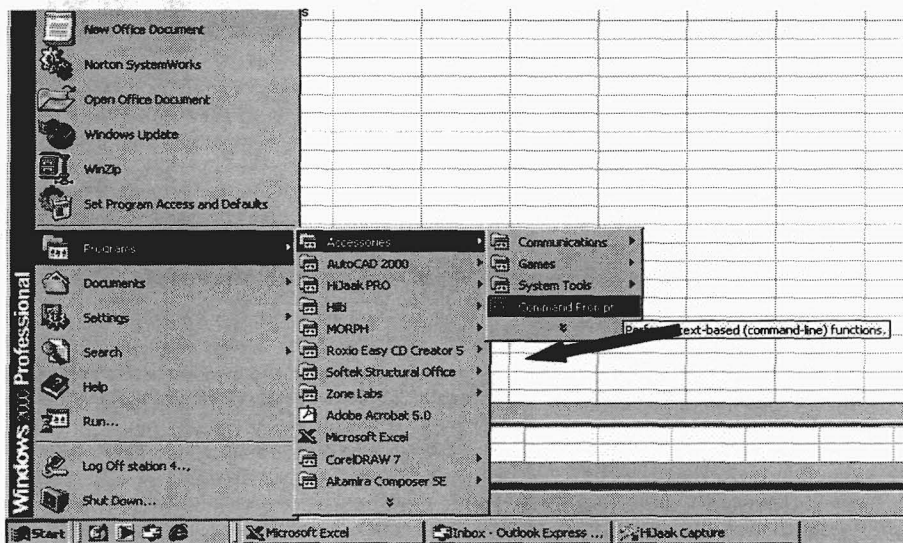


Figure 2-6 Selecting Command Prompt in the Windows Start menu.

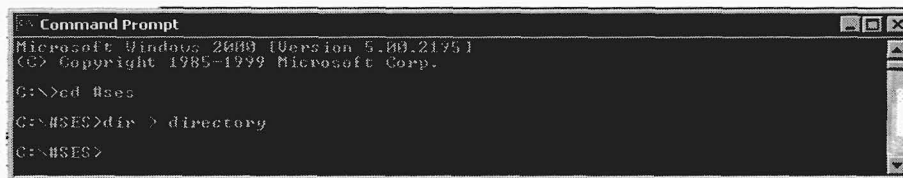


Figure 2-7 Change to the directory and save it to a file.

Go back to the spreadsheet and set Files of type: to **All Files (\*.\*)**. Find your text file and hit **[Return]**.



The **\*** global choice symbol can also be used in locating files.

Example: 60\*.xls  
60 Celerity 1b.\*

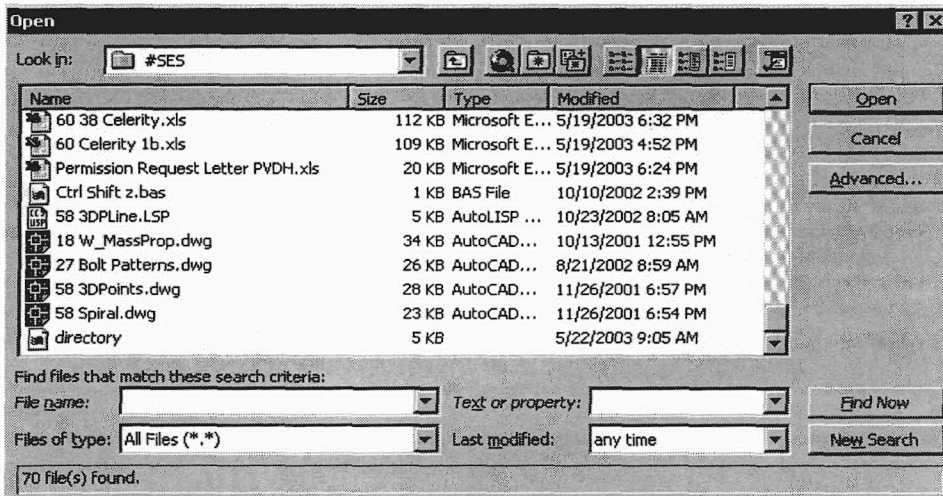
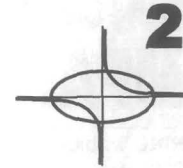


Figure 2-8 Select the "directory" file in the Excel File menu.



A B C D E F G H I J K L M N  
PRINTING A DIRECTORY -- Continued

What you get is the Text Import Wizard. Make it easy on yourself and choose "Finish."

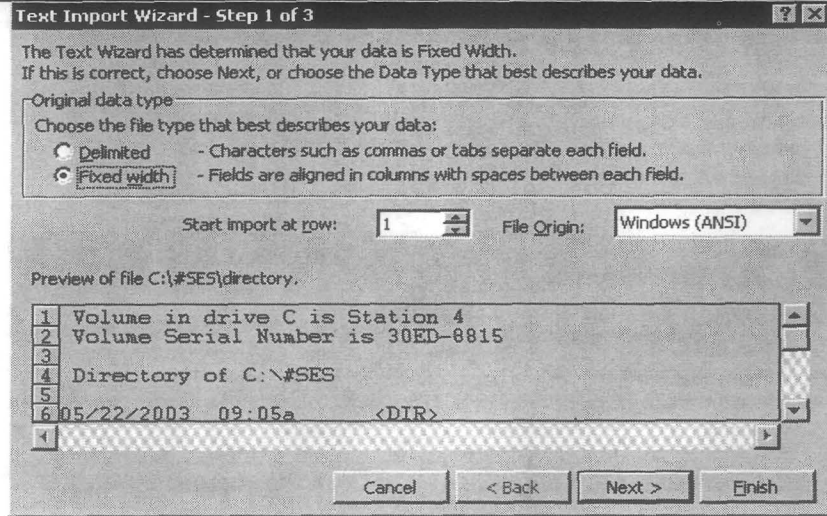


Figure 2-9 This is the Import Wizard for non-.xls files.

This is a text file. You can save it as an .xls file if you want.

This data can be sorted or processed in some other way and printed.

	A	B	C	D	E	F	G
10	1/30/2003	08:54a		31,744	11	Circular Reference.xls	
11	4/12/2003	01:51p		78,336	12	Logic.xls	
12	1/31/2003	08:44a		68,096	13	DATABASE.xls	
13	2/3/2003	09:39a		339,456	14	Regression Analysis.xls	
14	2/3/2003	09:39a		27,136	15	TAKEDOWN.xls	
15	2/3/2003	09:39a		73,728	16	POLE.xls	
16	4/12/2003	01:57p		175,104	17	Moment Distribution.xls	
17	5/21/2003	01:44p		251,904	18	Numerical Integration.xls	
18	10/13/2001	12:55p		34,368	18	W_MassProp.dwg	
19	10/13/2001	12:47p		729	18	W_MassProp.mpr	
20	2/2/2003	07:00p		245,248	19	Matrix Math.XLS	
21	5/1/2003	08:39p		146,944	20	Matrix Methods.XLS	
22	4/12/2003	01:36p		376,832	21	Matrix Frame and Truss.xls	

Figure 2-10 This is a partial display of the "directory" file.

**Method 2**

If what you need is a list of what is on a CD Rom, for instance, select the directory using Windows Explorer and hit [Print Screen]. Go into the spreadsheet and paste with [Ctrl] [v]. You have a picture that can be cropped with the drawing tool and printed.

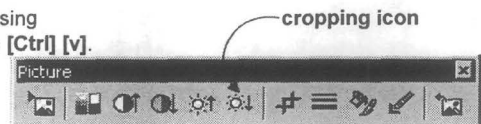


Figure 2-11 The Picture Editing menu.

row 360

row 370



**USING LINKS**

Linking spreadsheets together does have its advantages. Large spreadsheets are often better when broken up into smaller modules.

Linking can also be accomplished with the cut and paste command. Cut a formula from a spreadsheet and paste it into another spreadsheet.

Some links become obsolete or are accidentally introduced into the spreadsheet. Every time the file is loaded you get a flag asking you if you want to update the links.

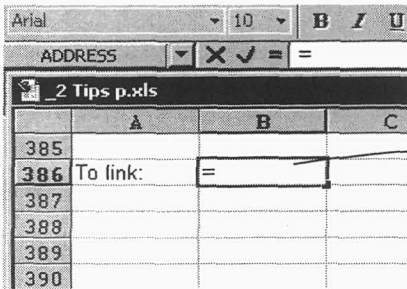
A link can be cleared by erasing/clearing the cell in which the link is located. Sometimes, though, these links are hard to find.

row 380

**Linking Spreadsheets**

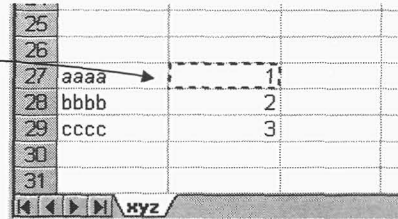
This example uses this file and a file named **\_2 Tips links.xls**.

To link: **1**



row 390

Figure 2-12 Enter an equals "=" sign in the cell to reference another spreadsheet.



row 400

Figure 2-13 While still in the edit mode, click on the cell to be referenced in the second spreadsheet.

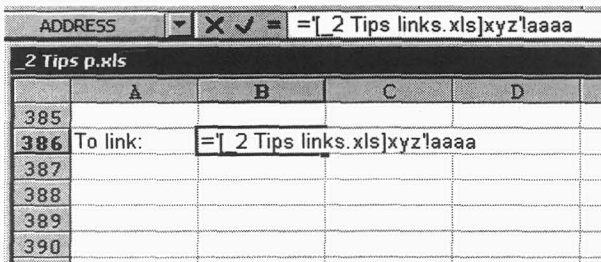
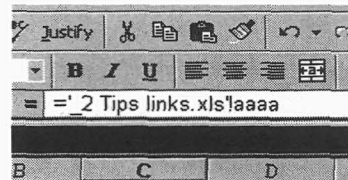


Figure 2-14 This is how the reference looks in the first spreadsheet while still in the edit mode.



row 410

Figure 2-15 Press [Return] to get this in the edit window.

Link: **1**

row 420

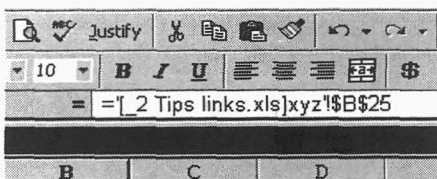
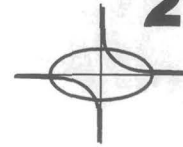


Figure 2-16 A referenced cell without range names will look like this in the edit window.

row 430



**REMOVING LINKS**

If an unwanted link is hard to find, try this procedure in the referenced file:

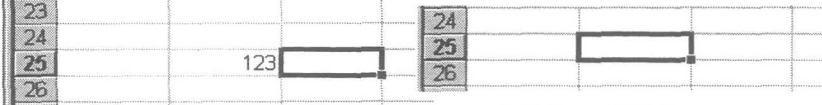


Figure 2-17 Move a range of cells into the referenced cell of the second spreadsheet.

Figure 2-18 Press "OK" to clear the caution flag and get this.



Figure 2-19 The referencing cell will look like this making it easier to find.

row 440

If the referenced spreadsheet is unknown or a phantom link, use this procedure:

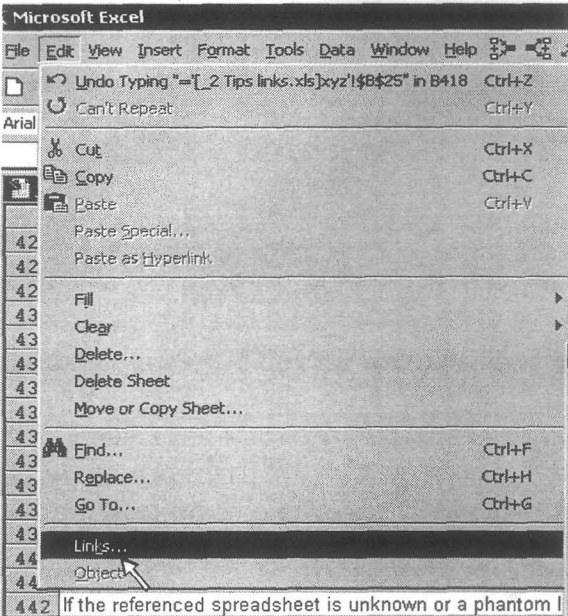


Figure 2-20 Go to the Edit menu and click on Links.

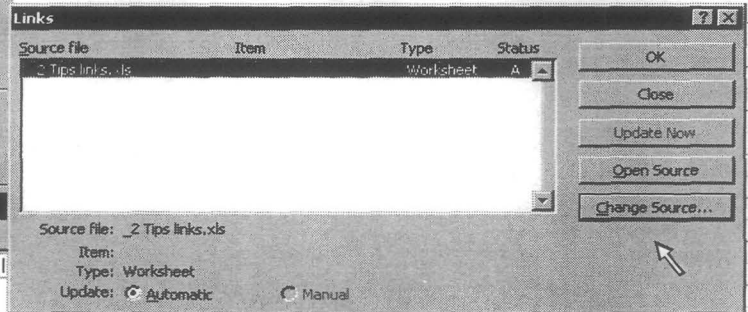


Figure 2-21 Select Change Source... to pick a temporary file as the referenced file.

row 450

row 470

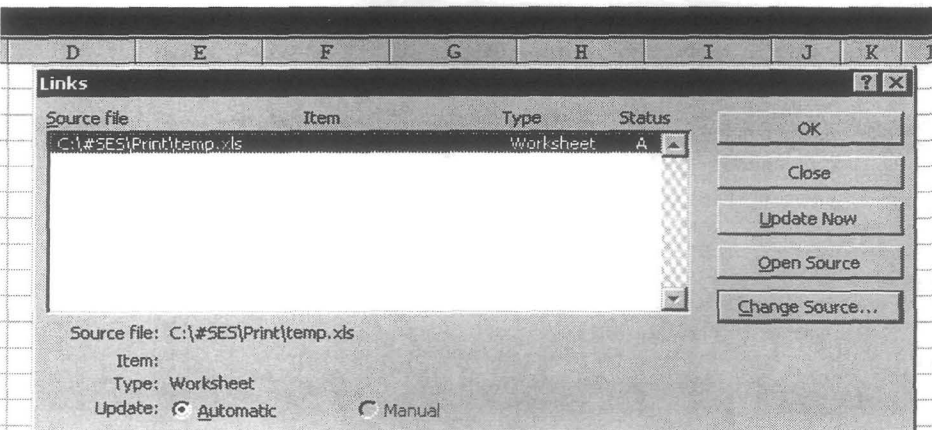


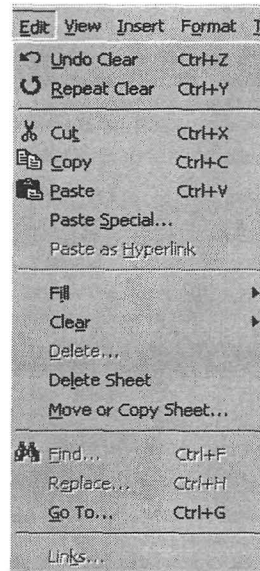
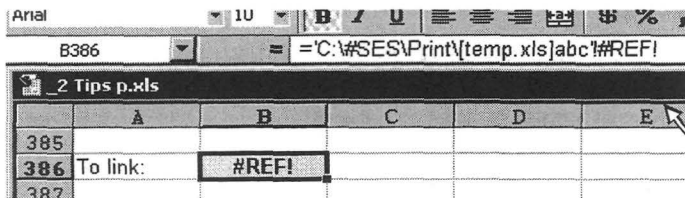
Figure 2-22 This is the new referenced file. Click "OK" in the Links window. Delete rows or columns in the temporary file to destroy the referenced cell(s).

row 480

row 490



A B C D E F G H I J K L M N  
REMOVING LINKS -- Continued



row 500

row 510

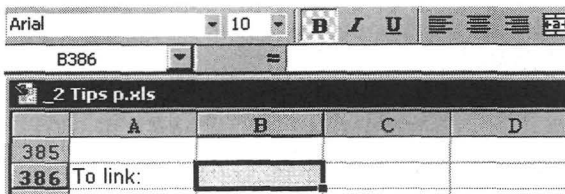


Figure 2-23 Erase/clear all of the #REF! cells. Cells that are not cleared will maintain a reference to the temporary file.

Figure 2-24 The Edit, Links dropdown menu will look like this when all links are removed.

row 520

Another method of finding links is to invoke the **E**dit menu and **F**ind command. Enter a likely file location such as C:\, your root directory. The find command will look for words and formulas containing this object. In this case it finds the cell linking this page number to the preceding chapter.

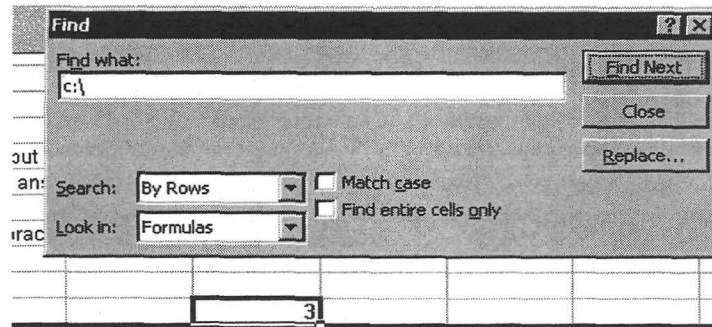


Figure 2-25 Enter a probable, global address to find the cell linked to another spreadsheet.



Figure 2-26 The Formula Bar displays the results of the Find command.

row 550



# WORKSHEET

This worksheet with header is 70 rows deep per page



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\_3 Worksheet\_70.xls

A B C D E F G H I J K L M N  
HEADERS

The header is usually 9 or 10 rows deep. This particular template is setup to print at 80%. The typical page of information is 60 rows deep. The bottom page break may have to be adjusted up when super and subscripting are used. Adjust up or down by increments of 10 rows.

To set a repeating header:

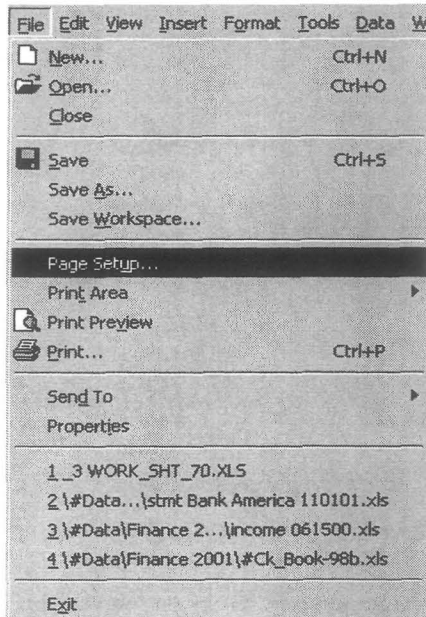


Figure 3-1 The File drop down menu.

Click on File and then Page Setup

In Sheet, click on Rows to repeat at top:

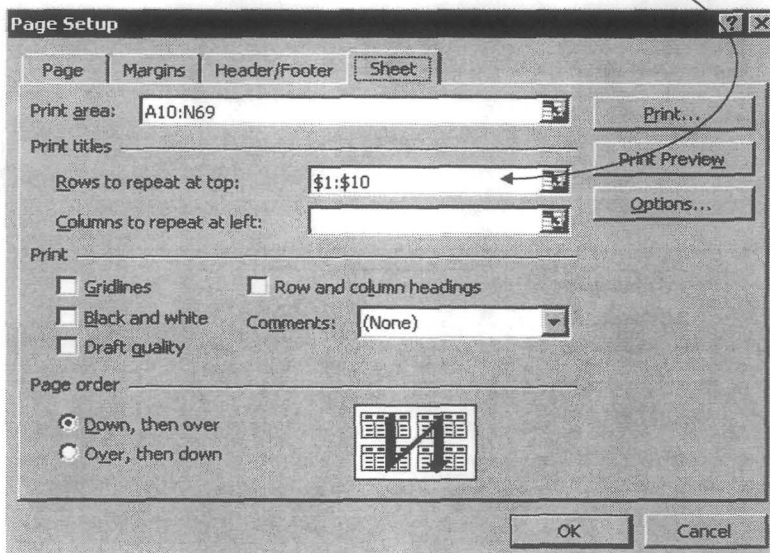


Figure 3-2 Rows to repeat at the top of the Page in the Setup menu.

The header repeats on each page and includes the alpha (alphabet) row which identifies each column. The alpha row is set to a 8 sized font. The row numbers on the right side of the page and the alpha column labels are very useful in phone conversations.

When you set the print range, do not include the header. The header prints automatically.

The logo in the header can be generated in AutoCAD or native spreadsheet drawing tools. Logos using native tools will print much faster than logos generated in AutoCAD but the AutoCAD logos can be resized and stretched more easily. This is because logos made up of Excel lines and text do not resize together.

Pages that measure a total of 70 to 80 lines deep by 14 columns wide seem to work best for containing a module of calculations. You must weigh the amount of information included on the page versus someone else's ability to read it. Small fonts can be a nuisance.

Column width is 9 characters wide except for K, L, and M columns in an 80% print sized template. If the date stamp doesn't fit in column N, reduce it to an 8 sized font from the default 10.

row 20

row 30

row 40

row 50

row 60

row 70

This worksheet with header is 70 rows deep per page

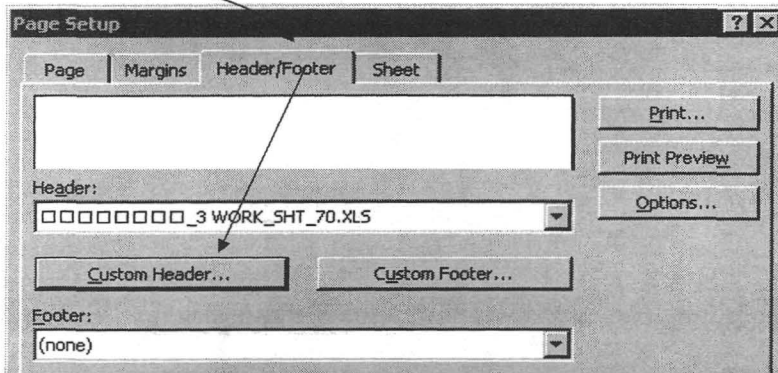


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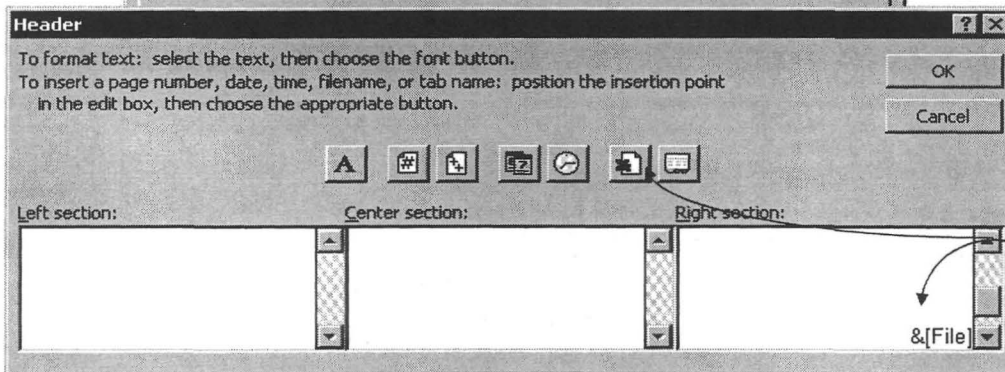
\_3 Worksheet\_70.xls

**DATE, TIME, AND FILE STAMPS**

To place a file stamp in the header, select Header/Footer in Page Setup and click on Custom Header...



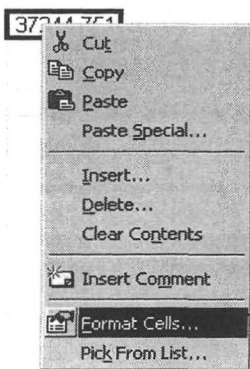
row 80



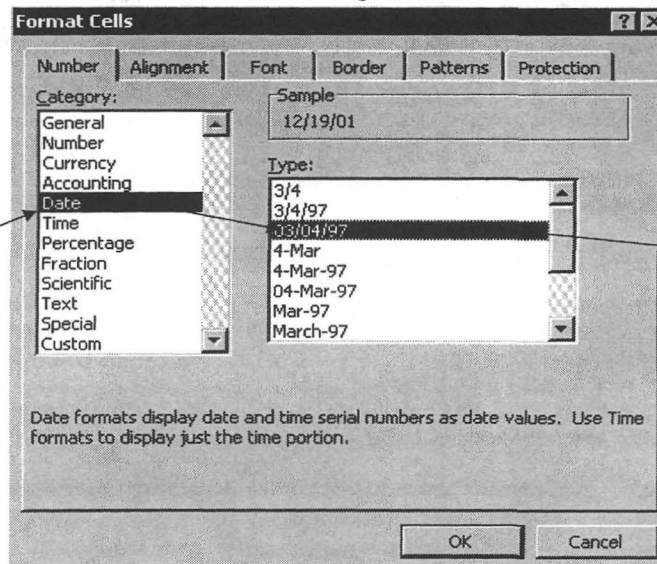
row 90

Press [Return] about 7 times and then click on the file identification icon.

Figure 3-3 Setting up the header.



Date and time stamps are generated with the NOW() operator. Format the operator through Format Cells... in the tool bar or right click the mouse and select Format Cells...



row 110

NOW()

The same formatting sequence applies for the time stamp.

If the date stamp doesn't fit in the column, set it to an 8 sized font.

Figure 3-4 Formatting for date and time.

row 130



# WORKSHEET

This worksheet with header is 70 rows deep per page



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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>DATE, TIME, AND FILE STAMPS -- Continued</b>													

Sometimes, the custom header information overlaps the right margin. Excel doesn't let you insert a couple of spacebar spaces to move the information to the left and you can't set the margins to greater than 0.75 in setup to adjust the position of the header information.

To crowd the header information to the left, locate your cursor to the far right of the character string, press [Num Lock] on, hold down the [Alt] key, and enter 255 on the keypad. This will insert an invisible space that is about half a character wide.

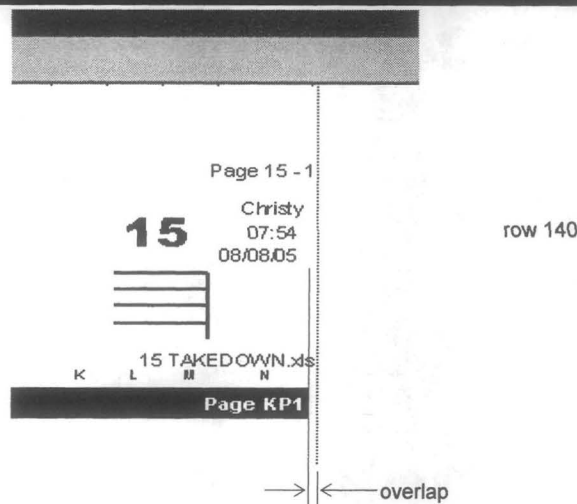


Figure 3-5 The header text extends beyond the printed margin.

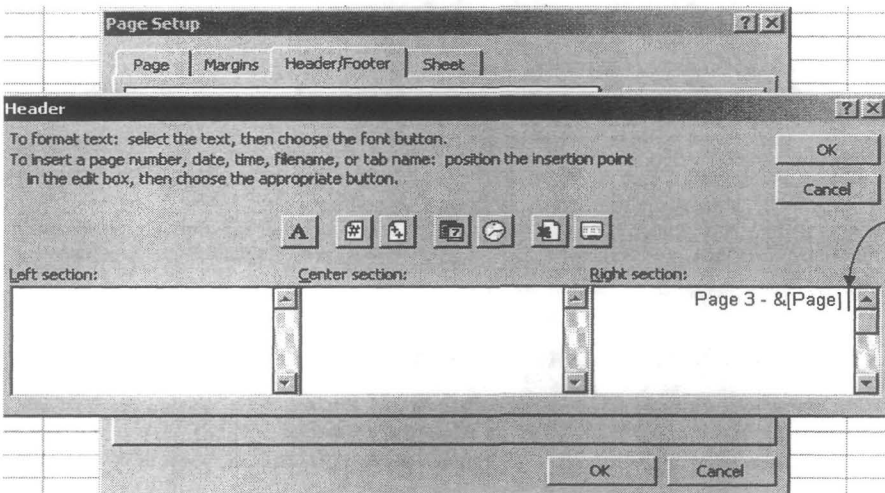


Figure 3-6 Inserting blank spaces into a header character string.

row 140

row 160

row 170

row 180

row 190



# WORKSHEET

This worksheet with header is 70 rows deep per page



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\_3 Worksheet\_70.xls

GUIDE TO ROW NUMBERS				
70 ROWS per PAGE		80 ROWS per PAGE		
	10		10	
	60		70	
	70	1150	80	1340
	130	1210	150	1410
	190	1270	220	1480
	250	1330	290	1550
	310	1390	360	1620
	370	1450	430	1690
	430	1510	500	1760
	490	1570	570	1830
	550	1630	640	1900
	610	1690	710	1970
	670	1750	780	2040
	730	1810	850	2110
	790	1870	920	2180
	850	1930	990	2250
	910	1990	1060	2320
	970	2050	1130	2390
	1030	2110	1200	2460
	1090	2170	1270	2530

Figure 3-7 Lengths of 70 and 80 row pages by row number.

## NOTES

The notes part of the template are located on your right hand side. They can start in column G, H, or I depending upon your style and the nature of your presentation.

Notes, highlights, sketches, and photos can be hand written on your printout. If you have to revise your calculations, simply cut the handwritten part out of the voided printout and tape it onto the new printout with the easy liftoff tape or the frosted style of tape. These generally go through a copy machine without casting tape shadows on the copy. Some times the clear tape works quite well, too.

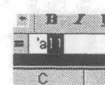
Dissect this template and the other templates in this manual to see how they were created.

row 220

row 230

row 240

row 250



A B C D E F G H I J K L M N

### SUBSCRIPTING AND SUPERSCRIPTING

Step 1

Super and subscripting are done with editing in the cell. Input the character with the super/subscripted characters and add a blank space by hitting the spacebar.

Step 2

While in the edit mode, highlight the characters to be subscripted (in this case) and right-click the mouse button.

row 20

Step 3

Choose Format Cells...

row 30

Step 4

Highlight Subscript with your cursor and click the left mouse button

row 40

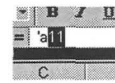
row 50

This is the result -- the row becomes deeper automatically

Figure 4-1 The pull down menu for super and subscripting.

row 60

row 70



### EDITING SUPER/SUBSCRIPTS AND OTHER CHARACTERS

To change  $a_{11}$  to  $a_{12}$  do the following:

Copy the character to the next cell and edit the sub/superscript. Hit Edit [F2] and then highlight the character with your cursor. Type in the new character (over the top of the old character) and hit [Return].

Step 1: The notation to be edited

Step 2: the space beyond the character (space bar) cursor mark

Step 3: highlight the character to be replaced

Step 4: this is the replacement character

the edit cell will look like this during the replacement process

this is the finished product

Figure 4-2 Changing super and sub scripting.

### FORMATTING ENGLISH CHARACTERS TO GREEK MATH CHARACTERS

To change a to  $\alpha$ :

Put your cursor on the cell to be reformatted. In the edit bar, highlight the "a" as shown above and click the right mouse button to display the drop down menu.

Font: GreekS

Font style: Regular

Size: 10

Underline: None

Color: Automatic

Effects:  Subscript

Preview: a α

This is a TrueType font. The same font will be used on both your printer and your screen.

OK Cancel

this is the finished product

In **Font**: scroll down the to font set that you need and highlight the font with a left click. Then click OK.

If the character prints too lightly, try making it bold or choose another character font.

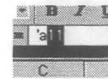
Greek letters can be found in the "Symbols" file.

70		
71	<b>Greek C</b>	
72	a α	A A
73	b β	B B
74	c γ	C X
75	d δ	D Δ
76	e ε	E E
77	f ς	F ς

Math and Greek letters can also be generated with Windows character map. See the explanation below

NOTE: SymbolSH will print a darker a. The font also be selected in the tool bar on the left hand side of the screen worksheet.

Figure 4-3 Formatting for Greek symbols.



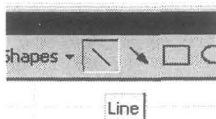
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**MAKE YOUR OWN MATH OPERATORS**

People unfamiliar with spreadsheets are sometimes puzzled by spreadsheet notation. An example of this is:

$2^{\wedge}0.5 = 1.41$       This is a simple relationship showing that square root of 2 is 1.41

Making the square root bracket is done as follows:

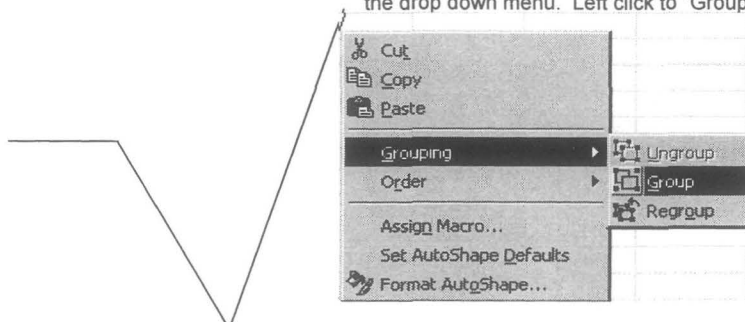


In the Drawing toolbar, double left click on the line symbol.

row 140

Figure 4-4 Choose "line" from the drawing toolbar.

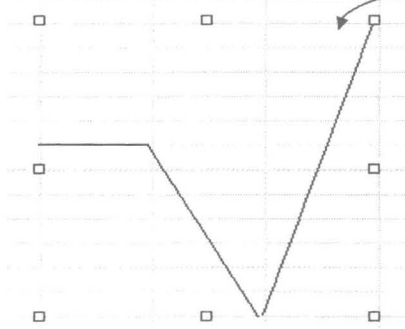
Draw in this symbol as shown. To "Group" the lines, hold down the shift key and left click on each line. Hold your pointer on one of the highlighted lines and then right click to get the drop down menu. Left click to "Group" the lines.



row 150

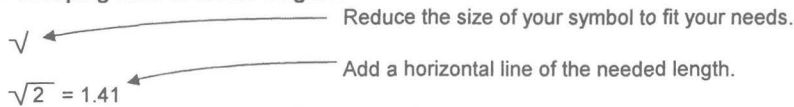
Figure 4-5 Layout the figure with individual lines.

To get this.



row 170

Figure 4-6 Grouping lines to create a figure.



row 180

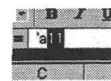
Figure 4-7 Re-size the large figure to suit your needs.

By the way -- for the "is-less-than-or-equal-to" symbol, simply underline the < or >. In a spreadsheet formula this looks like this  $\rightarrow 1 \leq 2$ . You can also get these symbols from the symbols chapter. Be sure to check your printout -- what you see is not always what you get.



This symbol was drawn in Excel  
See the Symbols Chapter of this manual for other methods

row 190



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\_4 Editing in Excel.xls

**ADJUSTABLE TEXT -- Text Justify**

The text justify button in EXCEL justifies text along an even left side border.

This button must be obtained from:  
Tools  
Customize...  
Edit

Select Justify, right click and drag it up to the tool bar(s).

Justifying with this command will drop individual formatting.

row 200

To remove a button from a tool bar open Tools, Customize..., and then right click on the button and drag it back to the Customize... popdown window.

**Wrapping within Single and Merged Cells**

Another method which is particularly useful in databases is the Wrap text command.

This can be done in a single cell which can be sorted in a database such as a phone list:

The quick brown fox jumped over the lazy dog's back.																			
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

or in a group of merged cells which cannot be sorted in a database:


The quick brown fox jumped over the lazy dog's back.																				row 210
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	---------

Choose Format, Cells..., Alignment from the tool bar or right click your mouse and choose Format Cells... from the popup menu. You'll find Merge and Wrap text here under Alignment. Be sure that your pointer is over the box when you right click.

**Adjustable / Referenced Text in a Drawing**

The drawing to the right is an AutoCad 2000 3D view of a Simpson HD6A holddown. It was copied out of a view port in paper space and pasted with the command: Paste Special, Picture (enhanced metafile).

row 220

From the drawing tool button pop down tool bar select the text box  Place the text box where you want it in the drawing. Then place your pointer in the edit row just below the tool bars and type in an equals = symbol. Then point to the text that will change -- in this case we call it Text\_1 and it is located in column B.

Text\_1    **The quick brown fox** \_\_\_\_\_

row 230

The text box can be formatted to have no borders or background. The text can be changed through user input or as the result of a calculation.

Text\_2    **jumped over the lazy dog's back.** \_\_\_\_\_

multiply    **12**  
by            **2**  
to get        **24**

row 240

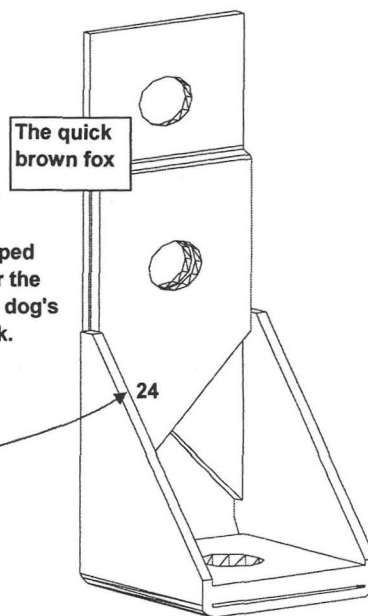
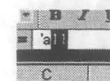


Figure 4-8 Drawing annotation.

row 250



### CONDITIONAL FORMATTING

Conditional formatting is a way to flag answers, make non-pertinent information fade into the background, and to make tables easier to read.

For example, input 0's and negative or positive numbers into this table where the 0's are simply place holders in a matrix:

due to unit displacement in coordinate

		$x_1$ ↑	$x_2$ →	$x_3$ ↻	$x_4$ ↑	$x_5$ →	$x_6$ ↻	
AB	$v_1$		1	0	0	0	0	0
	$v_2$	0	0	1	1	0	0	0
	$v_3$	0	0	1	1	0	0	0
BC	$v_1$	0	1	0	0	1	0	0
	$v_2$	1	1	1	1	0	1	1
	$v_3$	1	1	1	1	0	0	1
CD	$v_1$	0	0	0	1	0	0	0
	$v_2$	0	0	0	0	0	0	1
	$v_3$	0	0	0	0	0	0	1

a = independent displacements of elements

Figure 4-9 Flagging with conditional formatting.

In spreadsheet matrix math, an empty cell will cause the entire process to fail whereas a 0 or a number will give a result (providing it is the right input).

To invoke conditional formatting, click on the Format menu item

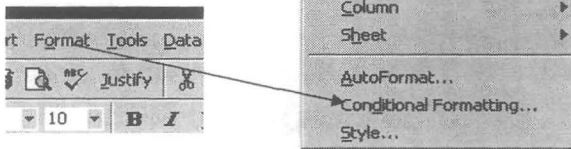
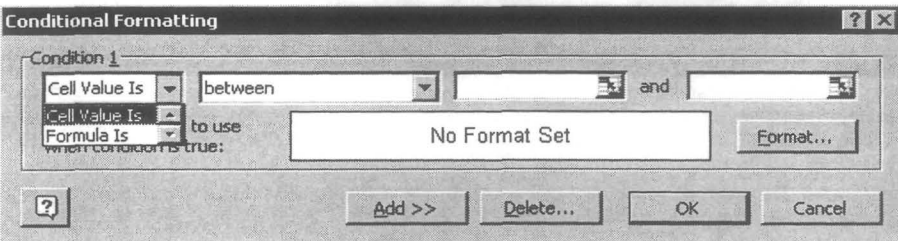


Figure 4-10 Select Conditional Formatting from the Format drop down menu.

to get:



The above table was formatted like this:

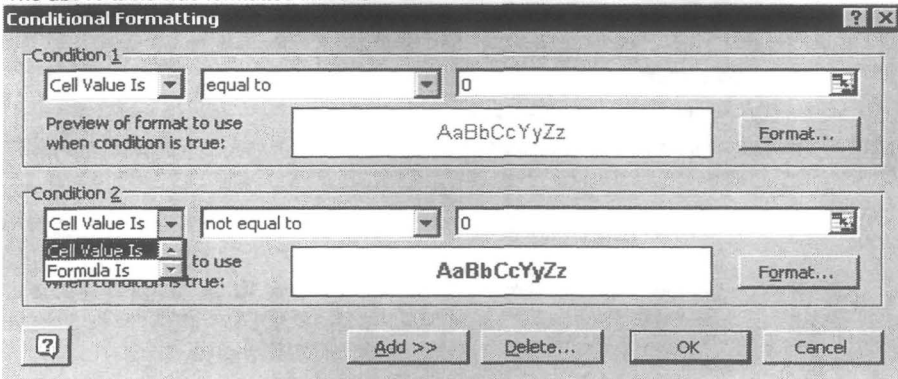
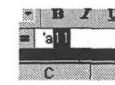


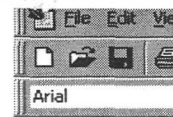
Figure 4-11 The Conditional Formatting window.

You can have three conditional formats. There are other examples of conditional formatting throughout this manual and disk.



### FORMATTING A NEW SHEET OR TAB

Format a new sheet by double clicking the Format Painter button.



Click the top left corner of the rows and columns cell of the spreadsheet. Double click or press [Escape] to turn the format painter button off.

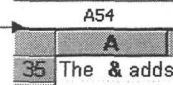


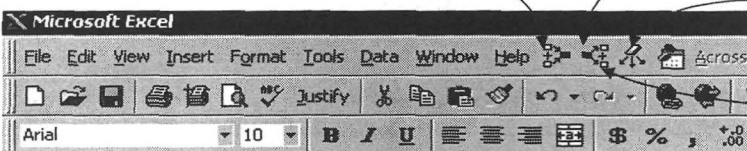
Figure 4-12 Formatting a sheet with the Format button.

Within a sheet, single click the format painter button to copy a format to one other cell. Double click the format painter button to format copy a format to several cells.

### THE TRACE COMMAND

The trace commands are used to determine what inputs an equation is using and what other equations depend upon it.

Trace Precedents      Trace Dependents      Remove All Arrows



These commands can be taken from the Tools Customize Commands pulldown menu and placed in the top menu row.

	A	B	C	D	E	F
133	D gross	0.5 in		gross diameter of bolt		
134	Force	1.00 k		required force		
135	n	13 threads/inch				
136	H	0.067 in				
137	K root	0.406 in		least diameter		
138	w thread	0.0577 in		actual width of thread	pitch - pitch/	
139	F/thread	1.158 k/thread		Fy * area of thread in shear		
140				21 ksi * 0.75 * 0.0577 inch * 0.406 in		
141	Th'ds	7 n		threads provided		
142	T_allow	8.11 k		7 threads * 1.158 k		
143				OK. 8.11 > 1.00		

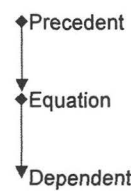


Figure 4-13 Click on the Trace Precedents button to locate inputs to the formula and click on the Trace Dependents button to locate results.

	A	B	C	D	E	F	G
133	D gross	0.5 in		gross diameter of bolt			
134	Force	1.00 k		required force			
135	n	13 threads/inch					
136	H	0.067 in					
137	K root	0.406 in		least diameter			
138	w thread	0.0577 in		actual width of thread	pitch - pitch/4		
139	F/thread	1.158 k/thread		Fy * area of thread in shear			
140				21 ksi * 0.75 * 0.0577 inch * 0.406 in * f			
141	Th'ds	7 n		threads provided			
142	T_allow	8.11 k		7 threads * 1.158 k			
143				OK. 8.11 > 1.00			

Figure 4-14 Click on the Trace Dependents button again to locate results of the results.



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This template uses typical Excel row and column width and height with Arial font at a 10 pitch. It is printed out at 70% in the page set-up menu. Review other features regarding margins, header, and page and tab identification in the header.

Column width is nine except for columns K, L, and M.

Tabs

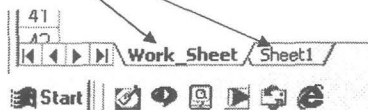


Figure 5-1 Spreadsheet tabs in the lower left corner of your screen.

This worksheet yields the equivalent of a 132 character per line format in terms of the old dot matrix printers. The overall worksheet is 80 rows deep on an HP LaserJet printer. Although this is somewhat condensed compared to a typical letter page, it seems to work well to create modules of information or calculations.

Included with this set of files is a worksheet that is less condensed. It yields 70 rows per page.

The row numbers to the right help greatly in telephone conversations. Rather than ask for a page number and approximate location on the page that the caller wants to know about, ask for a row number and column letter.

The row number is created through concatenation: `= "row "&FIXED(CELL("row",O60),0)`

Note that the cell "row" value is referenced in the next column over. Rarely do we do work in this area and, so, this value is seldom disturbed. When row labels get wiped out, simply copy one from a good sample somewhere else in the spreadsheet -- or another spreadsheet.

The logo at the top of the page is meant to be replaced by other users with their own logo(s). The generic logo was created with Excel drawing tools but it can be drawn in AutoCAD. Using Excel's drawing tools will create a file that uses less memory overhead and prints faster. However, there is no good substitution for importing AutoCAD drawings into Excel for design and documentation.

Merging cells to permit larger print is not recommended because it will not copy into another spreadsheet. Use the drawing toolbar instead and click on the text box button.

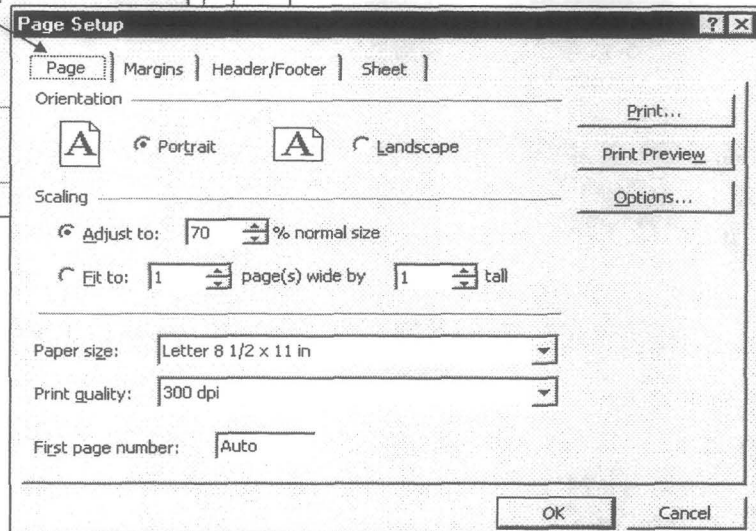
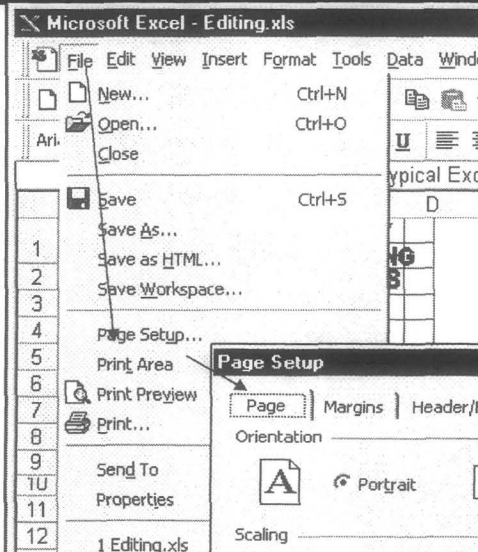


Figure 5-2 The File menu system.

row 20

row 50

row 60

row 70



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\_5 Math Editing.xls

**BOOLEAN ALGEBRA and the IF STATEMENT**

Math operators <, >, =, <=, >=  
 Dog 3 unit  
 Fox 4 unit  
 Boolean math  
 Result 1 logic  
 =Dog<Fox  
 3 Dog(s) < 4 Fox(s)  
 IF statements  
 Result\_2 More foxes  
 =IF(Result,"More foxes","More dogs")

Note: it is often wise to show the formula used as range-named cells or even as cell-addresses. Another aid in constructing and reviewing spreadsheets is to show the numbers in a concatenated string.  
 See below for a definition of concatenation.  
 row 80

The Boolean statement may be contained within the IF statement  
 quantity 2 unit  
 2 Foxes string  
 formula text formula  
 =IF(quantity=1, "1 Fox", FIXED(quantity,0,TRUE) & " Foxes")  
 row 90

In this case, the IF statement uses the Boolean output of another cell to return a text statement.  
 To park an equation, press the [F2] edit key, press [Home] to go to the front of the equation string, and press the space bar to insert an apostrophe and create a text string.  
 row 90

It could also return the result of a formula within the IF statement or reference a result from outside of the statement and returned from within the IF statement.  
 A 1  
 B More foxes  
 C 2 Foxes  
 Answer More foxes

The equation using range names:  
 row 100  
 A =Dog<Fox  
 B =IF(Result,"More foxes","More dogs")  
 C =IF(quantity=1,"1 Fox",FIXED(quantity,0,TRUE)&" Foxes")  
 =IF ( A, B, C )

**EQUATION EDITING -----**

Example 1 simply adds the words "The" and "fox" together in an equation. You can change the words in the highlighted input cell(s).

Input\_1 The We usually highlight input cells with bold, dark blue information into a light yellow background. This makes your work easier as well as helping other people using your spreadsheet.  
 Input\_2 fox

The concatenated equation/string looks like this:  
 Output = The fox

The actual equation looks like this after it has been "parked:"  
 ="Output = "&Input\_1&" "&Input\_2  
 row 120

The & (ampersand) adds strings in much the same way as the + adds numbers. Use fixed(x, n) to convert a value to a string for concatenation:

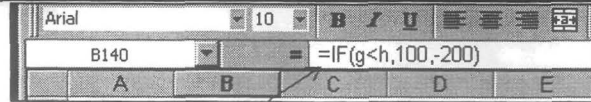
123.4568  
 =fixed(B125,3)  
 123.457 ← this is text

row 130

### EQUATION EDITING -- Continued

Example 2 demonstrates the "parking" of equations.

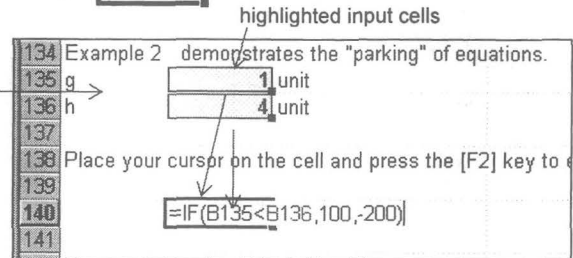
g 1 unit  
h 4 unit



Place your cursor on the cell and press the [F2] key to edit:  
100

Your equation should look like this:

=IF(B135<B136,100,-200)



Press the **Home** key to go to the beginning of the equation:

=IF(B135<B136,100,-200)

Figure 5-3 Parking an equation.

row 150

Press the space bar or insert a column before the = (equals) sign and press [Return] to finish parking the equation:  
=IF(B135<B136,100,-200)

An equation can be reproduced in other parts of the spreadsheet by inserting a comma or space to convert it to text. Copy the equation as required and then remove the comma to re-convert the text back to an equation.

Inserting a comma also works well to put a malfunctioning equation on hold.

### ADDING EQUATIONS with JUSTIFY

fa 4.00 ksi  
fb 6.00 ksi  
Fa\_allowed 10.000 ksi  
Fb\_allowed 18.000 ksi

ratio 1 0.400  
ratio 2 0.333

Add two equations by placing one above the other.

Park the equations with a space or apostrophe:

ratio 1 =B160/B162  
ratio 2 =B161/B163

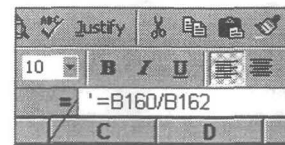


Figure 5-4 Adding equations together.

Use the justify command to create a row of text:

=B160/B162 =B161/B163

Replace the equals sign in the middle of the row and replace it with a math operator -- in this case it will be a "+".

Remove the space or apostrophe at the beginning of the row:

=B160/B162 + B161/B163  
0.733

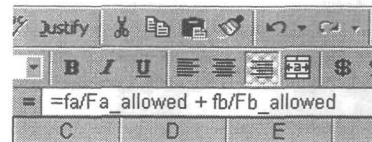


Figure 5-5 The added equations shown as range names.

The cells referenced in the formulas were range named.

Another important method of adding (combining) equations together is through concatenation. We normally think of concatenating text. Use your cursor on the cell displaying "The quick brown fox":

**The quick  
brown fox**  
=B156&B157  
The quick brown fox

row 190

A B C D E F G H I J K L M N  
**ANOTHER EXAMPLE of PARK and CONCATENATE**

An equation can be easily parked and copied without changing the references.  
The following example equation(s) use numbers only.

D                    2

Press the [F2] edit key. Press the [Home] key to go to the front of the equation. Press the [Space Bar] to insert a space and turn the equation into plain text.

=(1+1)

and

E                    4

convert to =(2+2)

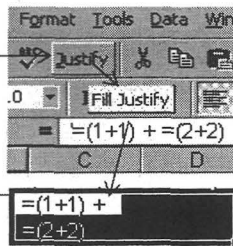
row 200

Create this equation, = D +E , by concatenation.

=(1+1) +

=(2+2)

Add the + operator  
now to keep the  
process simple or add  
it later if you forget.



row 210

Justify the range to create a text string on one row.

= (1+1) + = (2+2)

Now clean up the text by removing the = operator at mid-string and the space at the beginning of the string.

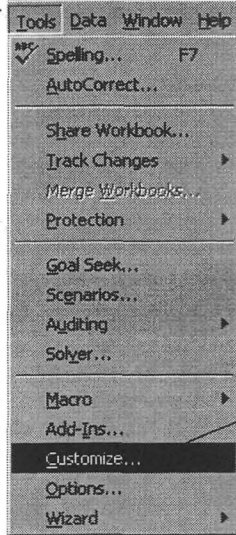
6

Figure 5-6 Adding equations.

Inserting a space or a comma in front of an equation also works well to put a malfunctioning equation on hold.

**PUTTING THE JUSTIFY BUTTON IN THE TOOLBAR**

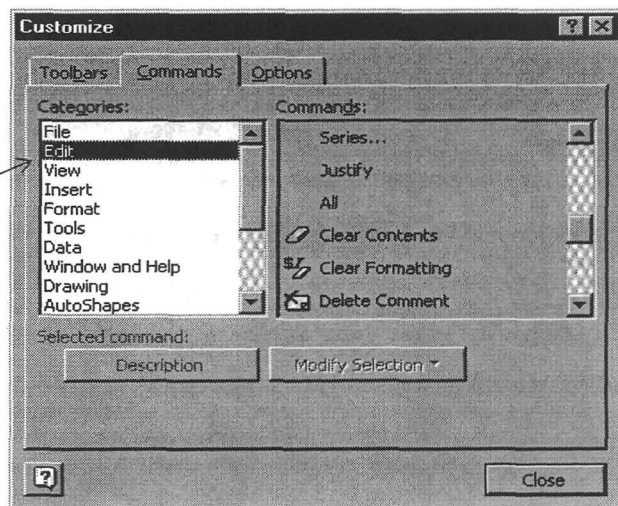
Select Tools in the toolbar.



row 220

Select Customize...

Choose the Commands tab.



Then select Edit and scroll to the Justify button. Click on Justify and drag this button up to your toolbar.

Figure 5-7 Placing commands in the tool bar.

row 250

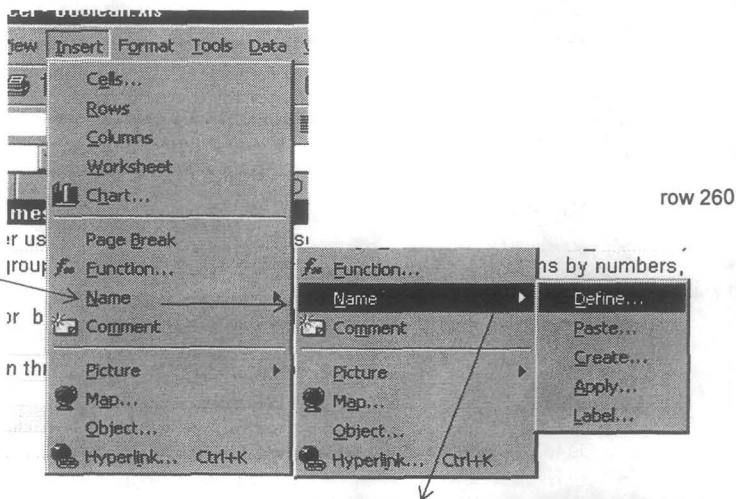
A B C D E F G H I J K L M N

### RANGE NAMES

Note: Never use a range name like **A1** (use **A\_1** instead)  
Organize groups of inputs and calculations by numbers, alpha characters, and keyboard characters.

To look for **bad range names**, click on **Insert** in the tool bar, **Name**, **Define** and click on the list.

Junk 4



row 260

Scroll down through the list to look for the **#REF!** comment.

Click on **Delete** to remove the faulty reference.

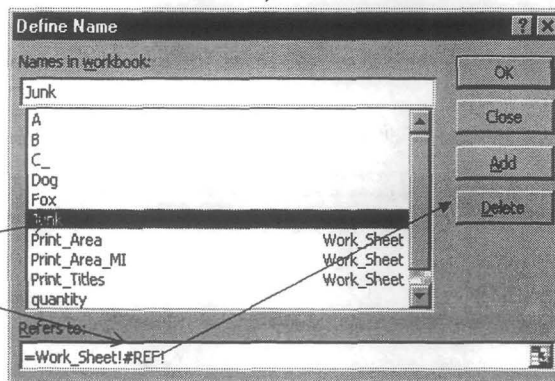


Figure 5-8 Looking for bad range names.

row 290

### Moving Around

Press the **[F5]** GoTo key to view a list of names to select from and go to or type in a spreadsheet address -- and go to that.

You can "go to" a cell address such as **B3** or to a range name. Use the **#** symbol in front of a range name to cause it to be listed in the beginning of the range name table.

row 300

row 310



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**Range Names in Equations**

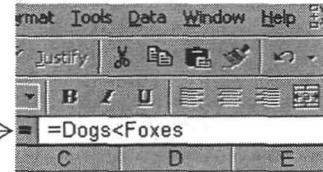
Display range names in a parked equation

Dogs 3 unit  
Foxes 4 unit  
Result 1 logic

Show the equation with its range names, not cell R1C1 references.

1 parked and copied from above

Press the [F2] key to edit the equation in the equation window.



row 320

Figure 5-9 Press [F2] to edit in the edit window.

Place the mouse pointer over or in front of the = sign and press the space bar.

Press [Return] and the equation under the cursor will turn from an equation of cell references to an equation of range name references.

This equation has been parked as text and can be copied to a comments area.

1  
=Dogs<Foxes

**Listing Range Names**

It can help to list range names with addresses to help in checking the appropriateness of range names for inputs and values and other trouble shooting functions.

row 330

Left click on the Insert button and select Define, Paste.  
Select the Paste List button to create a range name list at the cursor location.

A	=Editing!\$B\$94	
B	=Editing!\$B\$95	
C_	=Editing!\$B\$96	
D	=Editing!\$B\$195	row 340
Dog	=Editing!\$B\$73	
Dogs	=Editing!\$B\$312	
E	=Editing!\$B\$200	
fa	=Editing!\$B\$160	
Fa_allowed	=Editing!\$B\$162	
fb	=Editing!\$B\$161	
Fb_allowed	=Editing!\$B\$163	
Fox	=Editing!\$B\$74	
Foxes	=Editing!\$B\$313	
g	=Editing!\$B\$133	row 350
h	=Editing!\$B\$134	
Junk	=Editing!#REF!	
Print_Area	=Editing!\$A\$10:\$N\$489	
Print_Area_	=Editing!\$A\$291:\$N\$320	
Print_Titles	=Editing!\$1:\$9	
quantity	=Editing!\$B\$86	
Result	=Editing!\$B\$76	

Figure 5-10 The range name list.

row 360

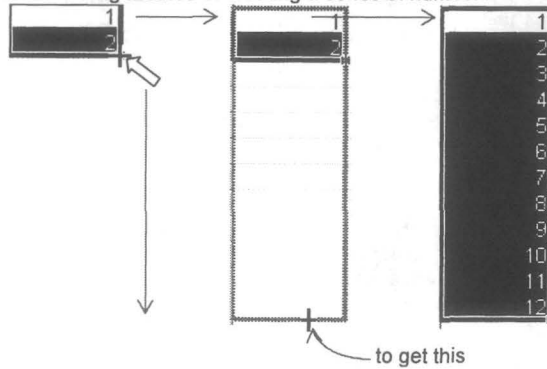
row 370

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**FILL -- DRAG FROM BEGINNING NUMBERS TO GET A TREND**

The original Lotus 1-2-3 /Fill command has been replaced with the drag method of creating a series of numbers in a row or column. For instance: start with 1 and 2,

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12



row 380

Figure 5-11 The fill operation using "drag."

Samples of the "fill in a series" command

- |           |           |
|-----------|-----------|
| 1 } start | 1 } start |
| 3 }       | 4 }       |
| 5         | 7         |
| 7         | 10        |
| 9         | 13        |
| 11        | 16        |
| 13        | 19        |
| 15        | 22        |
| 17        | 25        |
| 19        | 28        |
| 21        | 31        |
| 23        | 34        |

- |           |
|-----------|
| 1 } start |
| 1.1 }     |
| 1.2       |
| 1.3       |
| 1.4       |
| 1.5       |
| 1.6       |
| 1.7       |
| 1.8       |
| 1.9       |
| 2         |
| 2.1       |

- |           |
|-----------|
| 2 } start |
| 4 }       |
| 16        |
| 32        |
| 39        |
| 49.2      |
| 59.4      |
| 69.6      |
| 79.8      |
| 90        |
| 100.2     |
| 110.4     |

row 390

row 400

To develop a trend without using the fill drag command, enter a formula

=B404+3

- 0
- 3
- 6
- 9
- 12
- 15
- 18
- 21
- 24
- 27
- 30
- 33

=G404\*2

- 2
- 4
- 8
- 16
- 32
- 64
- 128
- 256
- 512
- 1024
- 2048
- 4096

row 410

← this is binary precision

See also Edit Fill Series

row 420

row 430

**TRANSPOSE -- COLUMN to ROW, ROW to COLUMN**

This is an obscure - yet useful command. Say that you have entered data in a column that you should have entered into a row instead. To switch data from a column to a row:

0  
3  
6  
9  
12  
15  
18 column

Highlight the column with your cursor

Copy

Paste Special

Select Transpose

Paste Special dialog box options:

- Paste:  All,  Formulas,  Values,  Formats,  Comments,  Validation,  All except borders
- Operation:  None,  Add,  Subtract,  Multiply,  Divide
- Skip blanks
- Transpose

to get

0 3 6 9 12 15 18 row

This does not work well to transpose an array (matrix). row 440

row 450

row 460

row 470

Figure 5-12 Transposing a column of numbers to a row.

To transpose a matrix array:

	1	2	3	4	5
1	0	0	1	0	0
2	0	1	0	-1	0
3	0	0	0	0	1
4	1	0	0	0	0
5	0.7071	0	0	-0.7071	0.7071
6	0	0.7071	0.7071	0	0

manually transposed numerical array:

	1	2	3	4	5	6
1	0	0	0	1	0.7071	0
2	0	1	0	0	0	0.7071
3	1	0	0	0	0	0.7071
4	0	-1	0	0	-0.7071	0
5	0	0	1	0	0.7071	0

paste special transpose:

	1	2	3	4	5	6
1	0	0	0	1	0.7071	0
2	0	1	0	0	0	0.7071
3	1	0	0	0	0	0.7071
4	0	-1	0	0	-0.7071	0
5	0	0	1	0	0.7071	0



**SYMBOLS**  
ENGLISH / GREEK / MATH and CHARACTER MAP

6

γ

\_6 Symbols.xls

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Symbol	Symath			Symap			SymbolSH			Symeteo									
a α	AA	a	AA	a	AA	a	AA	aa	AA	a	AA	aa	AA	a	AA	A.			
b β	BB	b	BB	b	BB	b	BB	bb	BB	b	BB	bb	BB	b \	BB	B.			
c χ	CX	c	CX	c	CX	c	CX	cc	CX	c	CX	cc	CX	c \	CX	C.			
d δ	DΔ	d	DΔ	d	DΔ	d	DΔ	dd	DΔ	d	DΔ	dd	DΔ	d -	DΔ	D.			
e ε	EE	e	EE	e	EE	e	EE	ee	EE	e	EE	ee	EE	e /	EE	E.			
f φ	FΦ	f	FΦ	f	FΦ	f	FΦ	ff	FΦ	f	FΦ	ff	FΦ	f	FΦ	F.			
g γ	GΓ	g	GΓ	g	GΓ	g	GΓ	gg	GΓ	g	GΓ	gg	GΓ	g \	GΓ	G.			
h η	HH	h	HH	h	HH	h	HH	hh	HH	h	HH	hh	HH	h /	HH	H.			
i ι	II	i	II	i	II	i	II	ii	II	i	II	ii	II	i \	II	I.			
j ϕ	Jϑ	j	Jϑ	j	Jϑ	j	Jϑ	jj	Jϑ	j	Jϑ	jj	Jϑ	j /	Jϑ	J.			
k κ	KK	k	KK	k	KK	k	KK	kk	KK	k	KK	kk	KK	k \	KK	K.			
l λ	LL	l	LL	l	LL	l	LL	ll	LL	l	LL	ll	LL	l /	LL	L.			
m μ	MM	m	MM	m	MM	m	MM	mm	MM	m	MM	mm	MM	m (	MM	M.			
n ν	NN	n	NN	n	NN	n	NN	nn	NN	n	NN	nn	NN	n )	NN	N.			
o ο	OO	o	OO	o	OO	o	OO	oo	OO	o	OO	oo	OO	o \	OO	O.			
p π	PΠ	p	PΠ	p	PΠ	p	PΠ	pp	PΠ	p	PΠ	pp	PΠ	p /	PΠ	P.			
q θ	QΘ	q	QΘ	q	QΘ	q	QΘ	qq	QΘ	q	QΘ	qq	QΘ	q \	QΘ	Q.			
r ρ	RP	r	RP	r	RP	r	RP	rr	RP	r	RP	rr	RP	r /	RP	R.			
s σ	SΣ	s	SΣ	s	SΣ	s	SΣ	ss	SΣ	s	SΣ	ss	SΣ	s \	SΣ	S.			
t τ	TT	t	TT	t	TT	t	TT	tt	TT	t	TT	tt	TT	t /	TT	T.			
u υ	UY	u	UY	u	UY	u	UY	uu	UY	u	UY	uu	UY	u \	UY	U.			
v ϖ	Vς	v	Vς	v	Vς	v	Vς	vv	Vς	v	Vς	vv	Vς	v /	Vς	V.			
w ω	WΩ	w	WΩ	w	WΩ	w	WΩ	ww	WΩ	w	WΩ	ww	WΩ	w \	WΩ	W.			
x ξ	XΞ	x	XΞ	x	XΞ	x	XΞ	xx	XΞ	x	XΞ	xx	XΞ	x /	XΞ	X.			
y ψ	YΨ	y	YΨ	y	YΨ	y	YΨ	yy	YΨ	y	YΨ	yy	YΨ	y \	YΨ	Y.			
z ζ	ZZ	z	ZZ	z	ZZ	z	ZZ	zz	ZZ	z	ZZ	zz	ZZ	z /	ZZ	Z.			
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-	-)	-	-)	-	-)	-	-)	--	-)	-	-)	--	-)	-- \	-)	-)			
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^	^	^	^	^	^	^	^	^	^	^	^	^	^	^	^	^			
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%			
\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$			
#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#			
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%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%			
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&	&			
^	^	^	^	^	^	^	^	^	^	^	^	^	^	^	^	^			
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%			
\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$			
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Table 6-1 Symbol, Symath, Symap, SymbolSH, and Symeteo



**SYMBOLS**  
ENGLISH / GREEK / MATH and CHARACTER MAP

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Greek C				Greek S				Script S											
a	α	A	Α	a	α	A	Α	alpha								a	α	A	Α
b	β	B	Β	b	β	B	Β	beta								b	β	B	Β
c	χ	C	Χ	c	χ	C	Χ	chi								c	χ	C	Χ
d	δ	D	Δ	d	δ	D	Δ	delta								d	δ	D	Δ
e	ε	E	Ε	e	ε	E	Ε	epsilon								e	ε	E	Ε
f	φ	F	Φ	f	φ	F	Φ	phi								f	φ	F	Φ
g	γ	G	Γ	g	γ	G	Γ	gamma								g	γ	G	Γ
h	η	H	Η	h	η	H	Η	eta								h	η	H	Η
i	ι	I	Ι	i	ι	I	Ι	iota								i	ι	I	Ι
j	ϑ	J	ϑ	j	ϑ	J	ϑ									j	ϑ	J	ϑ
k	κ	K	Κ	k	κ	K	Κ	kappa								k	κ	K	Κ
l	λ	L	Λ	l	λ	L	Λ	lambda								l	λ	L	Λ
m	μ	M	Μ	m	μ	M	Μ	mu								m	μ	M	Μ
n	ν	N	Ν	n	ν	N	Ν	nu								n	ν	N	Ν
o	ο	O	Ο	o	ο	O	Ο	omnicron								o	ο	O	Ο
p	π	P	Π	p	π	P	Π	pi								p	π	P	Π
q	ϑ	Q	Θ	q	ϑ	Q	Θ	theta								q	ϑ	Q	Θ
r	ρ	R	Ρ	r	ρ	R	Ρ	rho								r	ρ	R	Ρ
s	σ	S	Σ	s	σ	S	Σ	sigma								s	σ	S	Σ
t	τ	T	Τ	t	τ	T	Τ	tau								t	τ	T	Τ
u	υ	U	Υ	u	υ	U	Υ	upsilon								u	υ	U	Υ
v	ν	V	ν	v	ν	V	ν									v	ν	V	ν
w	ω	W	Ω	w	ω	W	Ω	omega								w	ω	W	Ω
x	ξ	X	Ξ	x	ξ	X	Ξ	xi								x	ξ	X	Ξ
y	ψ	Y	Ψ	y	ψ	Y	Ψ	psi								y	ψ	Y	Ψ
z	ζ	Z	Ζ	z	ζ	Z	Ζ	zeta								z	ζ	Z	Ζ
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::	^ ^	::	^ ^	::	^ ^	::	^ ^									::	^ ^	::	^ ^
::	% %	::	% %	::	% %	::	% %									::	% %	::	% %
::	\$ \$	::	\$ \$	::	\$ \$	::	\$ \$									::	\$ \$	::	\$ \$
::	# #	::	# #	::	# #	::	# #									::	# #	::	# #
::	@ @	::	@ @	::	@ @	::	@ @									::	@ @	::	@ @
::	! !	::	! !	::	! !	::	! !									::	! !	::	! !
::	~ ~	::	~ ~	::	~ ~	::	~ ~									::	~ ~	::	~ ~
::	% %	::	% %	::	% %	::	% %									::	% %	::	% %
::	* *	::	* *	::	* *	::	* *									::	* *	::	* *
::	& &	::	& &	::	& &	::	& &								::	& &	::	& &	
::	^ ^	::	^ ^	::	^ ^	::	^ ^									::	^ ^	::	^ ^
::	% %	::	% %	::	% %	::	% %									::	% %	::	% %
::	\$ \$	::	\$ \$	::	\$ \$	::	\$ \$									::	\$ \$	::	\$ \$
::	# #	::	# #	::	# #	::	# #									::	# #	::	# #
::	@ @	::	@ @	::	@ @	::	@ @									::	@ @	::	@ @
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::	~ ~	::	~ ~	::	~ ~	::	~ ~									::	~ ~	::	~ ~

Table 6-2 Greek C, Greek S, and Script S.

A B C D E F G H I J K L M N O P Q R S T  
**CHARACTER MAP**  
Windows Character Map Using UNICODE CHARACTERS

Click the "Start" button on the task bar and work your way through the menu system to bring up the character map.

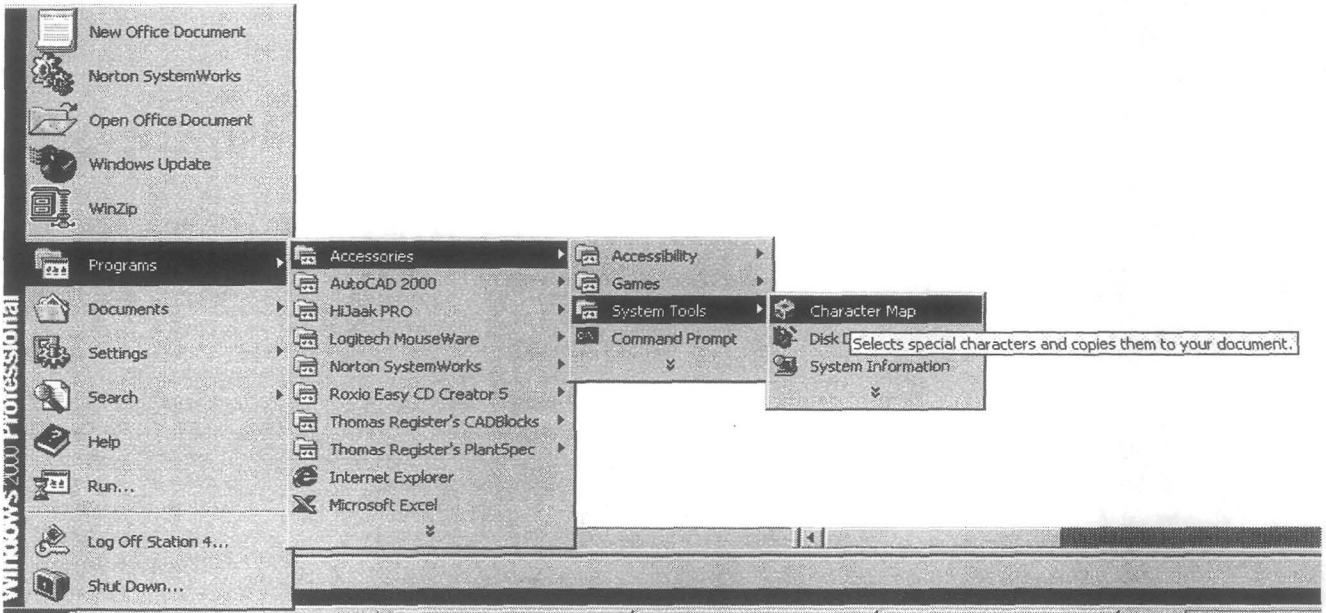


Figure 6-3 The Windows character map menu system.

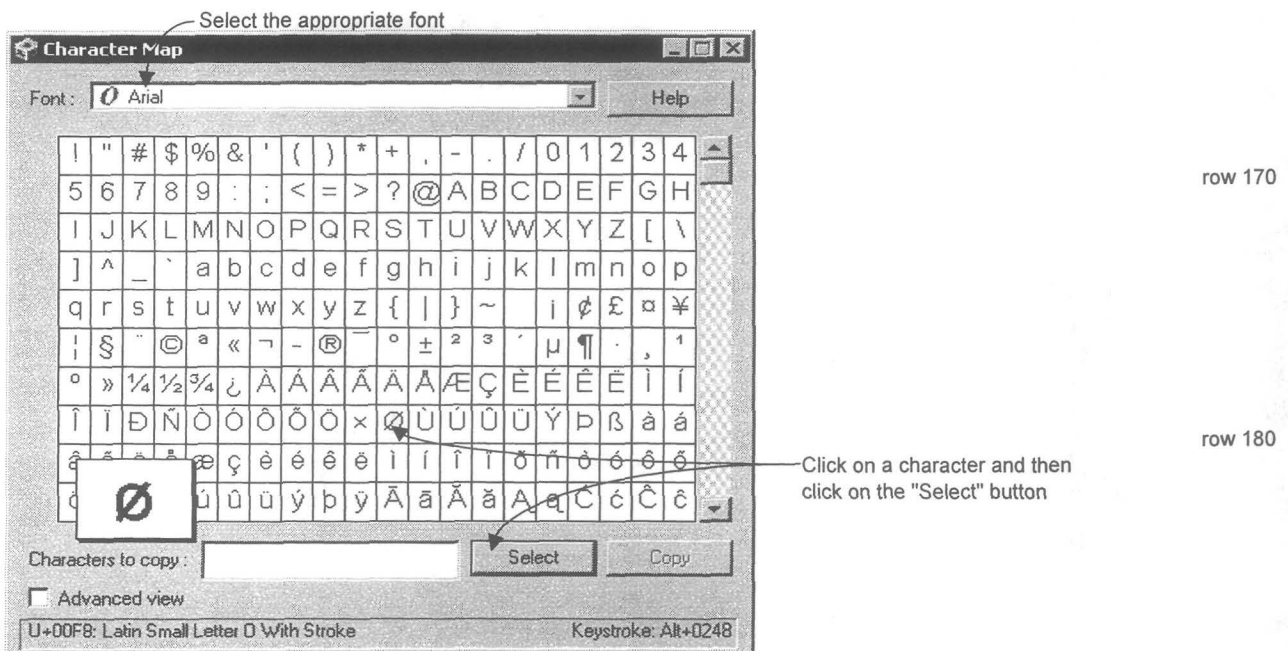


Figure 6-4 The Windows character table.



SYMBOLS
ENGLISH / GREEK / MATH and CHARACTER MAP

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\_6 Symbols 2.xls

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CHARACTER MAP -- CONTINUED
Table with columns A-T and rows of characters. Includes a screenshot of the 'Characters to copy' box and a 'Note' about using Alt+four digit number to input characters.

Figure 6-5 Copying a character from the character map table.

Note: The character map characters appear as the symbols they are in the edit window. Other characters such as W look like W in the edit window when SymbolSH and other fonts are used.

Samples

Print this sample from your printer to see what works best for you:

Table with 3 columns: character, Greek, SymbolSH. Rows include Ω, β, Σ.

Table with 3 columns: symbol, code, description. Rows include ø, Ø, β, μ.

Table with 2 columns: symbol, description. Rows include 1/4, 1/2, 3/4, Δ.

CHARACTERS TO BE COPIED
Row of various symbols and characters including Greek letters, math symbols, and special characters.

Table 6-6 Characters to be copied.

To use these letters and symbols in your spreadsheet:

- 1 Click on one of the cells above with your cursor either hit the [F2] edit key or edit in the edit window above.

Figure 6-7 Select the row and press [F2] edit.

- 2 Paint the symbol or symbols with the cursor and press [Ctrl] [C] or right click your mouse and select copy.

Figure 6-8 Highlight / 'paint' the character with your cursor.

- 3 Go to the cell containing the text to be edited, highlight the spot with your cursor and press [Ctrl] [V] or right click and paste the symbol into the text.

Place the reinforcing 3"1/2" clear from soil
'Place the reinforcing 3"1/2" clear from soil
'Place the reinforcing 3"±1/2" clear from soil
Place the reinforcing 3"±1/2" clear from soil

Figure 6-9 Go to your text, highlight the spot for your character, and paste.



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**GREEK CHARACTERS THAT SHOW AS RANGE NAMES**

cell range named	referencing range named cells	View these cells to see symbols as range names.
α β χ 1	1	=α_β_χ
δ Δ 2	2	=δ_Δ
ε Ε Φ 3	3	=ε_Ε_Φ
κ γ Γ 4	4	=κ_γ_Γ
η φ λ 5	5	=η_φ_λ
Λ π 6	6	=Λ_π
Θ ρ σ 7	7	=Θ_ρ_σ
Σ τ 8	8	=Σ_τ
ς ω Ω 9	9	=ς_ω_Ω
ξ Ξ ψ 10	10	=ξ_Ξ_ψ
Ψ ζ 11	11	=Ψ_ζ
∅ ø f 12	12	=∅_ø_f
ι υ 13	13	=ι_υ
β 14	14	=β

Excel puts in an underscore if a space or an apostrophe is in a range name where ε Ε Φ becomes ε\_Ε\_Φ.

Table 6-10 Greek characters that serve as range names

↓→ 15	15	=_↓→	™ % <sup>a</sup> 26	26	=_™_% <sup>a</sup>
←↑ 16	16	=_←↑	° 27	26	=_°
↔ 17	17	=_↔	3 1/3 28	26	=_3_1/3
⌈ ⌋ 18	18	=_⌈_⌋	3/8 29	26	=_3/8
■ ▨ 19	19	=_■_▨	3/4 30	26	=_3/4
■ □ 20	20	=_■_□	5/8 31	26	=_5/8
• ° 21	21	=_•_°	1/8 ° 32	26	=_1/8_°
▲ ► 22	22	=_▲_►	∞ 33	26	=_∞
▼ ◄ 23	23	=_▼_◄	√ ∞ 34	26	=_√_∞
◇ ● ○ 24	24	=_◇_●_○	≈ ≠ 35	26	=_≈_≠
☼ 25	25	=_☼	≡ ≤ ≥ 36	26	=_≡_≤_≥
			∏ 37	26	=_∏

Table 6-11 Characters that serve as range names

**FORMATTING CHARACTERS USED AS RANGE NAMES**

These characters come from the Arial character map and are formatted as follows:

Arial	GreekC	Courier New Greek
α β χ	α β χ	α β χ
δ	δ	δ
ε Ε Φ	ε Ε Φ	ε Ε Φ
κ γ Γ	κ γ Γ	κ γ Γ
η φ λ	η φ λ	η φ λ
Λ π	Λ π	Λ π
Θ ρ σ	Θ ρ σ	Θ ρ σ
Σ τ	Σ τ	Σ τ
ς ω Ω	ς ω Ω	ς ω Ω
ξ Ξ ψ	ξ Ξ ψ	ξ Ξ ψ
Ψ ζ	Ψ ζ	Ψ ζ
∅ ø f	∅ ø f	∅ ø f
ι υ	ι υ	ι υ

Table 6-12 Formatting characters that serve as range names



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A B C D E F G H I J K L M N O P Q R S T  
**KEYPAD ENTRY DIRECTLY INTO THE SPREADSHEET CELL**

As noted above, to input a character into a spreadsheet instead of copy clipping, set [Num Lock] on, hold down the [Alt] key and input this four digit number in the right hand key pad (not the top row) to get ø. Release the [Alt] key to finish.

Item 1. Unless you set Tools, Options, Transition Formula entry to on, these values will take a range name but, when you press the [F2] key, the cell address is not displayed. Also, the cell referencing the range named cell will copy as an absolutely referenced cell.

These inputs work with the menu command Edit, Find.

row 320

This is not a list of all available characters.

1 ☉	ascii ↓	71 G	111 o	
2 ●	32 hidden '	72 H	112 p	
3 ♥	33 !	73 I	113 q	
4 ♦	34 hidden "	74 J	114 r	looks like r_
5 ♣	35 #	75 K	115 s	
6 ♠	36 \$	76 L	116 t	
7 •	37 %	77 M	117 u	
8 ■	38 &	78 N	118 v	
9 ○	39 hidden '	79 O	119 w	
10 ■	40 (	80 P	120 x	
11 ♂	41 )	81 Q	121 y	
12 ♀	42 *	82 R	122 z	
13 ♪	43 +	83 S	123 {	row 340
14 ♫	44 ,	84 T	124	
15 ✨	45 -	85 U	125 }	
16 ►	46 .	86 V	126 ~	
17 ◄	47 command	87 W	127 ∆	
18 ↓	48 0	88 X	128 Ç	
19 !!	49 1	89 Y	129 ù	
20 ¶	50 2	90 Z	130 é	
21 §	51 3	91 [	131 à	
22 —	52 4	92	132 ä	
23 ↓	53 5	93 ]	133 à	row 350
24 ↑	54 6	94	134 á	
25 ↓	55 7	95 _	135 ç	
26 →	56 8	96 `	136 é	
27 ←	57 9	97 a	137 è	
28 L	58 :	98 b	138 è	
29 ↔	59 ;	99 c	139 ì	
30 ▲	60 <	100 d	140 î	
31 ▼	61 =	101 e	141 ï	
	62 >	102 f	142 Ä	
	63 ? looks like _?	103 g	143 Å	row 360
	64 @	104 h	144 É	
	65 A	105 i	145 æ	
	66 B	106 j	146 Æ	
	67 C looks like C_	107 k	147 ó	
	68 D	108 l	148 ö	
	69 E	109 m	149 ò	
	70 F	110 n	150 ú	

Table 6-13 ASCII Characters

row 370



**SYMBOLS**  
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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
KEYPAD ENTRY DIRECTLY INTO THE SPREADSHEET CELL -- Continuac																			
151	ü			210	π			right side [alt] key											
152	ÿ			211	ll			0260 .				0640	€						í
153	Ö			212	l			0386 ,				0193	Á						ï
154	Û			213	F			0132 „				0225	á						ÿ
155	φ			214	π			0133 ...				0192	À						ÿ
156	£			215	†			0134 †				0224	à						ÿ
157	¥			216	‡			0135 ‡				0194	Ã						ÿ
158	Pts			217	∫			0136 ~				0226	â						l
159	f			218	Γ			0137 ‰				0196	Ä						í
160	á			219	■			0139 ¸				0228	ä						í
161	i			220	■			0155 ›				0195	Å						í
162	ó			221	■			0141 □ does not print				0227	å				0205	í	
163	ú			222	■			0145 ´				0197	Ä				0204	í	
164	ñ			223	■			0352 `				0229	á				0206	î	
165	Ñ			224	α			0180 ´				Ä					0207	î	
166	ª			225	β			0440 „				ä							ÿ
167	º			226	Γ			0147 ¨				Ä							ÿ
168	¿			227	π			0148 ¨				ä							ÿ
169	ƒ			228	Σ			0149 •				ä							ÿ
170	¬			229	σ			0150 –				Å							row 390
171	½			230	μ			0351 _				0198	Æ						ÿ
172	¼			231	τ			0151 —				0230	æ						ÿ
173	ı			232	φ			0175 —				Ç							κ
174	«			233	Θ			0892				ç							Ł
175	»			234	Ω			0152 ~				Ç							í
176	█			235	δ			0894 ~				ç							Ł
177	█			236	∞			0153 ™				0199	Ç						ı
178	█			237	φ			0444 ¼				0231	ç						ı
179				238	ε			0445 ½				Ç							ı
180	†			239	∏			0446 ¾				ç							ı
181	‡			240	≡			0161 ¡				Č							ı
182	‡			241	±			0162 ¢				č							ı
183	∏			242	≥			0163 £				Ď							ı
184	∫			243	≤			0164 ¤				ď							ı
185	∫			244	∫			0165 ¥				0208	Đ						ı
186	∥			245	∫			0166 ¡				đ							ı
187	∫			246	÷			0167 §				0240	đ						ı
188	∫			247	≈			0168 ¨				0201	É						ı
189	∫			248	≠			0171 «				0233	é						ı
190	∫			249	·			0443 »				0200	È						ı
191	∫			250	·			0172 ¬				0232	è						ı
192	∫			251	√			0169 ©				0202	Ê						ı
193	∫			252	ª			0174 ®				0234	ê				0209	Ñ	ı
194	∫			253	²			0176 °				0203	Ë				0241	ñ	ı
195	∫			254	■			0177 ±				0235	ë				0442	°	ı
196	—			255	hidden ' This is the end of ascii characters ↑			0173 -				Ë							ı
197	†							0215 ×				ë							ı
198	†							0247 ÷				Ë							ı
199	∫							0441 ¹				ë							ı
200	∫							0434 ²				0387	f						row 420
201	∫							0179 ³				Ğ							ı
202	∫							0170 º				ğ							ı
203	∫							0180 ´				Ğ							ı
204	∫							0191 ¿				ğ							ı
205	=											Ğ							ı
206	∫											ğ							ı
207	∫											Ğ							ı
208	∫											ğ							ı
209	∫											ğ							row 430

Table 6-14 ASCII Characters and Characters From The Windows Character Map.



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**6**  
**γ**

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
0140	Œ																	
0156	œ																	
0211	Ó																	
0210	Ò																	
0212	Û																	
0214	Ö																	
0213	Û																	
0216	Ø																	
0248	ø																	
0245	õ																	
0223	ß																	
0222	Ɔ																	
0254	Ɔ																	
0153	™																	
0218	Ú																	
0250	ú																	
0217	Û																	
0249	ù																	
0219	Ù																	
0251	û																	
0220	Û																	
0252	ü																	
0221	Ý																	
0253	ÿ																	
0159	Ÿ																	
0255	ÿ																	
0142	Ž																	
0158	ž																	
	Ž																	
	ž																	
	ž																	
	ž																	
0437	μ																	
0439	·																	

Table 6- 15 ASCII Characters used to draw figures.

Table 6- 14 Continued ASCII Characters and Characters From The Windows Character Map.

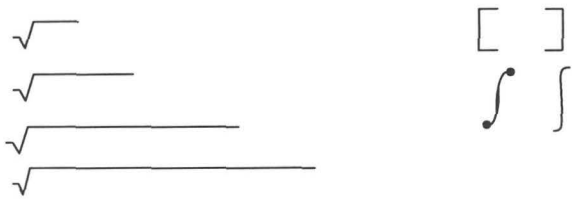


Figure 6-17 Figures that are used in formulas.

GETTING STARTED

Note: for Excel to print graphics correctly on a HP LaserJet 6P

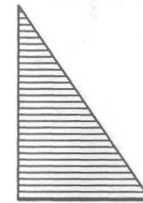
File

Print

Properties

Graphics

set to raster graphics



On our printer, the triangle will print as solid if vector graphics is selected. row 20

Figure 7-1 The File menu system to set graphics to raster graphics.

This is the Excel toolbar icon to bring up the drawing toolbar



Figure 7-2 Selecting the drawing toolbar.

If you are used to drafting in AutoCAD, drawing in Excel can be a little clumsy. Here are a few tips to make drawing doable and faster.

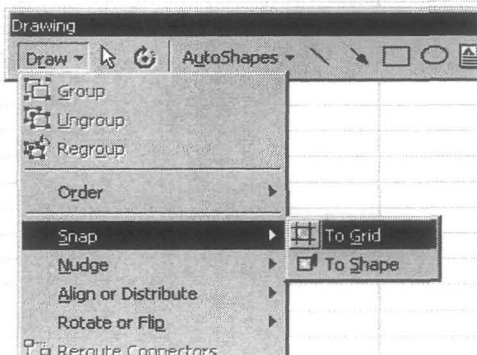


Figure 7-3 Choosing Snap-To-Grid.

In the drawing toolbar, select Draw and Snap. Select Snap to Grid and use the gridlines on the spreadsheet to aid in making lines meet. row 50

Draw images oversized, group, and reduce in size later. Also, zoom to 400% (which is the max zoom) to get accurate detail.

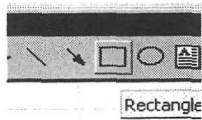
row 60

row 70

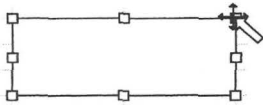


A B C D E F G H I J K L M N  
EXAMPLE -- BOX

For a quick example, we will select a box to highlight data.



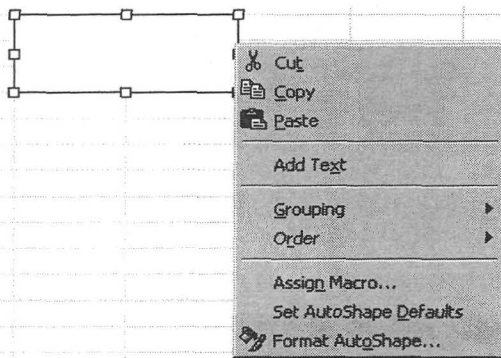
Highlight the box and left click



The box will snap to the grid.

row 80

However, this box is opaque and will hide your information.

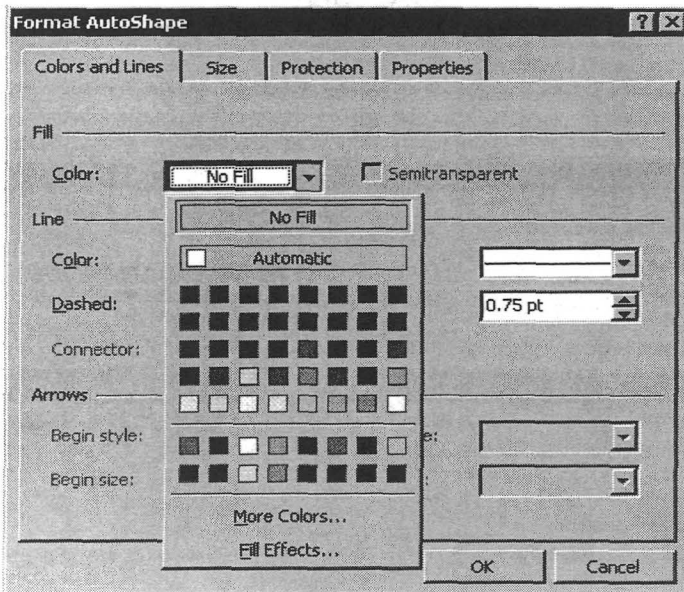


row 90

Select the box with the cursor and right click to get the drop down menu.

Left click on format shape.

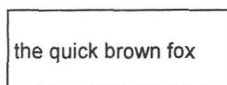
row 100



Select Fill, Color, No Fill.

row 110

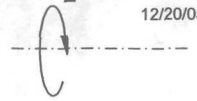
row 120



← This is the result.

Figure 7-4 Formatting a box without background.

row 130



EXAMPLE -- ARC AND POINTER

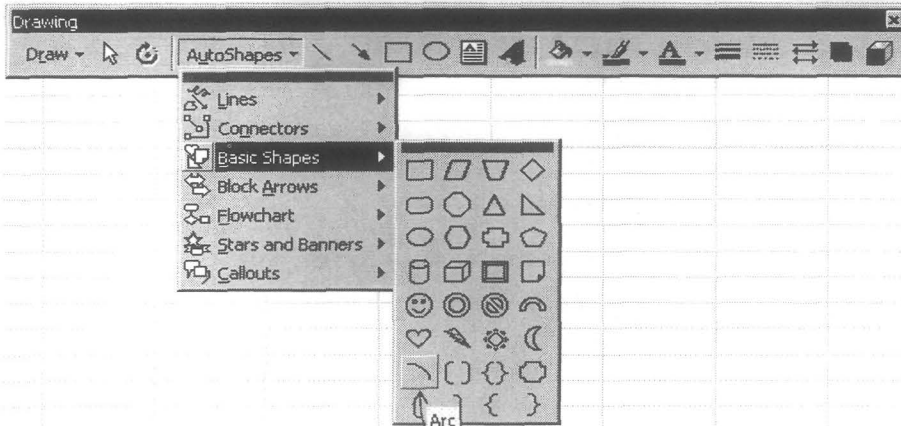


Figure 7-5 The "AutoShapes menu."

Pick AutoShapes, Basic shapes, and Arc.

row 140

row 150

Without much explanation, here are a few ways to manipulate the arc.

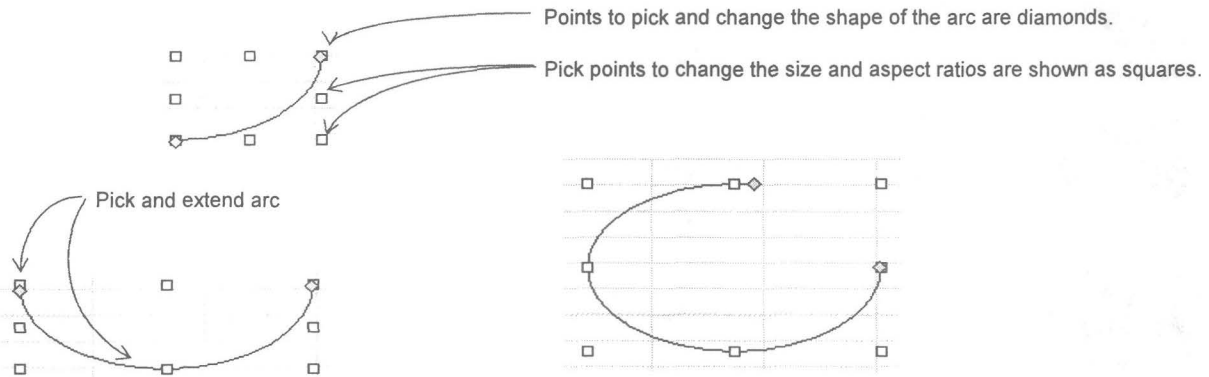
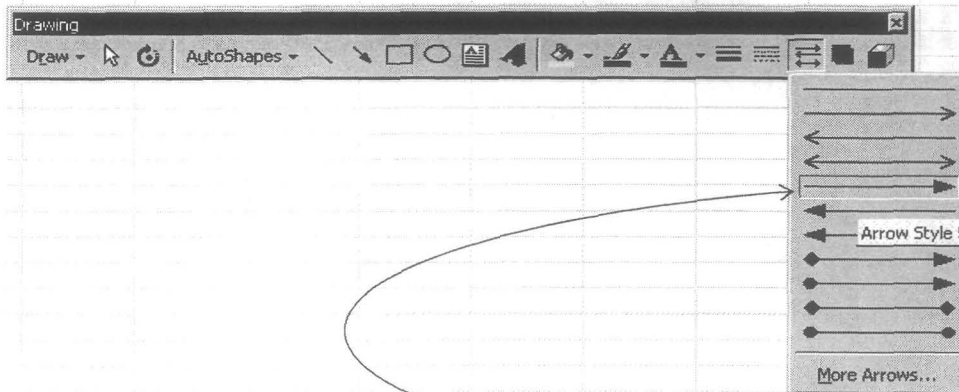


Figure 7-6 Drawing an arc.

row 160

row 170



Make an arc into a pointer by selecting arrowheads to put an arrowhead on either end of the arc.

Figure 7-7 Putting an arrowhead on the arc.

row 180

row 190

**DRAWING LINES**

Say that you want to draw a degrading sine wave.

First, in the drawing tool bar under Draw, set snap to Grid. This usually makes drawing easier.

Second, in the drawing tool bar under AutoShapes select Lines. For our purposes we will select Curve. Smash [Escape] to exit when finished with the line.

Curve works like a spline. Draw to a grid point and left click.

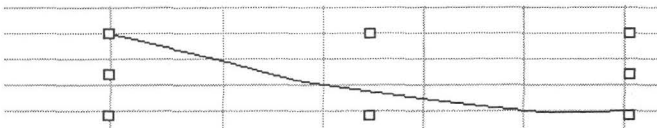


Figure 7-8 Drawing a mathematical curve.

If the line isn't correct, right click the line and click on Edit Points.

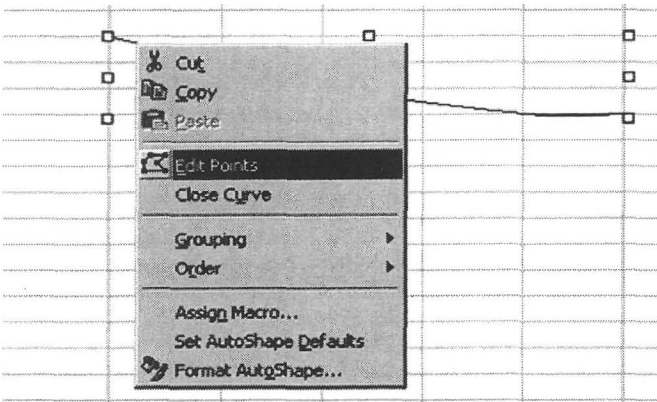


Figure 7-10 Editing a curve with Edit Points.

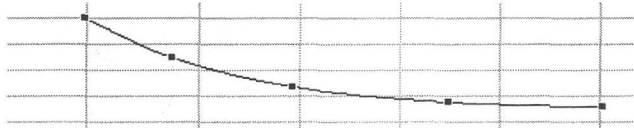
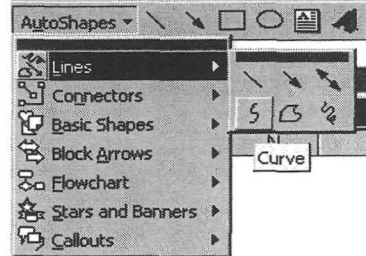


Figure 7-9 Edit Points along a line.

Edit Points allows you to move each of the nodes that you created with the left click. Edit Points will not snap to grid.

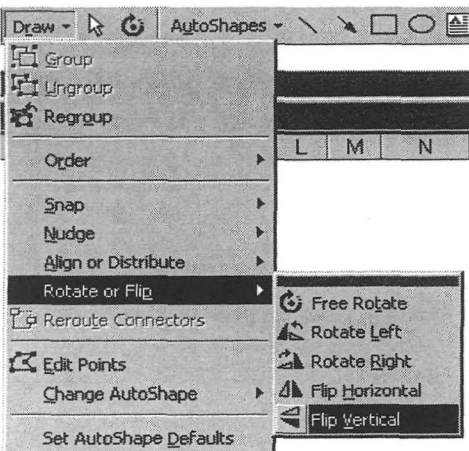


Figure 7-11 Select Rotate or Flip in the drawing toolbar.

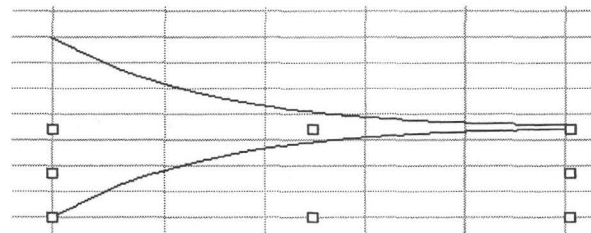


Figure 7-12 Flip a copy of the curve and then position it.

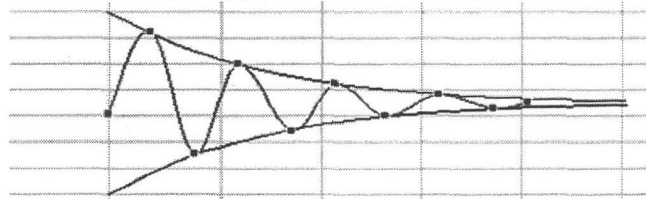
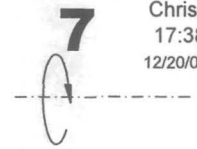
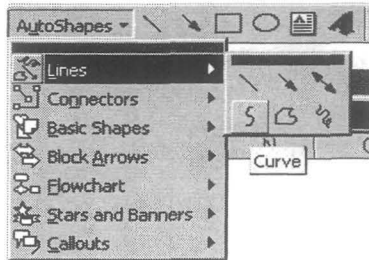


Figure 7-13 Using the Curve command from the AutoShapes Lines menu, draw in the sine wave. Here, use the Edit Points menu command to highlight the pick points used to create the wave.



A B C D E F G H I J K L M N  
DRAWING LINES -- Continued



Scribble  
Free Form  
Curve

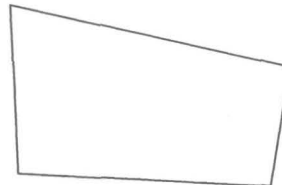


Figure 7-15 The Free Form line drawing tool.

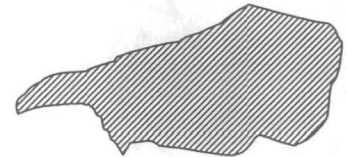


Figure 7-16 The Scribble drawing tool with a filled, closed line.

Figure 7-14 All three lines in the AutoShapes Lines pop-down menu will create closed line shapes which can be filled.

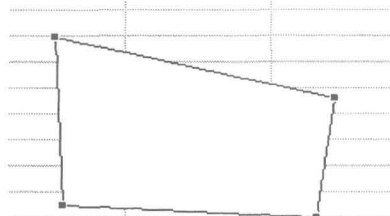


Figure 7-17 Point to this Free Form shape and right click to bring up the Edit Points menu.

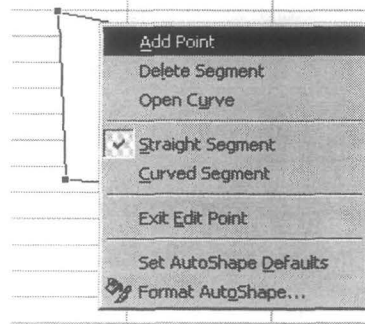


Figure 7-18 Put your cursor on a location on one of the lines and left click Add Point.

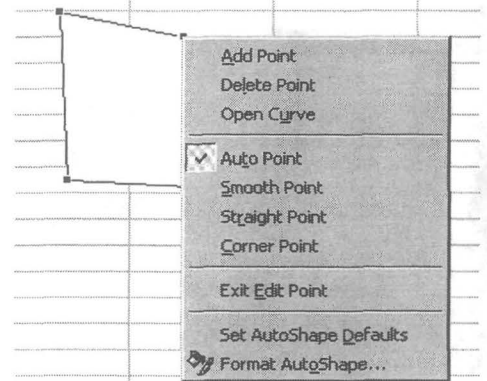


Figure 7-19 Highlight any point with your cursor, right click, and bring up the point edit menu.

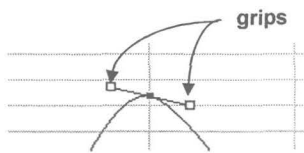


Figure 7-20 Note that the Excel Edit Points command does offer grips for closed shapes.

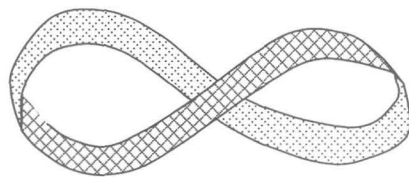


Figure 7-21 This Möbius strip was created using the Curve drawing tool and the Edit Points edit tool.

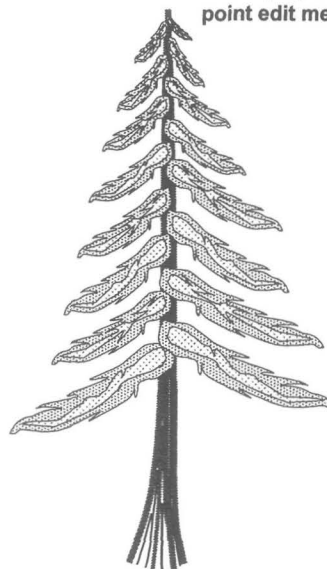
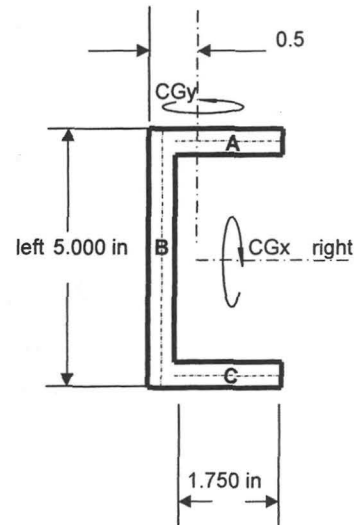
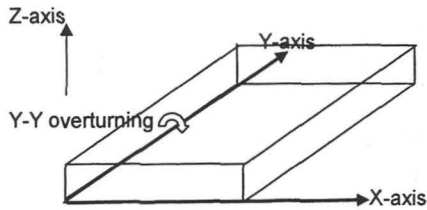


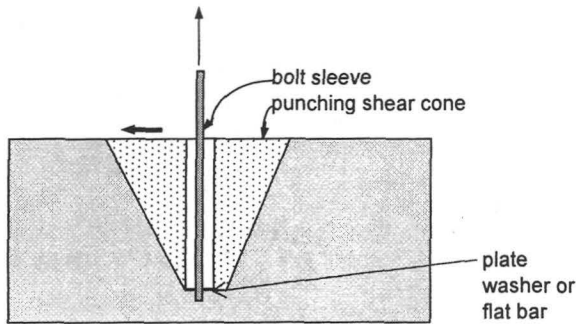
Figure 7-22 Generic conifer drawn in Excel drawing tools



A B C D E F G H I J K L M N  
EXAMPLE -- DIAGRAMS

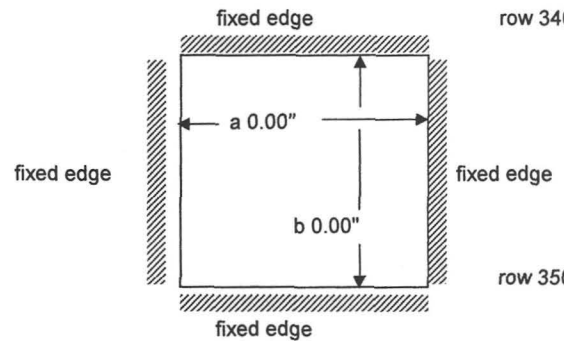


row 320



row 330

20.0" -- L = Embed Provided



row 340

row 350

∫ integral symbol

row 360

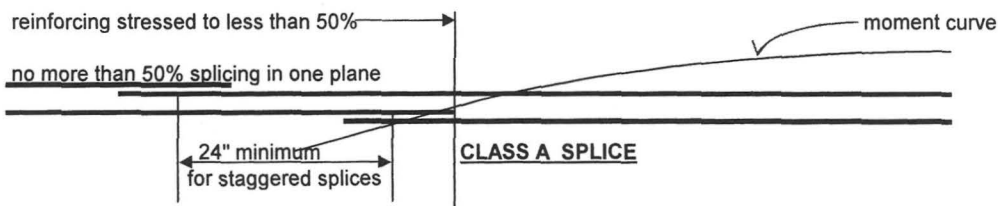
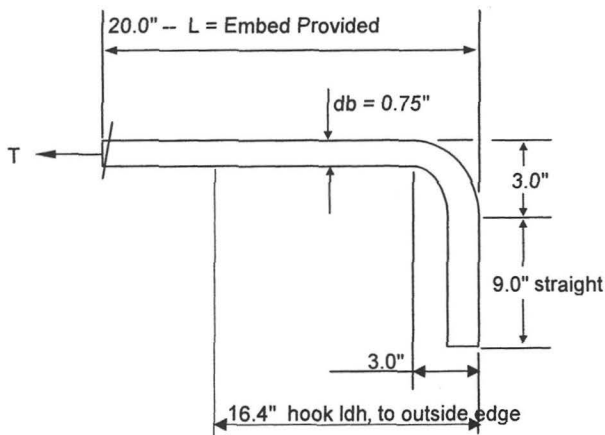


Figure 7-23 Sample drawings and symbols.

row 370



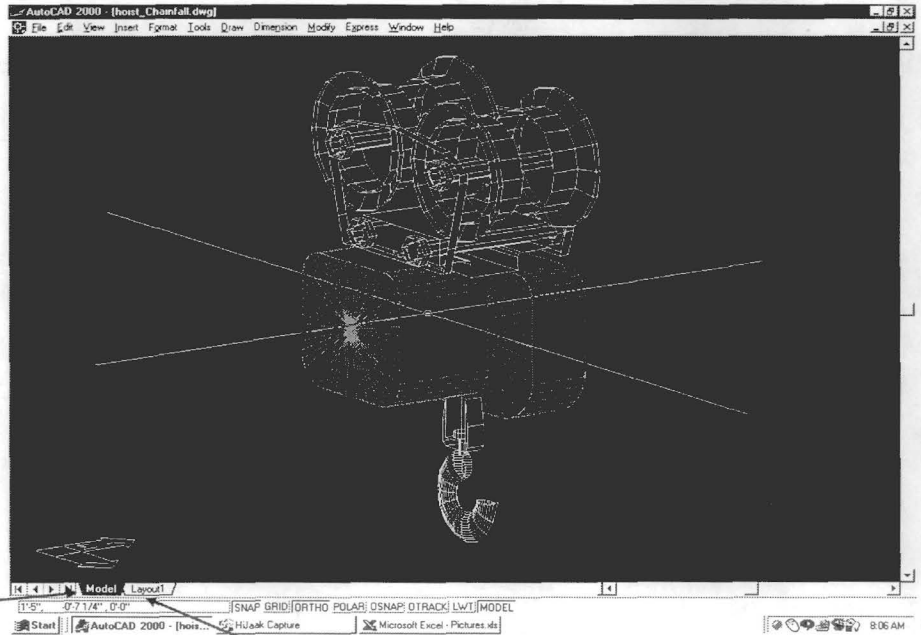
### AUTOCAD DRAWINGS

This write-up is aimed at intermediate and advanced users.

There are a couple of quick ways to bring AutoCad drawings into Excel.

First – you probably do a lot of your work in model space with a black background. But you can print out of paper space where you can xref in your title block(s) and create view ports. Set the paper space background color to white to make copy clipping an image easier. Otherwise, if you are working just in model space, you'll have to go to Tools, Options, Display, Colors, Background color, and set it to white.

This image can be AutoCAD 13, 14, or 2000.



Model space tab indicating that this view is model space

Paper space tab

Figure 8-1 Hoist displayed in AutoCad model space.

Viewport border

Paper space tab indicating that this view is paper space layout 1

Model space tab

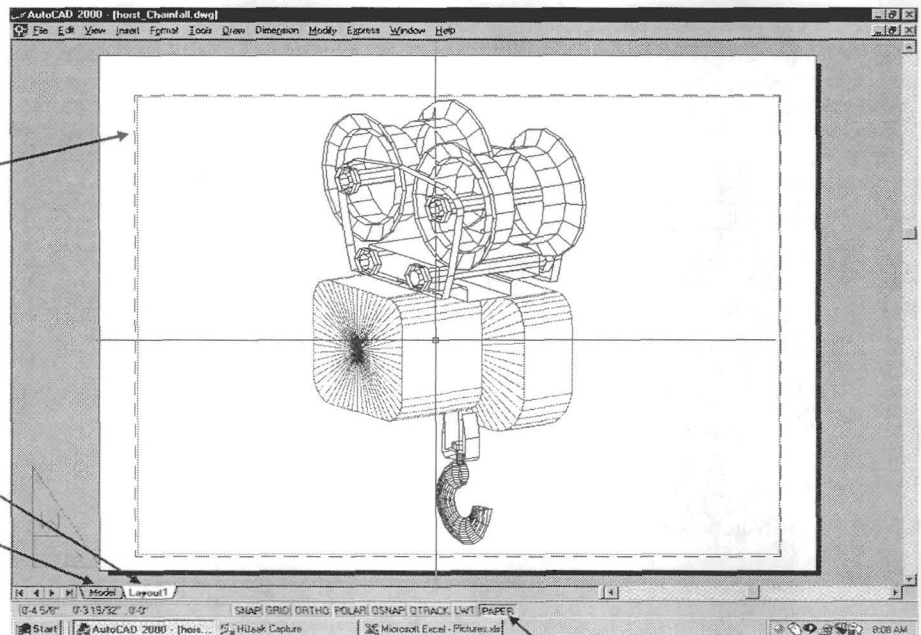


Figure 8-2 Hoist displayed in AutoCAD paper space.

Note that screen captures were done with HijakkPro and pasted into Excel as bit map files.

Switch into and out of model space with this tab. You can continue to draft in model space or switch into paper space for titles, notes, and etcetera.

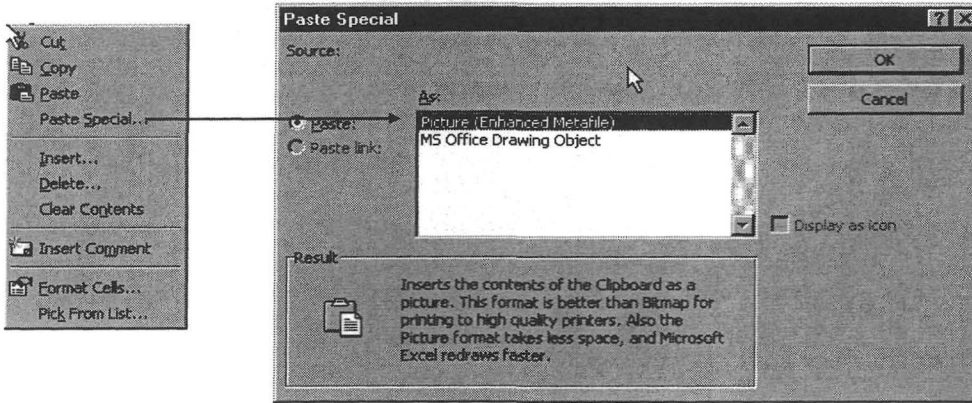


### DIAGRAMS WITH BACKGROUND

Often times, simple diagrams are more easily created in AutoCad.

This 3D diagram was created in AutoCAD and copy clipped with the command [Ctrl] [c] or Copy in the drop down menu (right click).

In Excel, use Paste Special Picture (Enhanced Metafile) This allows you to print the diagram without borders but, in this case, you are left with a opaque white background.



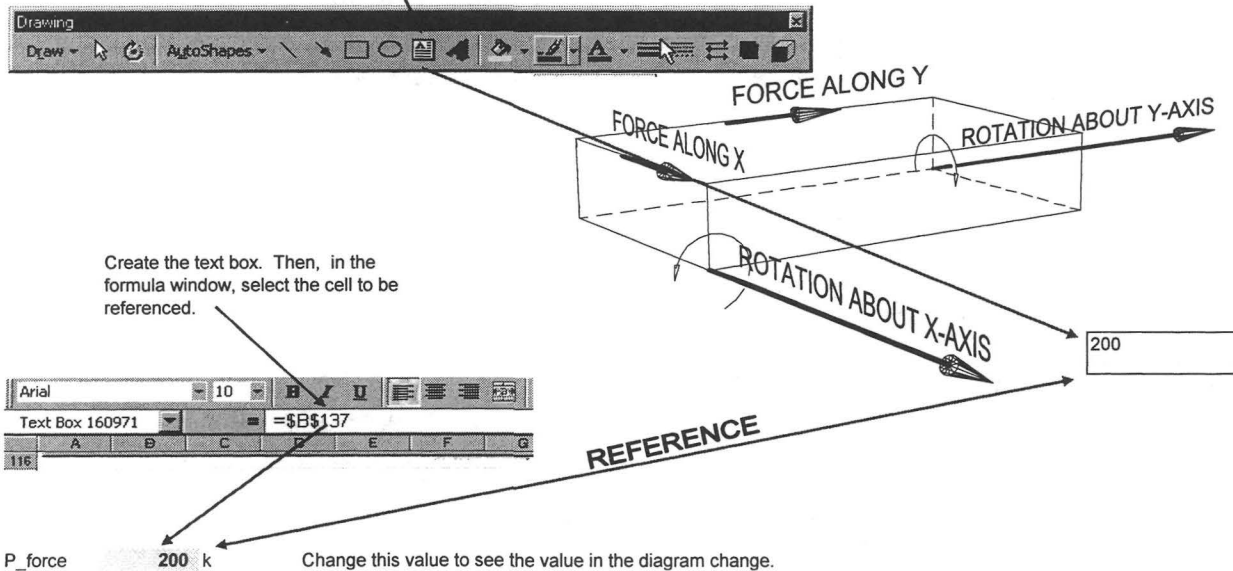
row 90

row 100

Figure 8-3 Cut-and-paste "Special."

If you want to have a dynamic diagram using numbers produced in your spreadsheet, you'll have to use the drawing tool bar and select the text button.

row 110



row 120

row 130

Create the text box. Then, in the formula window, select the cell to be referenced.

P\_force 200 k Change this value to see the value in the diagram change.

Figure 8-4 Active text in diagrams and drawings.

row 140

If the text box is hidden, send the diagram to back with a right click of the mouse button and the appropriate choice.

row 150



### DIAGRAMS WITHOUT BACKGROUND

To create a diagram without a background, copy clip out of AutoCAD and paste into the spreadsheet.

Then, click on the diagram and right click the mouse to select Grouping, Ungroup. From the same right click pop down menu select Format Object and the Colors and Lines tab.

At the Fill Color: window, click and choose No Fill.

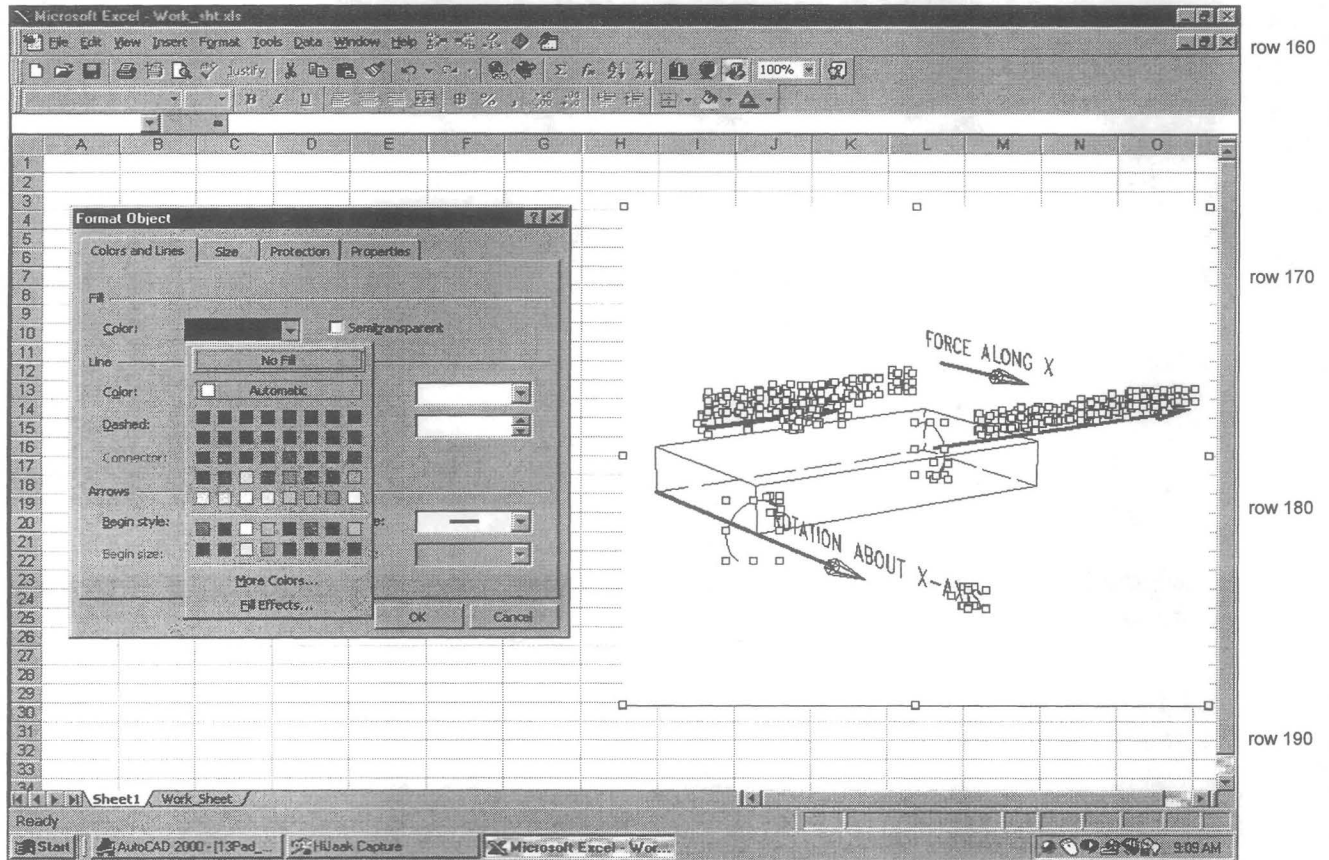


Figure 8-5 Removing the background from an AutoCAD drawing.

Then, while holding the [Shift] key down, highlight an item so that the mouse pointer shows a "+." This can be a bit tricky so be forewarned. From the pop down menu select Grouping, Group to turn the diagram back into one contiguous, moveable picture.

Now, values can be directly referenced in the drawing.

A complicated diagram will be harder to scroll past when you are moving around the spreadsheet. The borders will print and it cannot be edited with the Drawing tool bar.



**PHOTOGRAPHS**

Pictures can be downloaded into the spreadsheet from scanners, digital cameras, and digital and analog video tape.

This picture is downloaded from an analog video camera with **SNAPPY** by **PLAY**, Incorporated in Windows 95.

Also, simple diagrams can be created with the spreadsheet's drawing tools.

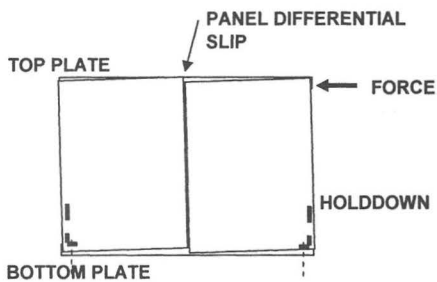
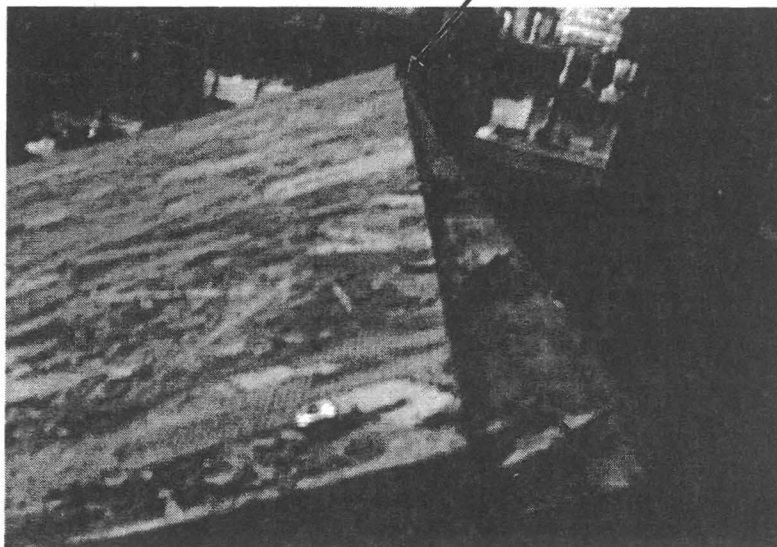


Figure 8-6 Elevation diagram of the test sample.



Gap between stud and plate  
Nails torn out vertically, not horizontally as would be expected in a shear wall

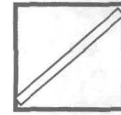
Figure 8-7 An analogue cam-corder picture of the tested sample.

row 260

row 270

row 280

row 290



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### GRAPHING RECTANGLES

Generally, the **XY Scatter** graph works best for most purposes. Graphing can be used for analysis and error trapping. You'll find graphing throughout this manual.

w diagonal	6 in	width of inside rectangle
Horiz_1	24 in	length of large rectangle in the x direction
Vert_1	24 in	height of the large rectangle in the y direction
adjust	3 unitless	adjust for accuracy in convergence

#### Shooting Method

	b	vertical	difference
	4.2426 in		0.000
	4.2426 in	23.6464	-0.018
	4.1890 in	23.6509	0.002
	4.1945 in	23.6505	0.000
	4.1940 in	23.6505	0.000
	4.1940 in	23.6505	0.000
	4.1940 in	23.6505	0.000
Horiz leg	4.1940 in	23.6505	0.000
Vert leg	4.2907 in		

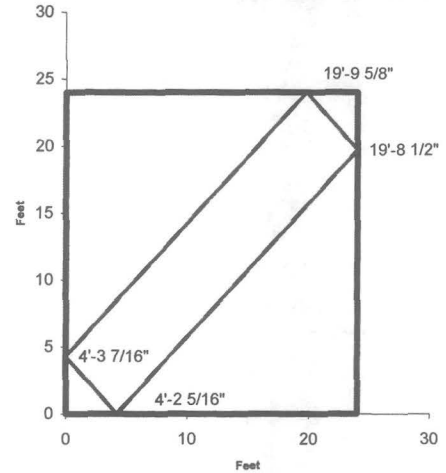


Figure 9-1 A rectangle within a rectangle.

row 30

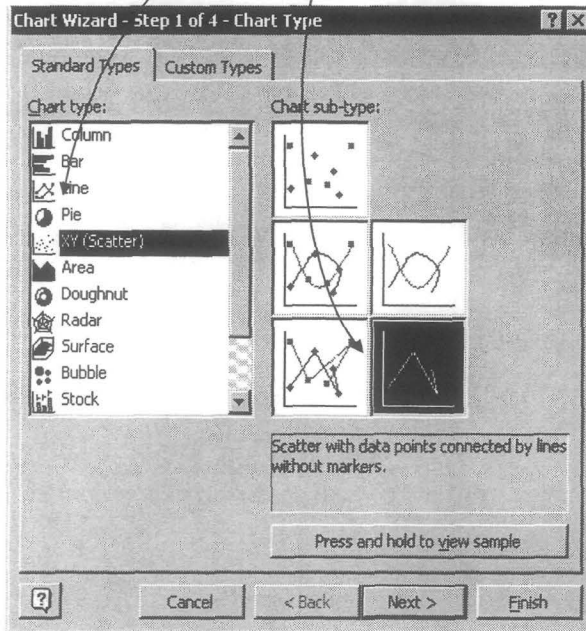
#### Graphing Ranges

x	a	b	labels
0	0	0	
0	24	24	
24	24	0	
24	0	0	
4.1940	0.0000	4.2907	4'-2 5/16"
0.0000	4.2907	4.1940	4'-3 7/16"
19.8060	24.0000	19.7093	19'-9 5/8"
24.0000	19.7093	19.8060	19'-8 1/2"
4.1940	0.0000		
24	24		values to maintain an aspect ratio

Figure 9-2 Graph ranges.

Highlight your graphing ranges and click on the graphing icon in the toolbar.

Select **XY (Scatter)** and, in this case, select the icon with straight lines only.



#### Fractions Table

0 "
0.06 1/16"
0.13 1/8"
0.19 3/16"
0.25 1/4"
0.31 5/16" row 40
0.38 3/8"
0.44 7/16"
0.5 1/2"
0.56 9/16"
0.63 5/8"
0.69 11/16"
0.75 3/4"
0.81 13/16"
0.88 7/8"
0.94 15/16"
1 1"

You can click on Next > or Finish. If you click on Next >, be sure to make sure that your data is in columns if that is how your data is arranged.

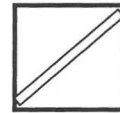
Figure 9-3 Selecting XY (Scatter) from the Chart Wizard window.

row 60



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**Graphing Rectangles -- Continued**

w diagonal	6 in	width of inside rectangle
Horiz_1	24 in	length of large rectangle in the x direction
Vert_1	24 in	height of the large rectangle in the y direction
adjust	3 unitless	adjust for accuracy in convergence

**Shooting Method**

b	vert	difference	
4.2426 in		0.000	
4.2426 in	23.6464	-0.018	
4.1890 in	23.6509	0.002	
4.1945 in	23.6505	0.000	
4.1940 in	23.6505	0.000	
4.1940 in	23.6505	0.000	
4.1940 in	23.6505	0.000	
Horiz leg	4.1940 in	23.6505	0.000
Vert leg	4.2907 in		vert leg of triangle

x	a	b	labels
0	0		
0	24		
24	24		
24	0		
0	0		
2.5260		0.0000	2'-6 5/16"
0.0000		4.2907	4'-3 7/16"
21.4740		24.0000	21'-5 11/16"
24.0000		19.7093	19'-8 1/2"
2.5260		0.0000	

24      24 ← values to maintain an aspect ratio

**Fractions Table**

0	0"
0.0625	1/16"
0.125	1/8"
0.1875	3/16"
0.25	1/4"
0.3125	5/16"
0.375	3/8"
0.4375	7/16"
0.5	1/2"
0.5625	9/16"
0.625	5/8"
0.6875	11/16"
0.75	3/4"
0.8125	13/16"
0.875	7/8"
0.9375	15/16"
1	1"

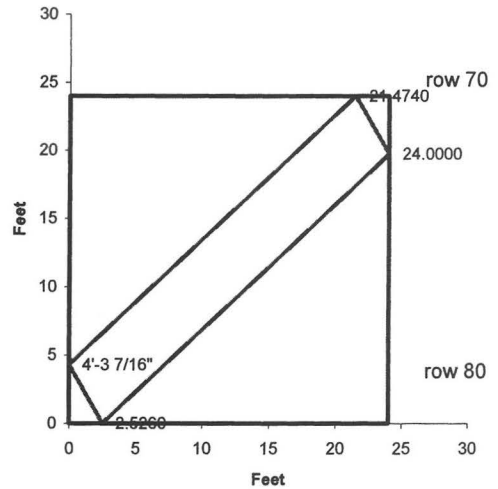


Figure 9-4 A rectangle within a rectangle.

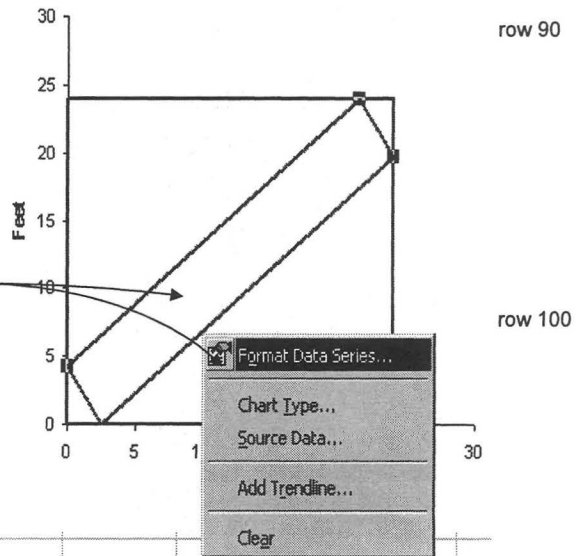
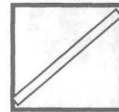
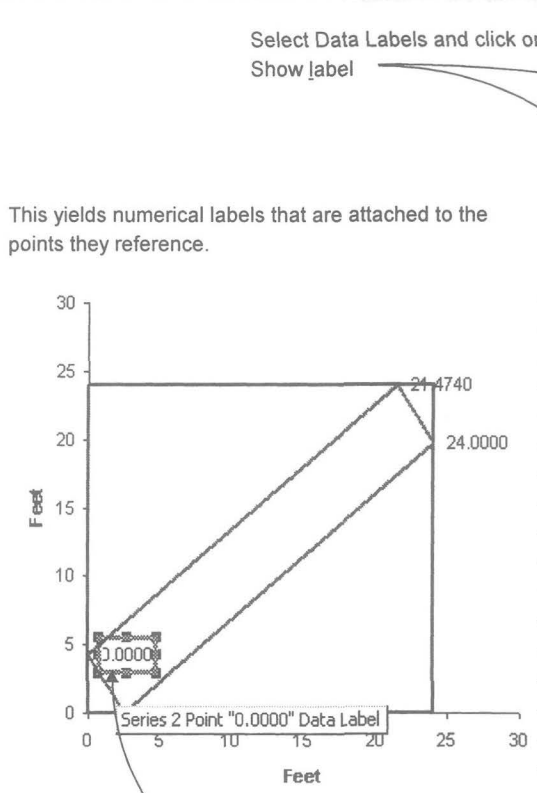


Figure 9-5 The graph formatting menu.



A B C D E F G H I J K L M N  
Graphing Rectangles -- Continued



Select Data Labels and click on Show label

This yields numerical labels that are attached to the points they reference.

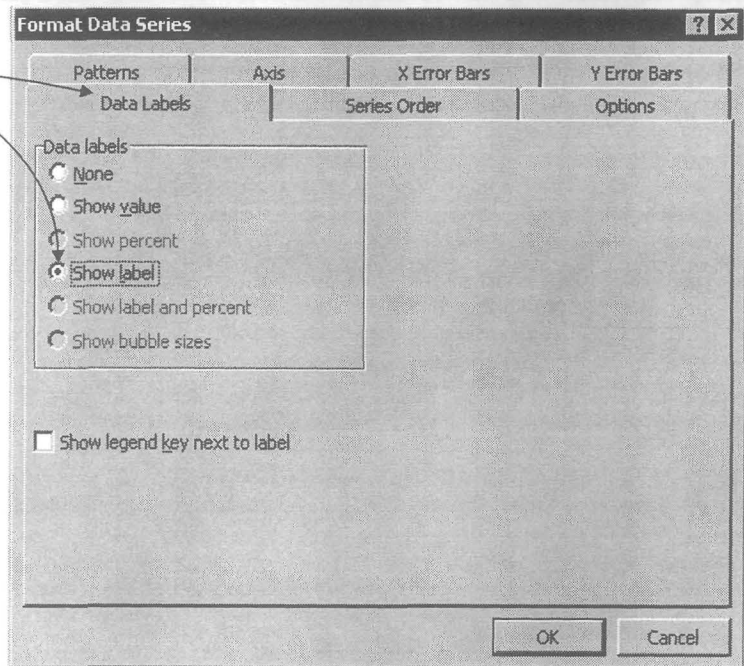


Figure 9-6 Formatting the graph.

To alter these labels to the foot and inch labels, click on the label to highlight it.

Figure 9-7 Setting up graph data labels.

Enter an equals sign "=" in the edit bar. Reference the appropriate cell to get this:

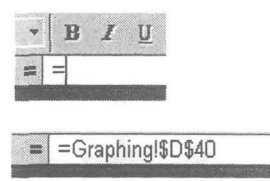


Figure 9-8 Creating the data label.

This yields a label that will follow the point it references

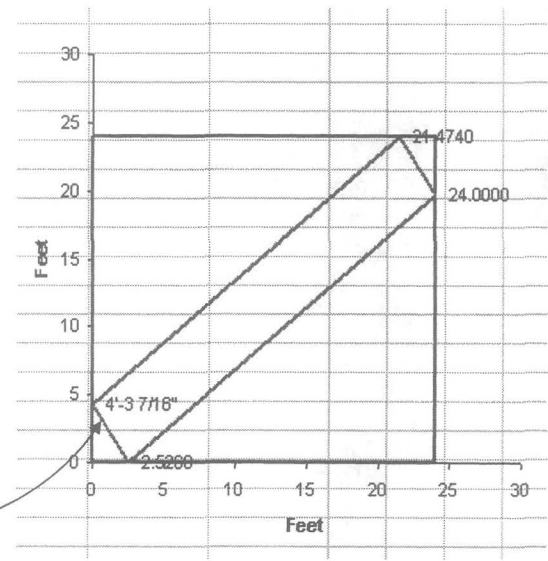


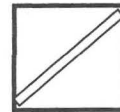
Figure 9-9 The finished data label.

Note: I did check this in AutoCAD to make sure that my math is accurate. row 160



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A B C D E F G H I J K L M N

## 3D ARRAY

This is a method of presenting information of a three dimensional data. In this example, Z represents individual planes. In a following example, a 3-dimensional spiral is represented where Z represents the length of the spiral.

We use an aspect ratio to allow adjustment for convenient viewing.

In this case, an aspect ratio of 0, 0 allows us to superimpose the three curves.

aspect\_x  unitless *inactive input for demonstration*  
 aspect\_y  unitless *inactive input for demonstration*

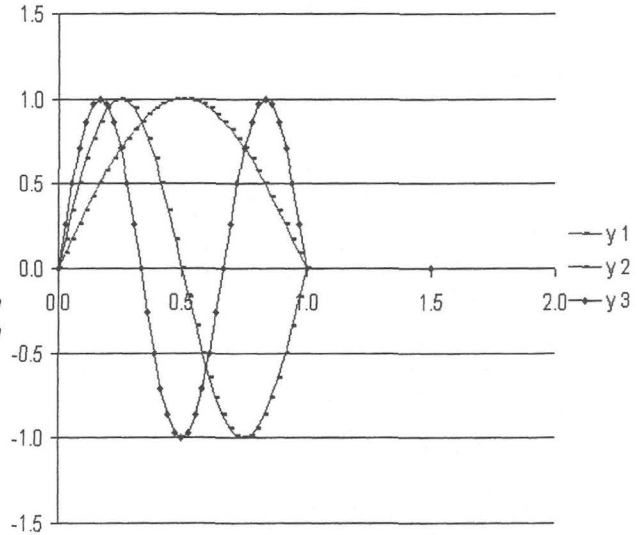


Figure 9-10 Superimposed data curves.

In this case, an aspect ratio of 0.5, 0.5 is used to display the ability to show the three curves on three different planes.

aspect\_x  unitless *this input is active*  
 aspect\_y  unitless *this input is active*

The grid lines are part of the graphing math. They are used to help relate the three curves to each other.

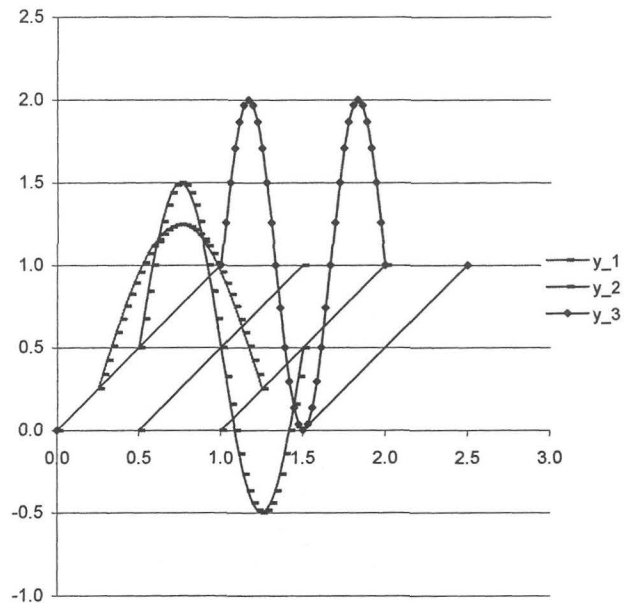
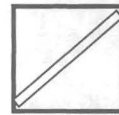


Figure 9-11 Data curves in an array.



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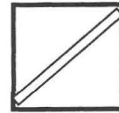
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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>3D ARRAY -- Continued</b>													
X 1 is an arbitrary array of numbers to plot the curves against		Z is a hard number that defines a plane				=SIN(X_1*2*PI())							
	=SIN(X_1*PI())			=X_1+Z_1*\$aspect_x	=Y_1+Z_1*\$aspect_y					=Y_2+Z_2*\$aspect_y			
										=X_2+Z_2*\$aspect_x			
X_1	Y_1	Z_1	x_1	y_1	Y_2	Z_2	x_2	y_2	Y_3	Z_3	x_3	y_3	
0	0.0000	0.5	0.2500	0.2500	0.0000		1	0.5000	0.500	0.00	2	1.00	1.00
0.0278	0.0872	0.5	0.2778	0.3372	0.1736		1	0.5278	0.674	0.26	2	1.03	1.26
0.0556	0.1736	0.5	0.3056	0.4236	0.3420		1	0.5556	0.842	0.50	2	1.06	1.50
0.0833	0.2588	0.5	0.3333	0.5088	0.5000		1	0.5833	1.000	0.71	2	1.08	1.71
0.1111	0.3420	0.5	0.3611	0.5920	0.6428		1	0.6111	1.143	0.87	2	1.11	1.87
0.1389	0.4226	0.5	0.3889	0.6726	0.7660		1	0.6389	1.266	0.97	2	1.14	1.97
0.1667	0.5000	0.5	0.4167	0.7500	0.8660		1	0.6667	1.366	1.00	2	1.17	2.00
0.1944	0.5736	0.5	0.4444	0.8236	0.9397		1	0.6944	1.440	0.97	2	1.19	1.97
0.2222	0.6428	0.5	0.4722	0.8928	0.9848		1	0.7222	1.485	0.87	2	1.22	1.87
0.2500	0.7071	0.5	0.5000	0.9571	1.0000		1	0.7500	1.500	0.71	2	1.25	1.71
0.2778	0.7660	0.5	0.5278	1.0160	0.9848		1	0.7778	1.485	0.50	2	1.28	1.50
0.3056	0.8192	0.5	0.5556	1.0692	0.9397		1	0.8056	1.440	0.26	2	1.31	1.26
0.3333	0.8660	0.5	0.5833	1.1160	0.8660		1	0.8333	1.366	0.00	2	1.33	1.00
0.3611	0.9063	0.5	0.6111	1.1563	0.7660		1	0.8611	1.266	-0.26	2	1.36	0.74
0.3889	0.9397	0.5	0.6389	1.1897	0.6428		1	0.8889	1.143	-0.50	2	1.39	0.50
0.4167	0.9659	0.5	0.6667	1.2159	0.5000		1	0.9167	1.000	-0.71	2	1.42	0.29
0.4444	0.9848	0.5	0.6944	1.2348	0.3420		1	0.9444	0.842	-0.87	2	1.44	0.13
0.4722	0.9962	0.5	0.7222	1.2462	0.1736		1	0.9722	0.674	-0.97	2	1.47	0.03
0.5000	1.0000	0.5	0.7500	1.2500	0.0000		1	1.0000	0.500	-1.00	2	1.50	0.00
0.5278	0.9962	0.5	0.7778	1.2462	-0.1736		1	1.0278	0.326	-0.97	2	1.53	0.03
0.5556	0.9848	0.5	0.8056	1.2348	-0.3420		1	1.0556	0.158	-0.87	2	1.56	0.13
0.5833	0.9659	0.5	0.8333	1.2159	-0.5000		1	1.0833	0.000	-0.71	2	1.58	0.29
0.6111	0.9397	0.5	0.8611	1.1897	-0.6428		1	1.1111	-0.143	-0.50	2	1.61	0.50
0.6389	0.9063	0.5	0.8889	1.1563	-0.7660		1	1.1389	-0.266	-0.26	2	1.64	0.74
0.6667	0.8660	0.5	0.9167	1.1160	-0.8660		1	1.1667	-0.366	0.00	2	1.67	1.00
0.6944	0.8192	0.5	0.9444	1.0692	-0.9397		1	1.1944	-0.440	0.26	2	1.69	1.26
0.7222	0.7660	0.5	0.9722	1.0160	-0.9848		1	1.2222	-0.485	0.50	2	1.72	1.50
0.7500	0.7071	0.5	1.0000	0.9571	-1.0000		1	1.2500	-0.500	0.71	2	1.75	1.71
0.7778	0.6428	0.5	1.0278	0.8928	-0.9848		1	1.2778	-0.485	0.87	2	1.78	1.87
0.8056	0.5736	0.5	1.0556	0.8236	-0.9397		1	1.3056	-0.440	0.97	2	1.81	1.97
0.8333	0.5000	0.5	1.0833	0.7500	-0.8660		1	1.3333	-0.366	1.00	2	1.83	2.00
0.8611	0.4226	0.5	1.1111	0.6726	-0.7660		1	1.3611	-0.266	0.97	2	1.86	1.97
0.8889	0.3420	0.5	1.1389	0.5920	-0.6428		1	1.3889	-0.143	0.87	2	1.89	1.87
0.9167	0.2588	0.5	1.1667	0.5088	-0.5000		1	1.4167	0.000	0.71	2	1.92	1.71
0.9444	0.1736	0.5	1.1944	0.4236	-0.3420		1	1.4444	0.158	0.50	2	1.94	1.50
0.9722	0.0872	0.5	1.2222	0.3372	-0.1736		1	1.4722	0.326	0.26	2	1.97	1.26
1.0000	0.0000	0.5	1.2500	0.2500	0.0000		1	1.5000	0.500	0.00	2	2.00	1.00
max x grid	1.0000												
max y grid	1.0000		0	0	0	0	0	0	0	0	0	0	
			0.2500	0.2500			0.5000	0.5000			1.00	1.00	
			0.5000	0			1	0			1.5	0	
			1.5000	1.0000			2.0000	1.0000			2.50	1.00	
													row 260



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## 3D SPIRAL

This example graphs three bolt threads in 3D.

aspect\_x 5 unitless  
aspect\_y 5 unitless

D\_threads 0.9729 in

Hard = (COS(Number/6\*PI()))

Number series = (SIN(Number/6\*PI()))

\$D\_threads \* Sine

\$D\_threads \* Cosine

=X + Z\*\$ε = Z + Z\*\$ε

Number series	Sine	Cosine	X	Y	Z	x	y
0	0.0000	1.0000	0.9729	0.0000	0.0000	0.9729	0.0000
1	0.5000	0.8660	0.8426	0.4865	0.0069	0.8773	0.5212
2	0.8660	0.5000	0.4865	0.8426	0.0139	0.5559	0.9120
3	1.0000	0.0000	0.0000	0.9729	0.0208	0.1042	1.0771
4	0.8660	-0.5000	-0.4865	0.8426	0.0278	-0.3476	0.9815
5	0.5000	-0.8660	-0.8426	0.4865	0.0347	-0.6690	0.6601
6	0.0000	-1.0000	-0.9729	0.0000	0.0417	-0.7646	0.2083
7	-0.5000	-0.8660	-0.8426	-0.4865	0.0486	-0.5995	-0.2434
8	-0.8660	-0.5000	-0.4865	-0.8426	0.0556	-0.2087	-0.5648
9	-1.0000	0.0000	0.0000	-0.9729	0.0625	0.3125	-0.6604
10	-0.8660	0.5000	0.4865	-0.8426	0.0694	0.8337	-0.4954
11	-0.5000	0.8660	0.8426	-0.4865	0.0764	1.2245	-0.1045
12	0.0000	1.0000	0.9729	0.0000	0.0833	1.3896	0.4167
13	0.5000	0.8660	0.8426	0.4865	0.0903	1.2940	0.9379
14	0.8660	0.5000	0.4865	0.8426	0.0972	0.9726	1.3287
15	1.0000	0.0000	0.0000	0.9729	0.1042	0.5208	1.4938
16	0.8660	-0.5000	-0.4865	0.8426	0.1111	0.0691	1.3981
17	0.5000	-0.8660	-0.8426	0.4865	0.1181	-0.2523	1.0767
18	0.0000	-1.0000	-0.9729	0.0000	0.1250	-0.3479	0.6250
19	-0.5000	-0.8660	-0.8426	-0.4865	0.1319	-0.1829	0.1733
20	-0.8660	-0.5000	-0.4865	-0.8426	0.1389	0.2080	-0.1481
21	-1.0000	0.0000	0.0000	-0.9729	0.1458	0.7292	-0.2438
22	-0.8660	0.5000	0.4865	-0.8426	0.1528	1.2504	-0.0787
23	-0.5000	0.8660	0.8426	-0.4865	0.1597	1.6412	0.3121
24	0.0000	1.0000	0.9729	0.0000	0.1667	1.8063	0.8333
25	0.5000	0.8660	0.8426	0.4865	0.1736	1.7106	1.3545
26	0.8660	0.5000	0.4865	0.8426	0.1806	1.3892	1.7454
27	1.0000	0.0000	0.0000	0.9729	0.1875	0.9375	1.9104
28	0.8660	-0.5000	-0.4865	0.8426	0.1944	0.4858	1.8148
29	0.5000	-0.8660	-0.8426	0.4865	0.2014	0.1644	1.4934
30	0.0000	-1.0000	-0.9729	0.0000	0.2083	0.0687	1.0417
31	-0.5000	-0.8660	-0.8426	-0.4865	0.2153	0.2338	0.5899
32	-0.8660	-0.5000	-0.4865	-0.8426	0.2222	0.6246	0.2685
33	-1.0000	0.0000	0.0000	-0.9729	0.2292	1.1458	0.1729
34	-0.8660	0.5000	0.4865	-0.8426	0.2361	1.6670	0.3380
35	-0.5000	0.8660	0.8426	-0.4865	0.2431	2.0579	0.7288
36	0.0000	1.0000	0.9729	0.0000	0.2500	2.2229	1.2500

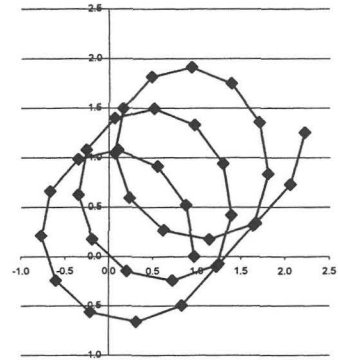


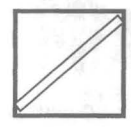
Figure 9-12 A 3D spiral.

row 280

row 290

row 300

row 310



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### 3D BOX -- SIMPLE PROJECTION

Vpoint            **45** degrees  
                      0.785 rad  
x                    **0.70711**  
y                    **0.70711**  
  
L<sub>x</sub>                 **10**  
L<sub>y</sub>                 **10**  
L<sub>z</sub>                 **10** depth

This is just one method of showing 3D data in a 2D graph. The image of a box is fairly easy to manipulate. Notice that the X, Y, and Z axis are displayed in a different color. Gridlines could be shown in a third color with lines formatted to be much thinner than the box outline.

The box can be replaced with another figure or data points. Separate data groups are separated by a blank row.

	x	y	z
x axis	-0.5	11	
y axis		0	0
z axis	7.0710678		7.071067812
	0	0	
	10	0	
	10	10	
	0	10	
	0	0	

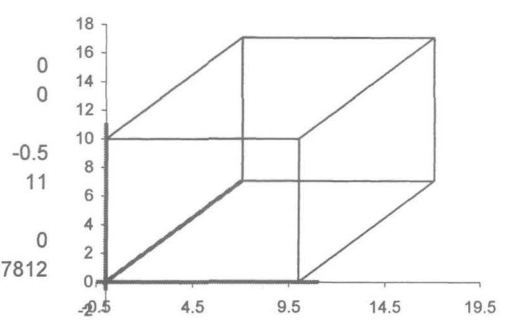


Figure 9-13 Set the aspect ratio for this 3D box in L<sub>x</sub>, L<sub>y</sub>, and L<sub>z</sub> above.

7.0710678	7.0710678
17.071068	7.0710678
17.071068	17.071068
7.0710678	17.071068
7.0710678	7.0710678

0	0
0	7.0710678
10	0
17.071068	7.0710678

10	10
17.071068	17.071068
0	10
7.0710678	17.071068

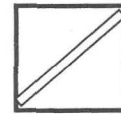
row 320

row 330

row 340

row 350

row 360



**3D BOX -- ORTHOGRAPHIC PROJECTION**

This is another method of showing 3D data in a 2D graph. The inputs are the same as AutoCAD inputs and the results are similar to AutoCAD views. The Z-axis is always vertical.

Notice that in the Excel the X, Y, and Z axis are displayed in a different color. Gridlines could be shown in a third color with lines formatted to be much thinner than the box outline.

The image of a box is fairly easy to manipulate. The box can be replaced with another figure or data plots. Separate data groups are separated by a blank row.

	VPoint
VPx	-0.2
VPy	-0.2
VPz	1
Lx	10
Ly	10
Lz	10

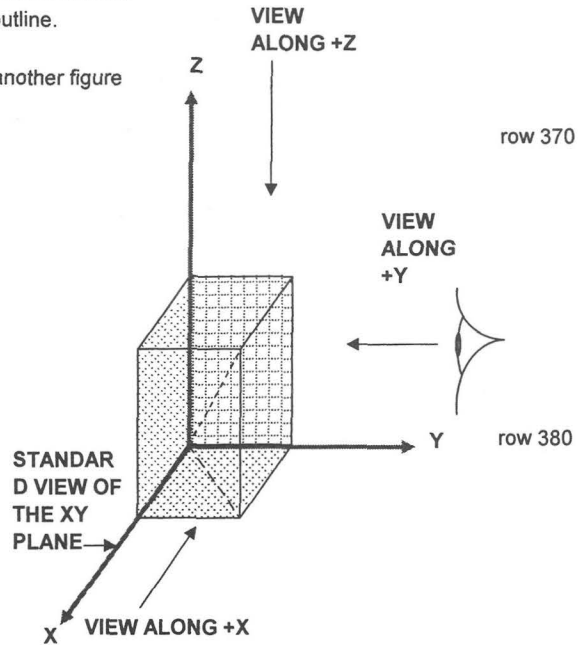
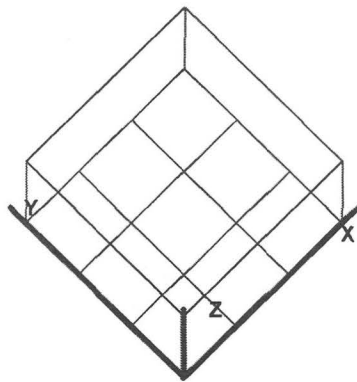


Figure 9-14 The diagram of ACAD type orthographic views.

Figure 9-15 Graph of an orthographic box.

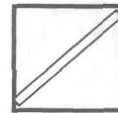
Logic Table	1, 1, 1	0, 1, 1	1, 0, 0	1, 1, 0	0, 1, 0	1, 0, 1	-1, -1, 0	-1, -1, 1	-1, 0, -1	-1, 0, -1	-1, -1, -1	
logic	0	0	0	0	0	0	0	1	0	0	0	0
VPx mult x	-1	-1	1	-1	-1	1	1	1	1	1	1	-1
VPx mult y	-1	1	-1	1	1	-1	1	1	-1	1	-1	1
VPy mult x	1	-1	1	1	1	1	-1	-1	1	1	-1	-1
VPy mult y	-1	-1	1	1	1	1	1	1	1	-1	-1	-1
VPx mult x	0	0	0	0	0	0	0	1	0	0	0	0
VPx mult y	0	0	0	0	0	0	0	1	0	0	0	0
VPy mult x	0	0	0	0	0	0	0	-1	0	0	0	0
VPy mult y	0	0	0	0	0	0	0	1	0	0	0	0
logic results												
x	1											
y		1										
x	-1											
y			1									

Conditional formatting to row 390 highlight logic choice



# GRAPHING

9



Christy  
17:38  
12/20/05

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\_9 Graphing.xls

**3D BOX -- ORTHOGRAPHIC PROJECTION -- Continued**

A	B	C	D	E	F	G	H	I	J	K	L	M	N
0, 0, 0	0, 0, -1	1, 0, 0											
	0	0	0										
	1	-1	0										
	0	0	0										
	0	0	-1										
	1	1	0										
				logic results									
	0	0	0	0									
	0	0	0	0									row 420
	0	0	0	0									
	0	0	0	0									

**Reference**

Radians	Degrees
0.524	30
0.785	45
1.047	60
1.571	90
3.142	180

	0.276	calculations	x	y	output to graph	x	y
VPx	0.272	x axis	0.70711	0.68041	x axis	0.70711	0.6804
VPy	0.272	y axis	0.70711	0.68041	y axis	-0.7071	0.6804
VPz	0.283	z axis	0	0.27217	z axis	0	0.2722

**X, Y, and Z axis**

multiplier	1.1												row 430
max	10												
max mult	11												

Note that the graph makes use of two X-axis to conserve space in the template (and printout).

	x	y	y <sup>2</sup>		x	y
x axis	0	0	0	along x	-2.357	2.268
	7.77819		7.48454		4.71406	9.07218
y axis	0	0	0		-4.7141	4.5361
	-7.77819		7.48454		2.35703	11.34
z axis	0	0	0	along y	2.35703	2.268
	0		2.99382		-4.71406	9.07218
standoff	-0.8556		-0.8233		4.71406	4.5361
	0.8556		-0.3293		-2.35703	11.3402
					7.07109	6.8041
top plane	0	0			7.07109	9.5258
	7.0710855	6.8041316				
	0	13.60826			0	13.608
	-7.0710855	6.8041316			0	16.33
	0	0				
					-7.0711	6.8041
bottom plane	0	2.7216527			-7.0711	9.5258
	7.0710855	9.5257844				
	0	16.329916				
	-7.0710855	9.5257844				
	0	2.7216527				

row 450

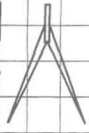
row 460

**PART 2:**

**APPLICATION**

**BASICS**

# CONSULTING COMPANY



## NOTES

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A

B

C

D

E

F

G

H

I

J

K

L

M

N

20

30

40

50

60



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10 Absolute Relative References.xls

A B C D E F G H I J K L M N

**OVERVIEW**

Absolute and relative cell referencing are important when copying equations.

A relative reference is not a permanent reference to a particular cell. If a relatively referenced equation is copied to another position, the cell(s) it refers to will change.

An absolute reference is a permanent reference to a particular cell. When the absolutely referenced equation is copied to another position, it will still refer to the same cell(s).

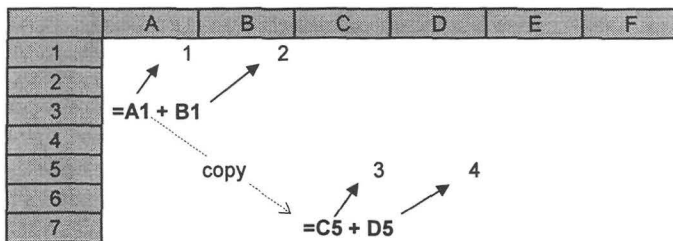
Absolute and relative references may be mixed, as can be seen in the examples below.

row 20

You can input the \$ by hand or press the [F4] key while in edit mode. Pressing the [F4] key two or three times will cycle the reference through:

- absolute column and row                    =:\$A\$14
- relative column and absolute row        =:\$A\$14
- absolute column and relative row        =:\$A14
- relative column and relative row         =:\$A14

row 30

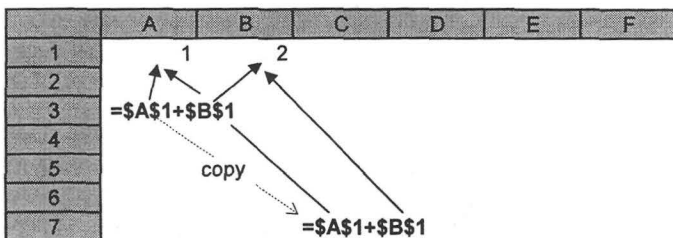


A relative reference is not a permanent reference to a particular cell. If a relatively referenced equation is copied to another position, it will refer to a new cell address.

row 40

This is useful in creating look-up tables and in numerical integration.

Figure 10-1 RELATIVE REFERENCING



An absolute reference is a permanent reference to a particular cell. When the absolutely referenced equation is copied to another position, it will still refer to the same \$A \$1+\$B\$1 cell(s).

row 50

Figure 10-2 ABSOLUTE REFERENCING

**Samples of Referencing**

- =B\$3+B4
- =SUM(\$B\$5:\$D\$7, B8)     where B5 through D7 is a rectangular range of cells

row 60



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OVERVIEW -- Continued

The Sample Matrix

Relative reference back to A.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

=	=B14
C	D

Figure 10-3 Look at the formula bar.

Then copy this cell to the rest of the matrix

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

This is what the above matrix looks like with all of the cells "parked."

=A63	=B63	=C63	=D63
=A64	=B64	=C64	=D64
=A65	=B65	=C65	=D65
=A66	=B66	=C66	=D66

Figure 10-4 Relative Column / Relative Row Array

Here, the row is relatively referenced and the columns are absolutely referenced.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

A	A	A	A
E	E	E	E
I	I	I	I
M	M	M	M

And with the cells parked.

=\$A86	=\$A86	=\$A86	=\$A86
=\$A87	=\$A87	=\$A87	=\$A87
=\$A88	=\$A88	=\$A88	=\$A88
=\$A89	=\$A89	=\$A89	=\$A89

Figure 10-6 Relative Column / Relative Row Array

Here, the row is absolutely referenced and the columns are relatively referenced.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

A	B	C	D
A	B	C	D
A	B	C	D
A	B	C	D

This is what the matrix looks like with all of the cells "parked."

=\$I\$63	=J\$63	=K\$63	=L\$63
=I\$63	=J\$63	=K\$63	=L\$63
=I\$63	=J\$63	=K\$63	=L\$63
=I\$63	=J\$63	=K\$63	=L\$63

Figure 10-5 Relative Column / Absolute Row Array

Row and column for the cell containing A are absolutely referenced.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

A	A	A	A
A	A	A	A
A	A	A	A
A	A	A	A

And with the cells parked.

=\$I\$86	=\$I\$86	=\$I\$86	=\$I\$86
=\$I\$86	=\$I\$86	=\$I\$86	=\$I\$86
=\$I\$86	=\$I\$86	=\$I\$86	=\$I\$86
=\$I\$86	=\$I\$86	=\$I\$86	=\$I\$86

Figure 10-7 Absolute Column / Absolute Row Array

park put an apostrophe or hit the spacebar in front of the equals "=" sign to park the equation

row 110



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10 Absolute Relative References.xls

**MOVING AN ENTIRE MODULE THAT INCLUDES ABSOLUTE REFERENCES**

A	B	C	D	A	B	C	D
E	F	G	H	E	F	G	H
I	J	K	L	I	J	K	L
M	N	O	P	M	N	O	P

A is absolutely referenced in this array

A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A

=\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112

Figure 10-8 Absolute Column / Absolute Row Array

=\$H\$112 =\$H\$112 =\$H\$11: =\$H\$112  
 =\$H\$112 =\$H\$112 =\$H\$11: =\$H\$112  
 =\$H\$112 =\$H\$112 =\$H\$11: =\$H\$112  
 =\$H\$112 =\$H\$112 =\$H\$11: =\$H\$112

Figure 10-9 Relocated Input

But try to copy the entire array.

A	B	C	D	row 130
E	F	G	H	
I	J	K	L	
M	N	O	P	

A is absolutely referenced in this array

A	A	A	A	row 140
A	A	A	A	
A	A	A	A	
A	A	A	A	

And this is what you get.  
 The referenced cell is still cell A112.

=\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112  
 =\$A\$112 =\$A\$112 =\$A\$112 =\$A\$112

Figure 10-10 The copied array.

**Note:**

If you copy this array to another spreadsheet, the array will refer back to cell A112 in the new spreadsheet. In this way you create a link between two spreadsheets. You may not want to have done this.

**COPYING AN ENTIRE MODULE THAT INCLUDES ABSOLUTE REFERENCES**

A.	<b>SAVE THE TEMPLATE THAT YOU ARE GOING TO COPY FROM.</b> This is to prevent a disaster.	A	B	C	D	row 150
		E	F	G	H	
		I	J	K	L	
	<b>DO NOT SAVE THE SPREADSHEET AFTER THE NEXT STEP.</b>	M	N	O	P	

B.	Remove all range names. Otherwise, you will have unwanted references to the spreadsheet you are copying from.	A	A	A	A	
		A	A	A	A	
		A	A	A	A	
		A	A	A	A	

Figure 10-11 An array to be copied.

row 160



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COPYING AN ENTIRE MODULE THAT INCLUDES ABSOLUTE REFERENCES -- Continued

C. Highlight the array or module to be copied to another spreadsheet and invoke the Cut command.

Position your cursor in the other template and press Copy ( [Ctrl] [V] ). You will have copied the entire array (module) with all references and absolute references intact.

D. Make sure that transition formula evaluation and Transition formula entry are checked in the Tools, Options menu or some functions will not calculate correctly.

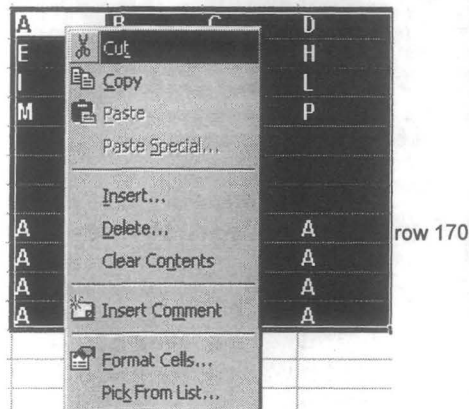


Figure 10-12 Cut the array.

ALTERNATIVE: COPY AN ARRAY OR MODULE BACK INTO THE SAME TEMPLATE

A. Open a new (temporary) spreadsheet.

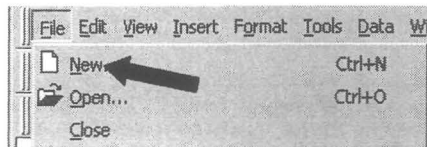


Figure 10-13 The control panel.

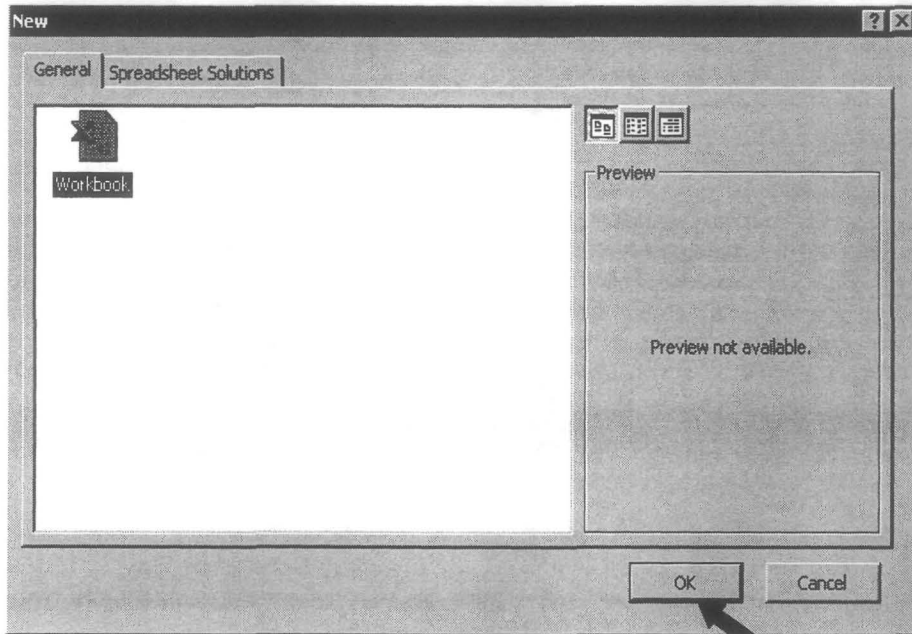


Figure 10-14 The control panel menu.

Press OK and bring up the new spreadsheet.

row 210



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# ABSOLUTE and RELATIVE REFERENCES

**10** Christy  
17:55  
12/20/05  
**B\$14**

10 Absolute Relative References.xls

A B C D E F G H I J K L M N  
**ALTERNATIVE: COPY AN ARRAY OR MODULE BACK INTO THE SAME TEMPLATE -- Continued**

B. Highlight and Cut the array.

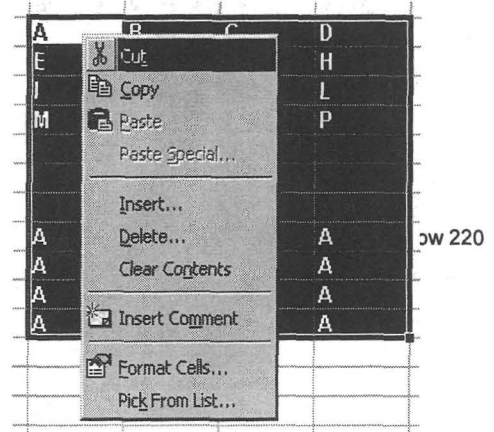


Figure 10-15 A pop-down menu.

C. Reopen your current spreadsheet and press "Yes" when Excel asks you if you really want to reopen this file discard the changes in you made. Press "No" and you have made an error that the backup button can't fix.

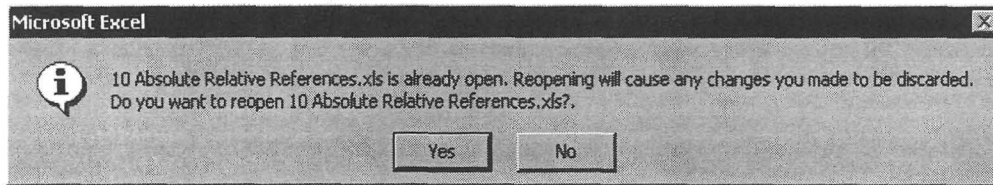


Figure 10-16 A menu flag.

D. Position your cursor in the template and press Paste to get this result:

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

A	A	A	A
A	A	A	A
A	A	A	A
A	A	A	A

```

=$B$241 =$B$241 =$B$241 =$B$241
=$B$241 =$B$241 =$B$241 =$B$241
=$B$241 =$B$241 =$B$241 =$B$241
=$B$241 =$B$241 =$B$241 =$B$241

```

Figure 10-18 The CUT and PASTE, COPIED Array

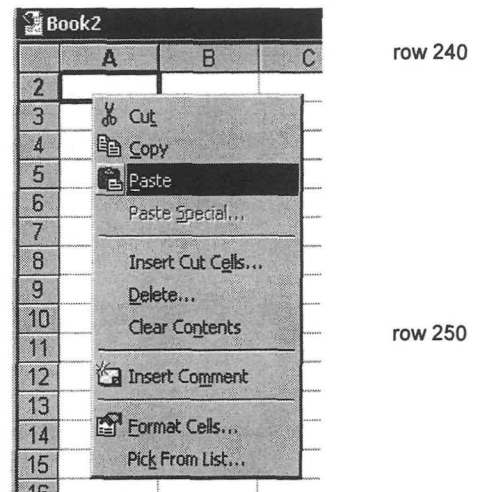


Figure 10-17 Another pop-down menu.

row 230

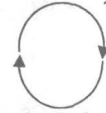
row 240

row 250



# CIRCULAR REFERENCE

**11** Christy  
17:39  
12/20/05



11 Circular Reference.xls

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A B C D E F G H I J K L M N

## CIRCULAR REFERENCE

The circular reference is intentional in this file.

You will get this error message when you open the file. Click on the x to cancel this message if it occurs.



In Tools, Options... set Iterations to 1.

Figure 11-1 The circular reference pop-up flag.

Try different numbers in the highlighted cell and press [F9] (calculate) several times to see the answer in the "Output" cell quit changing (converge).

row 20

Input	+	0.05*Output	=	Output
1	+	0.0526316	=	1.0526316

The circular reference may be used, at times, to advantage. One example is the P-delta effect that takes place in columns and slender walls. If a column is already bent and an axial load is placed on it, it will bend more. This is because the load times its distance from the centerline at the bowed part of the column creates an additional moment which bends the column further. In a template, this relationship becomes a circular reference which will converge in about four iterations.

e	24 in	load eccentricity
P	100 k	load
L	12 ft	length of column
E	29000 k/in <sup>2</sup>	modulus of elasticity
I	50 in <sup>4</sup>	moment of inertia
M <sub>1,2</sub>	2603.2 k-ft	moment at top and bottom of column
L/2	6.0 ft	where L/2 = x
D	0.032 ft 0.388 in 203.2 k-ft	h / 371 additional moment
M <sub>D</sub>	2606.5 k-ft	

Try different numbers in the highlighted cell and press [F9] (calculate) several times to see the answer in the "Output" cell "converge."

row 30

row 40

row 50

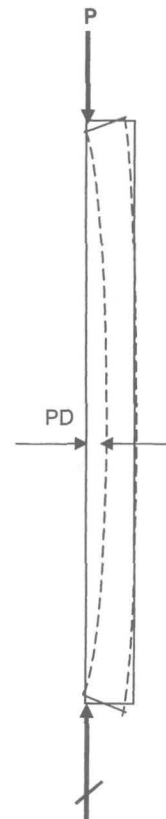


Figure 11-2 Using a circular reference to calculate the PΔ effect.

row 60



### OVERVIEW

Math operators <, >, =, <=, >=

Dog 3 unit  
Fox 4 unit

Result 1 logic  
=Dog<Fox  
3 Dog(s) < 4 Fox(s)

IF statements  
Result\_2 More foxes  
=IF(Result,"More foxes","More dogs")

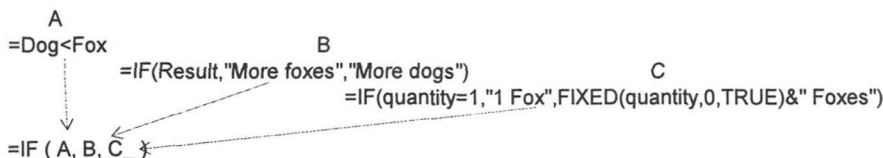
The Boolean statement may be contained within the IF statement  
quantity 2 unit  
2 Foxes string

formula text formula  
=IF(quantity=1, "1 Fox", FIXED(quantity,0,TRUE) & " Foxes")

It could also return the result of a formula within the IF statement or reference a result from outside of the statement and returned from within the IF statement.

A 1  
B More foxes  
C 2 Foxes  
Answer More foxes

The equation using range names:



**Note:** it is often wise to show the formula used. Another aid in constructing and reviewing spreadsheets is to show the numbers in a concatenated string.

In this case, the IF statement uses the Boolean output of another cell to return a text statement.

row 20

When using **MIN( )** and **MAX( )** functions, where the logic value **true = 1**, the **1** must operate on another number to be recognized.

- For example:
- a. MIN( 1, 2, 3)  
returns 2 if the 1 references a logic result
  - b. MIN( 1\*1, 2, 3)  
returns 1 because the logic result operates on another number

### PARK AND CONCATENATE

An equation can be easily parked and copied without changing the references. The following example equations use numbers only.

Equation D 2

Press the **[F2]** edit key. Press the **[Home]** key to go to the front of the equation. Press the **[Space Bar]** to insert a space and turn the equation into plain text. This yields:

row 50

=(1+1)

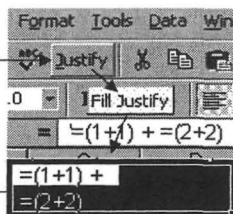
Equation E 4

converts to =(2+2)

Create this equation, = D + E, by concatenation.

=(1+1) +  
=(2+2)

Add the "+" operator now to keep the process simple or add it later if you forget.



row 60

Justify the range to create a text string on one row.

=(1+1) + =(2+2)

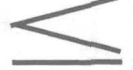
Figure 12-1 Concatenation with Justify command.

Now clean up the text by removing the = operator at mid-string and the space at the beginning of the string.

Equation F 6

Inserting a space or a comma in front of an equation also works well to put a malfunctioning equation on hold.

row 70



A B C D E F G H I J K L M N  
**PARK, CONCATENATE, AND JUSTIFY**

Add this button to your tool bar with Tools, Customize, Commands, Edit, and Justify. Drag this selection to the tool bar.

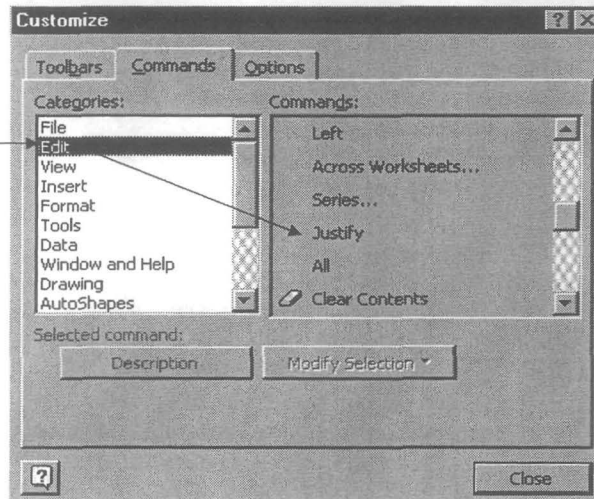


Figure 12-2 Adding a button to your tool bar in the Customize window.

### RANGE NAMES IN EQUATIONS

Dogs 3 unit  
Foxes 4 unit  
Result 1 logic

Show the equation with its range names, not cell R1C1 references.  
1 \_\_\_\_\_ parked and copied from above  
Press the [F2] key to edit the equation in the equation window.

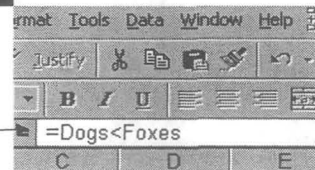


Figure 12-3 Range names in the formula bar.

Place the mouse pointer over or in front of the = sign and press the [space bar]. Press [Return] and the equation under the cursor will turn from an equation of cell references to an equation of range name references. This equation has been parked as text and can be copied to a comments area.

1 =Dogs<Foxes

This method provides an audit trail or map of the logic process. A good audit trail is important for verifying the template design.

### OTHER LOGIC FUNCTIONS

IF (condition, x, y)  
CHOOSE (x, v0, v1..vn)

VLOOKUP (x, range, column offset number)  
HLOOKUP (x, range, row offset number)

MIN (range\_1, range\_2,..range\_n, value, formula)  
MAX (range\_1, range\_2,..range\_n, value, formula)

#NOT# logical NOT  
#AND# logical AND  
#OR# logical OR



**LOGIC  
BOOLEAN ALGEBRA AND THE  
"IF" STATEMENT**



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A B C D E F G H I J K L M N

**THE LOGIC SIEVE, BOOLEAN ALGEBRA, and BOOLEAN OPERATORS**

Here we use two Boolean expressions to yield a 1 or a 0 for A, BB, or BC.

If one criteria or the other isn't met (i.e. Number not< 2), then at least one 0 is returned and  $B0*B0$  or  $B0*B1$  equals  $B0$ .

Three methods for creating a logic sieve are used in this example.  
You may substitute numbers or formulas for A, B, and C in Example A.

**Example A**

row 140

Number	3	Input	
A	1	Number <= 1	
B	1	Number <= 2	
C	1	Number <= 3	
Choice	A	Nested IF statement for text or numbers	
	A	@Choose(x,n1..) for text or numbers	

**Example B**

row 150

A	1	$0 < \text{Number} \leq 1$	A
B	0	$1 < \text{Number} \leq 2$	B
C	0	$2 < \text{Number} \leq 3$	C
Choice	A	Concatenated IF statements for text	

row 160

**BOOLEAN TABLE**

A	B	A<B	A>B	A xor B		A and B	A or B			not A		A nor B	
				A=B	A<>B						A nand B		
1	1	0	0	1	0	1	1	0	0	0	0	0	0
1	0	0	1	0	1	0	1	0	1	0	1	1	0
0	1	1	0	0	1	0	1	1	1	1	1	0	0
0	0	0	0	1	0	0	0	0	1	1	1	1	1
T	T	0	0	1	0	1	1	0	0	0	0	0	0
T	F	0	1	0	1	0	1	0	1	0	1	1	0
F	T	1	0	0	1	0	1	1	1	1	1	0	0
F	F	0	0	1	0	0	0	0	1	1	1	1	1

row 180

row 190

### D DIRECT DATABASE FUNCTIONS

The following are examples of spreadsheet direct database functions D.

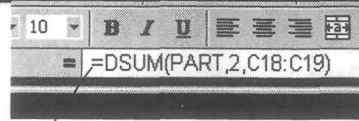


Figure 13-1 The entry window and formula bar.

**DSUM:** the Dfunction used to summarize total cost by Part # data

INPUT		CRITERIA		OUTPUT						
Part #	Amount	Part #	# Part	Sum	Avg	Count	Max	Min	Std	Var
1	\$40.00	1	1 Nuts							
2	\$40.00	Part #	2 Bolts	\$75.00	18.75	4	40	5.00	13	180
1	\$20.00	2	3 Washers	\$100.00	33.33	3	55	5.00	21	439
1	\$5.00	Part #		\$50.00	10.00	5	20	5.00	5	30
2	\$55.00	3								
2	\$5.00			\$225.00						
3	\$5.00									
3	\$10.00									
1	\$10.00									
3	\$10.00									
3	\$20.00									
3	\$5.00									
	\$225.00									

**NOTES:** Data range includes Part # and Amount

Criteria range includes the field name Part # and the part number immediately below

The D function is set up in a manner similar to data base input range, criteria range, and output range

### SORT THE SAMPLE DATABASE

The DATABASE file serves as a working example for database commands and D database functions.

Item	Description	Quantity
N12	#12 nut	2000
N10	#10 nut	1500
B10	#10 bolt	1800
B12	#12 bolt	1700
W10	#10 washer	2100
W12	#12 washer	1800
N6	#6 nut	2000
N8	#8 nut	1500
B6	#6 bolt	1800
B8	#8 bolt	1700
W6	#6 washer	2100
W8	#8 washer	1800

The first column is an item stock description of the part.

The second column is a description the type of part.

The third column is the quantity on hand.

Highlight the database first and then click on the Data button and then Sort.

Note that although the headings were not included in the highlighted area, they show up in the drop-down menu.

You can choose to sort by a name in the Header row or by entering the cell address at the top of the row.

Item	Description	Quantity
N12	#12 nut	2000
N10	#10 nut	1500
B10	#10 bolt	1800
B12	#12 bolt	1700
W10	#10 washer	2100
W12	#12 washer	1800
N6	#6 nut	2000
N8	#8 nut	1500
B6	#6 bolt	1800
B8	#8 bolt	1700
W6	#6 washer	2100
W8	#8 washer	1800

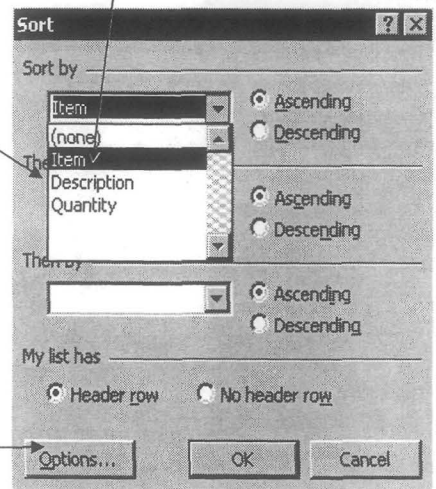
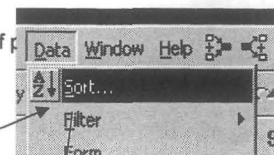
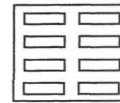


Figure 13-2 The Data, Sort window.



# DATABASE



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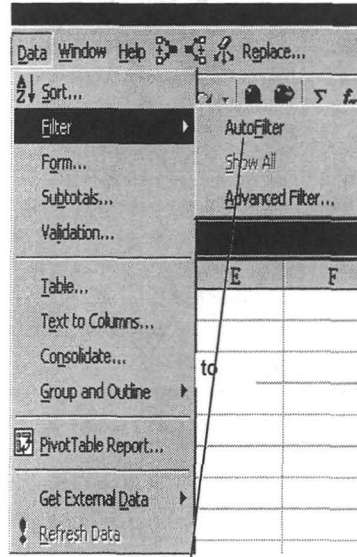
13 Database.xls

A B C D E F G H I J K L M N

## FILTER THE SAMPLE DATABASE

Item	Description	Quantity
N12	#12 nut	2000
N10	#10 nut	1500
B10	#10 bolt	1800
W8	#8 washer	800
N8	#8 nut	900
N8	#8 nut	600
B12	#12 bolt	1700
W10	#10 washer	2100
W12	#12 washer	1800
N6	#6 nut	2000
N8	#8 nut	1500
B6	#6 bolt	1800
B8	#8 bolt	1700
W6	#6 washer	2100
W8	#8 washer	1800

In lieu of using the D functions, you can use the Data Filter command.



row 70

row 80

Item	Description	Quantity
N12	#12 nut	2000
N10	#10 nut	1500
B10	#10 bolt	1800
W8	#8 washer	800
N8	#8 nut	900
N8	#8 nut	600
B12	#12 bolt	1700
W10	#10 washer	2100
W12	#12 washer	1800
N6	#6 nut	2000
N8	#8 nut	1500
B6	#6 bolt	1800
B8	#8 bolt	1700
W6	#6 washer	2100
W8	#8 washer	1800

row 90

Figure 13-3 The data toolbar and output.

row 100

row 110



A B C D E F G H I J K L M N  
**FILTER THE SAMPLE DATABASE -- Continued**

Ite	Descripti	Quant
N1	(All)	2000
N1	(Top 10...)	1500
N1	(Custom...)	1500
B1	#10 bolt	1800
W1	#10 nut	800
N	#10 washer	900
N	#12 bolt	600
N	#12 nut	600
B1	#12 washer	1700
W1	#6 bolt	2100
W1	#6 nut	1800
W1	#6 washer	1800
N	#8 bolt	2000
N	#8 nut	1500
N	#8 washer	1800
B8	#8 bolt	1700
W6	#6 washer	2100
W8	#8 washer	1800

Click on one of the buttons to select an item.

row 120

to get

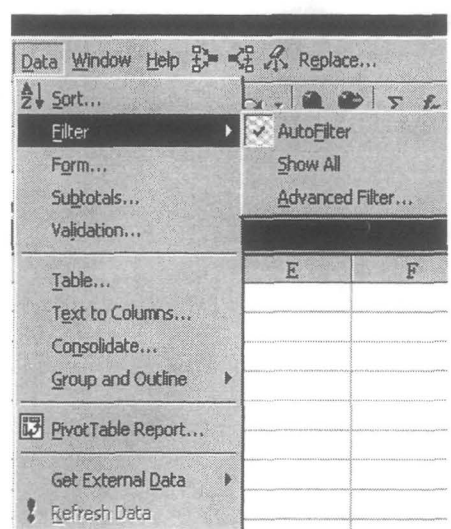
row 130

74	Ite	Descripti	Quant
79	N8	#8 nut	900
80	N8	#8 nut	600
85	N8	#8 nut	1500

notice that the spreadsheet has contracted by several rows

row 140

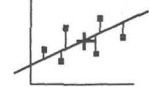
You can return the database to its original form by selecting (All) or clicking on Data, Filter and click on the check mark to disable the AutoFilter tool, or click on the Show All command.



row 150

Figure 13-4 The filtering process in the Data toolbar menu system.

row 160



**GETTING STARTED**

This spreadsheet tool calculates by the "least squares" method.

Click on Tools, Data Analysis, Regression

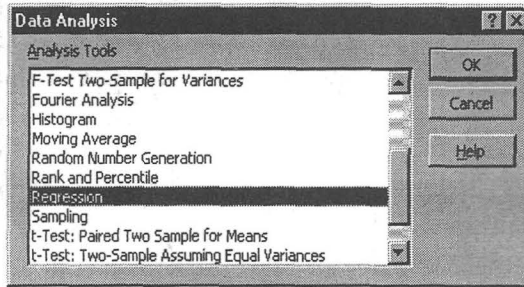
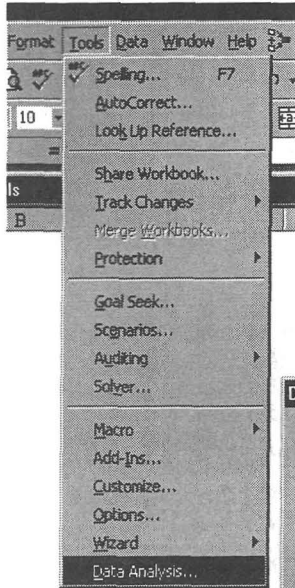


Figure 14-1 The Analysis window.

If the Data Analysis selection is not on your Tools drop down menu, go to Add-Ins in the Tools drop down menu and click on Analysis ToolPak

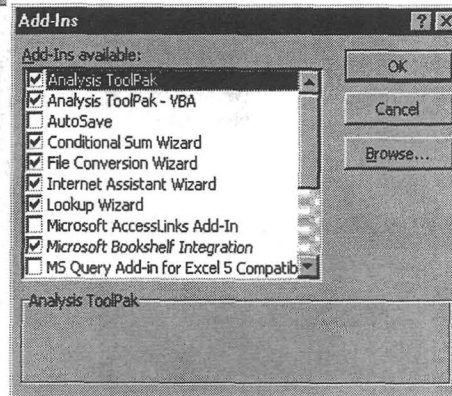
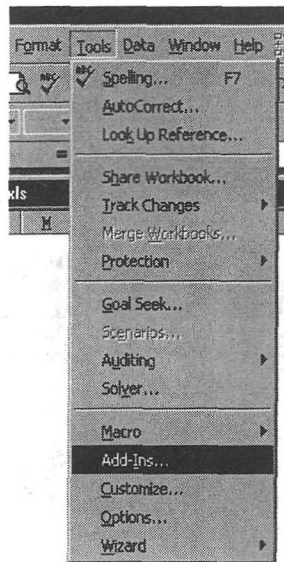


Figure 14-2 The Add-Ins window.

**Definition:**

$Y = mX + b$  describes a straight line on a graph

where:

- Y values plotted along the vertical Y axis
- m slope of the line
- X values plotted along the horizontal X-axis
- b the Y-axis intercept  
the point at which the line starts for a given value of X and Y along the slope m

**Definition:**  $Y = m_1X_1 + m_2X_2 + b$

where: Y the y variable depends upon values of  $X_1$  and  $X_2$  for a single line

**NOTE:** Some references use the equation  $y = a + bx$ . where a is the Y intercept and b is the slope. This can get a bit confusing.

**Note:** Capitalized X and Y refer to actual plot values. Lower case x and y are the distances from the actual plot to the calculated values.

row 20

row 30

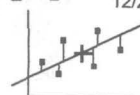
row 40

**NOTE:** This template is printed at roughly 80 lines per page because of the tables of calculations. Normally, we print at 70 lines per page.

row 50

row 60

row 70



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**AN EXAMPLE**

Analyze the following data used in calibrating a string gage.

The quickest way to get results is to use the Regression tool.  
The solution is an attempt to fit a curve to the data.

Note that the resulting table does not change with adjustments to the data.

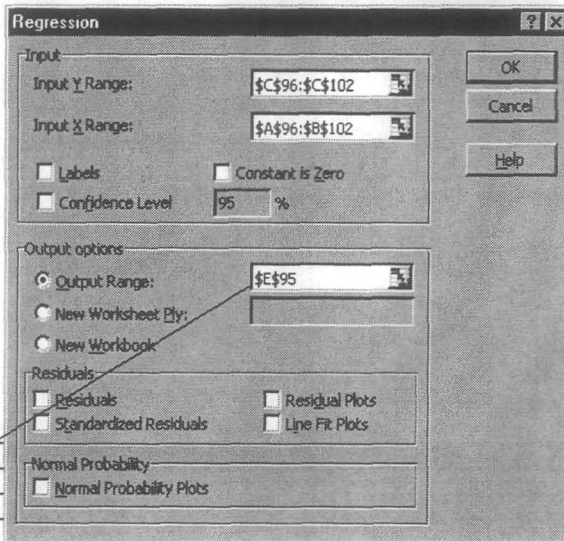


Figure 14-3 The Regression analysis window.

to read the entire label(s), increase the column width

String 1	x <sup>2</sup>	Distance	compare	SUMMARY OUTPUT	
4010	16080100	0.00	0.044	Regression Statistics	
2863	8194479	0.25	0.152	Multiple R	0.9902058
1783	3177306	0.50	0.492	R Square	0.9805075
1097	1202312	0.75	0.827	Adjusted R Square	0.9707613
682	464988	1.00	1.075	Standard Error	0.0923469
399	159281	1.25	1.264	Observations	7
213	45369	1.50	1.396	ANOVA	

	df	SS	MS	F	Significance F
Regression	2	1.7158882	0.857944	100.6037	0.00038
Residual	4	0.0341118	0.008528		
Total	6	1.75			

x  
x<sup>2</sup>  
X Variable 1 X Variable 2  
variables must be arrayed in this order --  
do not reverse

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.5563964	0.0816755	19.05585	4.47E-05	1.32963	1.78316	1.32963	1.78316
X Variable 1	-0.0007731	0.0001111	-6.96165	0.002238	-0.0011	-0.0005	-0.0011	-0.0005
X Variable 2	9.873E-08	2.614E-08	3.776497	0.019495	2.6E-08	1.7E-07	2.6E-08	1.7E-07

The Distance curve is the raw data.  
The compare curve is the distance calculated using the values resulting from the regression analysis.

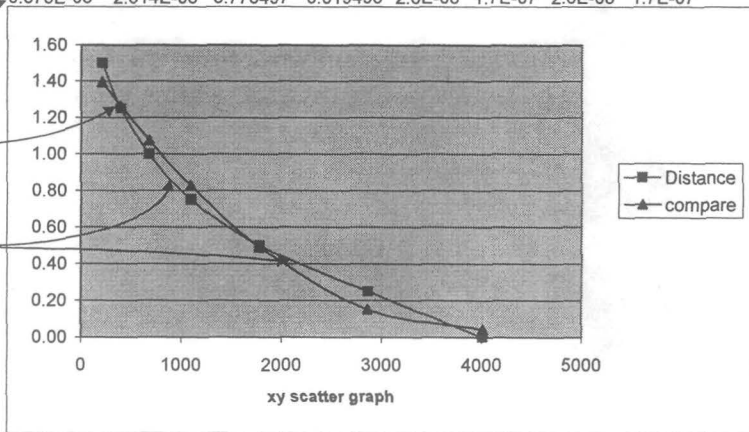


Figure 14-4 Curve fitting with regression analysis.

Now that we have all of this data, what does it mean?  
The following pages address the information presented by the regression tool and the linest function.



# REGRESSION ANALYSIS



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14 Regression Analysis.xls

## STRAIGHT LINE REGRESSION ANALYSIS -- LEAST SQUARES

Straight Line Regression Analysis  $Y = mX + b$

Where a least squares line is plotted using the values of x and y from the gage readings.

X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY	X - X <sub>m</sub>	Y - Y <sub>m</sub>	(X - X <sub>m</sub> ) <sup>2</sup>	(Y - Y <sub>m</sub> ) <sup>2</sup>	straight line x	y
53	45	2809	2025	2385	2.1	11.1	4.2	123.2	22	24.9
36	43	1296	1849	1548	19.1	13.1	362.9	171.6	89	88.1
88	89	7744	7921	7832	33.0	32.9	1085.7	1082.4		
84	79	7056	6241	6636	29.0	22.9	838.1	524.4		
86	84	7396	7056	7224	31.0	27.9	957.9	778.4		
64	66	4096	4356	4224	9.0	9.9	80.1	98.0		
45	49	2025	2401	2205	10.1	7.1	101.0	50.4		
48	48	2304	2304	2304	7.1	8.1	49.7	65.6		
39	43	1521	1849	1677	16.1	13.1	257.6	171.6		
67	76	4489	5776	5092	12.0	19.9	142.8	396.0		
54	59	2916	3481	3186	1.1	2.9	1.1	8.4		
73	77	5329	5929	5621	18.0	20.9	322.2	436.8		
65	56	4225	3136	3640	10.0	0.1	99.0	0.0		
29	28	841	784	812	26.1	28.1	678.6	789.6		
52	51	2704	2601	2652	3.1	5.1	9.3	26.0		
22	27	484	729	594	33.1	29.1	1092.3	846.8		
76	76	5776	5776	5776	21.0	19.9	438.9	396.0		
32	34	1024	1156	1088	23.1	22.1	531.3	488.4		
51	60	2601	3600	3060	4.1	3.9	16.4	15.2		
37	32	1369	1024	1184	18.1	24.1	325.8	580.8		
1101	1122	68005	69994	68740	325.2	322.2	7394.95	7049.8		

row 140  
row 150

n	20 each	Sxy =	6974
X <sub>m</sub>	Y <sub>m</sub>	XY <sub>m</sub>	
55.05	56.1	3437	

### SUMMARY OUTPUT

*Regression Statistics*  
Multiple R 0.965872  
R Square 0.932909 ← r2 is the correlation of estimated and actual y values  
Adjusted R Square 0.929182  
Standard Error 5.126058 ← standard error for the y estimate  
Observation: 20

ANOVA	df	SS	MS	F	Significance F
Regression	1	6576.824	6576.82	250.29	5.3E-12
Residual	18	472.9765	26.2765		
Total	19	7049.8			

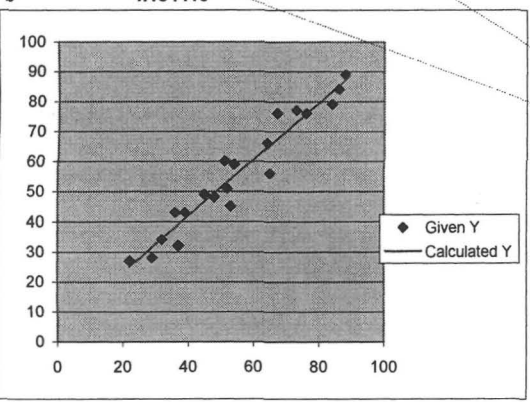
Solve for the equations:

$$SY = mSX + n b$$

$$SXY = bSX + mSX^2$$

for m  $\frac{n * (Sxi yi) - Sxi Syi}{n * Sxi^2 - (Sxi)^2} = \frac{1374800}{1360100} = \frac{1235322}{1212201}$   
m **0.94306**

for b  $\frac{Sxi^2 Syi - Sxi Syi^2}{n * Sxi^2 - (Sxi)^2} = \frac{76301610}{1360100} = \frac{75682740}{1212201}$   
b **4.184410**



Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4.1844096	3.475932	1.203824	0.24425	-3.1183
X Variable 1	0.9430625	0.05961	15.82066	5.3E-12	0.81783

linest  
slope m 0.94306  
standard error se 0.05961  
R Square, r<sup>2</sup> 0.93291  
chance relation F 250.293  
SS Regression 6577

b 4.184 y intercept  
3.476 standard error for the coefficient m  
5.126 standard error for the y estimate  
18 degrees of freedom n - k  
472.98 SS Residual, SSE

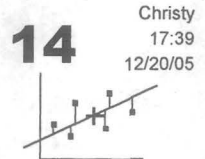
Note: move table labels for easier reading

Figure 14-5 The straight line regression analysis process..

row 190



# REGRESSION ANALYSIS



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14 Regression Analysis.xls

**STRAIGHT LINE REGRESSION ANALYSIS -- LEAST SQUARES** Continued

**The Long Hand Approach**

n	20 each	number of samples		
k	2 each	number of constants in the equation		
SSE	$S(Y - Y_m)^2 - b_1 / n (nSXY - SX SY)$			
SSE	7049.8	-0.0471531	1374800	-1101.00 1122.00
SSE	<b>472.98</b>			

$s^2 = \frac{SSE}{(n - k)} = \frac{472.98}{18} = 26.276$

$r = \frac{n SXY - S X SY}{\sqrt{(n S X^2 - (SX)^2) (n SY^2 - (SY)^2)}}$

$r = \frac{1374800 \cdot -1101 \cdot 1122}{\sqrt{1360100 \cdot -1212201 \cdot 1399880 \cdot -1258884}}$

$r = \frac{139478}{\sqrt{147899 \cdot 140996}} = \mathbf{0.966}$

$r^2 = \mathbf{0.933}$  R square

$S_{yX} = \sqrt{\frac{Sy^2 - mSxy}{n - k}}$

$S_{yX} = \sqrt{\frac{7049.8 - (-0.9430625) \cdot 6974}{20 - 2}}$

$S_{yX} = \mathbf{5.1261}$  standard error of estimate

$s^2_Y = \frac{Sy^2}{n - 1} = \frac{7049.8}{20 - 1}$

$s^2_Y = \mathbf{371}$  estimated total variance  
 $S_Y = \mathbf{19.3}$  standard deviation

$s_b = \frac{S_{yX}}{\sqrt{Sx^2}} = \frac{5.1261}{\sqrt{7395}} = \mathbf{0.0596}$  error of regression coefficient

**where:**  $Y_c = mX + b$   
 $Y_c$  the computed/expected value of y  
 $X_m, Y_m$  the mean value(s) of X and Y  
 $x, y$  deviations from their means  $x = X - X_m$  and  $y = Y - Y_m$   
**b** the y-axis intercept  
**m** slope of the line  $(y_2 - y_1) / (x_1 - x_2)$   
**SSE** sum of squares for error =  $S(Y - Y_m)^2$   
**df** degrees of freedom  $n - k$  row 200

**where:**  
**n** number of samples  
**k** number of constants in the equation, hence:  
 $y = mx + b$  m and b = 2 constants  
 $y = m_1 + m_2 + b$  3 constants

$Sx^2$   $Sx^2$  represents standard error of regression coefficient: the dispersion of X values around their mean.

$r^2$  compares estimated and actual y-values value ranges from 0 to 1 with 1 being a perfect correlation also known as R Square.

$S_{yX}$  Standard Error of Estimate of the dependent variable Y regressed against the independent variable(s) X

$se_y, se$  standard error of the y estimate row 220  
 the standard error values for the coefficients  $m_1, m_2$ , etc.

$s_b, se_b$  Standard Error of the Regression Coefficient which is a measure of the sampling error in b.

**t** describes the sampling distribution of a deviation from the population mean divided by the standard error row 230

**ssresid** the sum of the squared differences for estimated y values and the actual y values for each point sum  $(y \text{ estimated} - y \text{ actual})^2$   $S(Y - Y_c)^2$  called the residual sum of the squares

the  $(Y - Y_c)$  's above the line roughly equal the sum of the  $(Y - Y_c)$  's below the line hence:  $S(Y - Y_c) = 0$

STRAIGHT LINE REGRESSION ANALYSIS -- LEAST SQUARES Continued

s	$\sqrt{\frac{S(X - X_m)^2}{n-1}}$	$\sqrt{\frac{7394.95}{19}}$
s	19.7	standard deviation
X <sub>m</sub>	55.05	from above
X <sub>m</sub> - s	35.3	0
	35.3	90
X <sub>m</sub> + s	74.8	0
	74.8	90
count	13	data points between the s cursors
%	68.4 %	13 points / n = 19 * 100

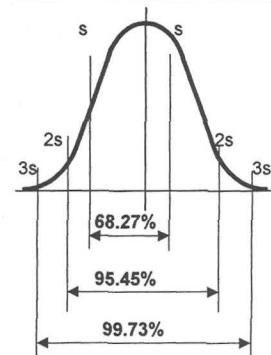


Figure 14-6 Standard deviations.

$$S_f = S_{yx} \sqrt{1 + 1/n + x^2 / Sx^2}$$

5.1261  $\sqrt{1 + 0.0500 \quad x^2 / \quad 7394.95 \quad F}$

s, s standard deviation, standard measure of dispersion row 270

X 55 sample value for X  
S<sub>f</sub> 5.253 standard error of forecast  
Spurr and Bonini pg 472

ssreg the sum of the squared differences for the actual values and the average y values for each point  
sum (y actual - y average)<sup>2</sup>  
called the regression sum of squares

Standard Error of an Individual Forecast

X	x	x <sup>2</sup>	S <sub>yx</sub>	S <sub>f</sub>	S <sub>f</sub> 95%	Y <sub>c</sub>	S <sub>f</sub> + 95%	S <sub>f</sub> - 95%
15	-40.05	1604.00	5.1261	5.77	12.116	18.330	30.447	6.214
35	-20.05	402.00	5.1261	5.39	11.312	37.192	48.504	25.879
55	-0.05	0.00	5.1261	5.25	11.031	56.053	67.083	45.022
75	19.95	398.00	5.1261	5.39	11.310	74.914	86.224	63.604
95	39.95	1596.00	5.1261	5.77	12.111	93.775	105.887	81.664

row 280

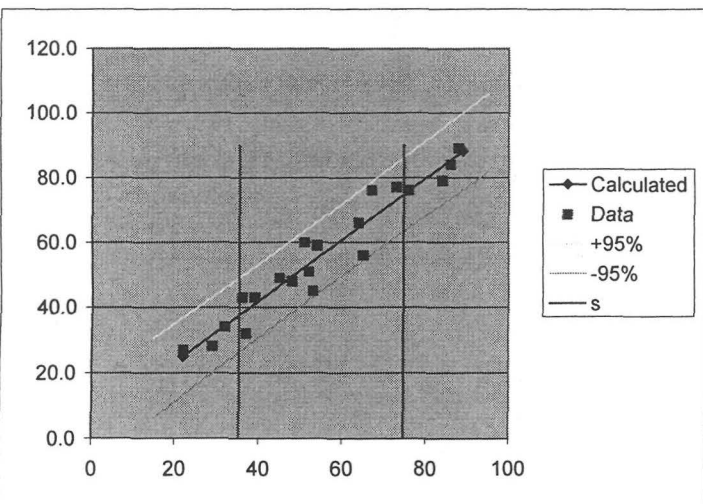


Figure 14-8 Regression analysis with the least squares concept.

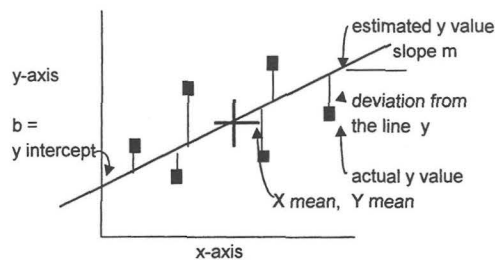


Figure 14-7 Straight line regression analysis.

total sum of squares  
regression sum of squares + residual sum of the squares

F statistic determines whether the observed relationship between dependent and independent variables occurs by chance. Always positive.

row 310



### LINEST VALUE

The **linest** function is the simpler, easier, and more dynamic way to do straight line, multiple straight line, and curvilinear regression analysis. You can fit a straight or curved line and watch the **linest** function change to reflect your iterations.

String 1	Distance	
X <sub>1</sub>	Y	
4010	0.00	
2863	0.25	
1783	0.50	
1097	0.75	
682	1.00	
399	1.25	
213	1.50	
11045.6	5.25	

linest	m <sub>1</sub>	b
m	-0.0003661	1.3276942
se	5.117E-05	0.1047367
r <sub>2</sub>	0.9110075	0.1764862
F	51.184493	5
SS <sub>reg</sub>	1.5942631	0.1557369

To get help with the equation entry, click on the "=" sign in front of the edit bar.

String 1	Distance	
x <sub>1</sub>	y	
4010	0.00	
2863	0.25	
1783	0.50	
1097	0.75	
682	1.00	
399	1.25	
213	1.50	
11045.6	5.25	

	m <sub>1</sub>	b
m	1.3276942	
se	5.1173E-05	0.1047367
r <sub>2</sub>	0.91100747	0.17648622
F	51.184493	5
SS <sub>reg</sub>	1.59426308	0.15573692

Figure 14-9 The Linest value process.



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14 Regression Analysis.xls

LINEST VALUE -- Continued

To utilize the **linest** tool, first select an area to edit or input the formula and then park it with a space in front of the "=" sign.

String 1	Distance
$x_1$	$y$
4010	0.00
2863	0.25
1783	0.50
1097	0.75
682	1.00
399	1.25
213	1.50
<hr/>	
11045.6	5.25

Degrees of freedom	$P = 0.1$	$P = 0.05$
1	6.314	12.706
2	2.900	4.303
3	2.330	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
17	1.740	2.110
18	1.734	2.101
19	1.729	2.093
20	1.725	2.086
21	1.721	2.080
22	1.717	2.074
23	1.714	2.069
24	1.711	2.064
25	1.708	2.060
26	1.706	2.056
27	1.703	2.052
28	1.701	2.048
29	1.699	2.045
30	1.697	2.042
infinity	1.645	1.960

Describe an array with your cursor and press the [F2] key.

$m_1$	$b$
=linest(D247:D253,B247:B253,true,true)	

Remove the " " and space in front of the "=" sign. Press the [Ctrl] [Shift] [Return] keys at the same time.

$m_1$	$b$
=LINEST(D247:D253,B247:B253,TRUE,TRUE)	

To get this result:

$m_1$	$b$
=LINEST(D247:D253,B247:B253,TRUE,TRUE)	

	$m_1$	$b$
m	-0.0003661	1.3276942
se	5.1173E-05	0.1047367
$r^2$	0.91100747	0.17648622
F	51.184493	5
SS <sub>reg</sub>	1.59426308	0.15573692

Figure 14-11 The Linest process.

Figure 14-10 Values of t and probability P.

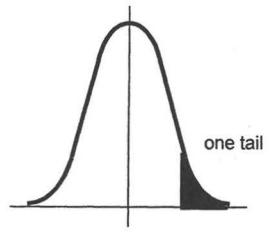


Figure 14-12 The one tail curve.

row 380  
row 390  
row 400  
row 410  
row 420  
row 430

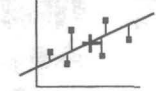


# REGRESSION ANALYSIS

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Christy  
17:39  
12/20/05



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## MULTI-STRAIGHT LINE REGRESSION ANALYSIS

We will use fabricated data for this example

plot the mean of the two values through the data scatter

Area	Height	Value	$X_1^2$	$X_2^2$	$Y^2$	$X_1 Y$	$X_2 Y$	$X_1 X_2$	$X_1$	$X_2$	$Y$	
14.7	155	4.1	216.1	24025	16.81	60.27	635.5	2278.5	9.921	105.03	3.048	4.06738
14.2	155	3.9	201.6	24025	15.21	55.38	604.5	2201	16.535	175.05	5.08	
12.7	158	3.2	161.3	24964	10.24	40.64	505.6	2006.6	24.803	262.58	7.620	
13.8	158	2.9	190.4	24964	8.41	40.02	458.2	2180.4				
14.4	155	3.9	207.4	24025	15.21	56.16	604.5	2232				
17.4	157	4.1	302.8	24649	16.81	71.34	643.7	2731.8				row 440
21.8	172	5.8	475.2	29584	33.64	126.44	997.6	3749.6				
14.0	170	5.1	196.0	28900	26.01	71.4	867	2380				
17.5	175	6.8	306.3	30625	46.24	119	1190	3062.5				
23.0	185	6.8	529.0	34225	46.24	156.4	1258	4255				
18.3	185	6.5	334.9	34225	42.25	118.95	1202.5	3385.5				
19.4	205	7.0	376.4	42025	49.00	135.8	1435	3977				
15.2	215	5.8	231.0	46225	33.64	88.16	1247	3268				
18.3	195	5.1	334.9	38025	26.01	93.33	994.5	3568.5				
21.7	178	5.3	470.9	31684	28.09	115.01	943.4	3862.6				
16.7	160	4.9	278.9	25600	24.01	81.83	784	2672				row 450
13.6	205	6.0	185.0	42025	36.00	81.6	1230	2788				
14.5	190	5.3	210.3	36100	28.09	76.85	1007	2755				
12.1	203	4.8	146.4	41209	23.04	58.08	974.4	2456.3				
17.4	125	4.3	302.8	15625	18.49	74.82	537.5	2175				
330.7	3501	101.6	5657.41	622729	543.44	1721.48	18119.9	57985.3				
n	20											
mean	$X_{1m}$	$X_{2m}$	$Y_m$	$X_{2m} X_1$	$X_{2m} X_2$	$Y_m Y$	$Y_m X_1$	$X_{2m} Y$	$X_{2m} X_1$			
	16.535	175.05	5.08	5468.12	612850	516.13	1679.96	17785.08	57889.0			row 460
				$SX_1^2$	$SX_2^2$	$Sy^2$	$SX_1 Y$	$SX_2 Y$	$SX_1 X_2$			
				189.29	9879	27.312	41.524	334.82	96.3			

### Long Hand Calculations

Simultaneous Equations for  $y = m_1 x_1 + m_2 x_2 + b$

$$\begin{aligned}
 Sx_1 y &= m_1 x_1^2 + m_2 x_1 x_2 \\
 41.524 &= m_1 189.29 + m_2 96.3 \\
 Sx_2 y &= m_1 x_1 x_2 + m_2 x_2^2 \\
 334.82 &= m_1 96.3 + m_2 9879
 \end{aligned}$$

linest

	$m_1$	$m_2$	b	
slope m	0.0319	0.2031	-3.8653	y intercept
standard error se	0.007001	0.05058	1.44269	standard error for m
R Square, $r^2$	0.70007	0.69416	#N/A	standard error for the y est
chance relation F	19.83996	17	#N/A	degrees of freedom n - k
SS Regression	19.12031	8.19169	#N/A	SSE

multiply  $Sx_2 y$  by  $\rightarrow$  1.966  
to get 658.36 189.29 19425 row 470

subtract from  $Sx_1 y$   
to get -616.83 0 -19328.676

$m_1$  0.2031  
 $m_2$  0.0319

$$\begin{aligned}
 Y \text{ mean} - m_1 X_1 \text{ mean} - m_2 X_2 \text{ mean} \\
 5.08 - 3.359 - 5.586
 \end{aligned}$$

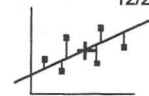
b -3.8653 row 480

To predict y with inputs for  $x_1$  and  $x_2$

$x_1$	15		
$x_2$	180		
y	3.047	5.744	-3.865
y	4.926		

n 20 each number of samples from above  
k 3 each number of constants in the regression equation

row 490



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**MULTI-STRAIGHT LINE REGRESSION ANALYSIS -- Continued**

$$S_{yx} = \sqrt{\frac{S_y^2 - m_1 S_{x_1 y} - m_2 S_{x_2 y}}{n - k}}$$

$S_{yx}$	$\sqrt{\frac{27.312}{20} - 0.2031(-3) - 0.0319(334.82)}$
$S_{yx}$	<b>0.6942</b> standard error of estimate

$$S_t = S_{yx} \sqrt{1 + 1/n + x^2 / S_x^2}$$

$$s_y^2 = \frac{S_y^2}{n - 1} = \frac{27.312}{19}$$

$$s_y^2 = 1.437$$

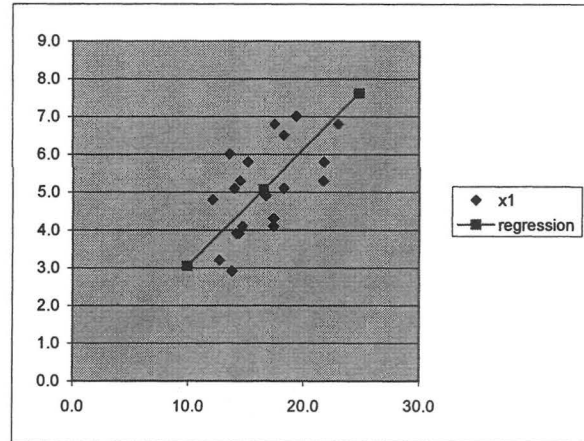
estimated total variance

$$R^2 = 1 - S^2_{yx} / s_y^2$$

$$R^2 = 0.6648$$

coefficient of multiple determination  
also known as R Square

$$R = 0.8153$$



row 500

row 510

Figure 14-13 Regression Graph

b is a pure number representing the net regression coefficient expressed in units of its own standard deviation.

row 520

Compare these values to see which values, X<sub>1</sub> or X<sub>2</sub>, have greater significance.

**Beta Coefficients**

$$b_1 = \frac{S_{x_1 y}}{S_{x_1^2}}$$

$$b_1 = 0.2031 \sqrt{\frac{189.29}{27.312}}$$

$$b_1 = 0.535$$

$$b_2 = \frac{S_{x_2 y}}{S_{x_2^2}}$$

$$b_2 = 0.0319 \sqrt{\frac{9879}{27.312}}$$

$$b_2 = 0.607$$

**Standard Error of Regression Coefficient**

$$r^2_{12} = \frac{(S_{x_1 x_2})^2}{(S_{x_1^2})(S_{x_2^2})} = \frac{96.3^2}{189.29 \cdot 9879}$$

$$r^2_{12} = 0.0050$$

$$sm_1 = \frac{S_{yx}}{\sqrt{S_{x_1^2} (1 - r^2_{12})}}$$

$$sm_1 = \frac{0.694}{\sqrt{189.29 \cdot 0.9950}}$$

$$sm_1 = 0.0506$$

Standard Error of the Regression Coefficient

$$sm_2 = \frac{S_{yx}}{\sqrt{S_{x_2^2} (1 - r^2_{12})}}$$

$$sm_2 = \frac{0.694}{\sqrt{9879 \cdot 0.9950}}$$

$$sm_2 = 0.0070$$

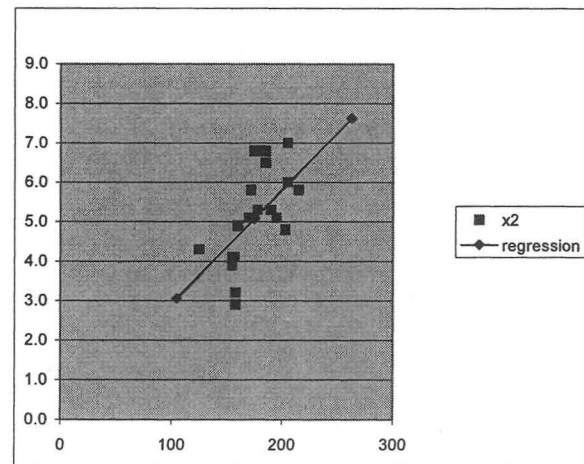
$$m_1 = 4.016 \text{ standard errors from } B_1 = 0$$

$$0.2031 m_1 / 0.0506 sm_1$$

$$m_2 = 4.558$$

For n - k degrees of freedom, the one tailed t value is 2.567 at a significance of 0.01.

Both m<sub>1</sub> and m<sub>2</sub> are greater than 2.567 at a significance of 0.01.

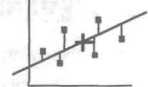


row 530

row 540

Figure 14-14 Regression Graph No. 2

row 550



### THE F COEFFICIENT

Are the methods different enough from each other to be significant?

Method	1	2	3	4
scores	65	75	59	94
	87	69	78	89
	73	83	67	80
	79	81	62	88
	81	72	83	
	69	79	76	
		90		

T X	454	549	425	351	1779
group mean	75.67	78.43	70.83	87.75	
$T_m (SX)^2$	34353	43057	30104	30800	138314.4

n 23  
p 4 groups, populations

CM  $(SX)^2 / n$  1779 23  
CM 137602 correction for the mean

Total SS  $S(X - X_m)^2 - CM$  139511 137602  
Total SS 1909.2

SST  $Sn(T_m - X)^2 = ST^2/n - CM$  138314 137602  
SST 712.6

SSE Total SS - SST 1909.2 712.6  
SSE 1196.6

Mean squares for treatment and error  
MST 712.6 3  
MST 237.5

MSE  $SSE / (n - p)$  1196.6 19  
MSE 63.0

F  $MST / MSE$  237.53 62.98  
F 3.77

to find the F statistic for

$n_1$  p - 1  
3

$n_2$  n - p  
19

for  $F_{.05}$  3.13 OK  $3.13 < 3.77$

$X_{mm}$  overall mean denoted in text books as X with double bars on top

CM correction for the mean

Total SS SST + SSE row 569

SST sum of squares for treatment

SSE pooled sum of squares of the deviations, sum of the squares for error

MST mean squares for treatment

MSE mean square for error

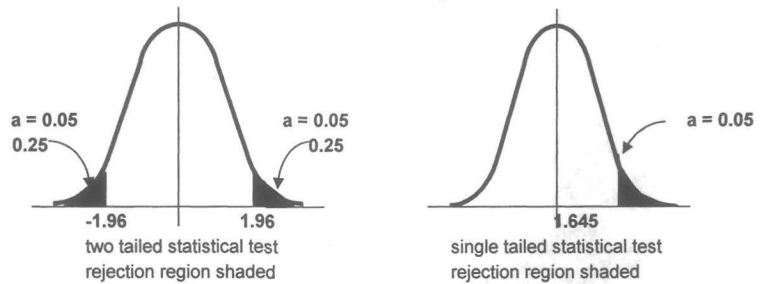


Figure 14-15 Two tailed and single tailed curves.

F  $MST / MSE$  the chance relation between data groups and within a group the F statistic determines whether the observed relationship between dependent and independent variables occurs by chance. Always positive.

$n_1$  factor for the groups in the F statistic

$n_2$  factor for the number of observations within a number of groups

$r^2$  the coefficient of correlation between y and x, A measure correlation varies from 0 to 1 with 1 being the best correlation



# REGRESSION ANALYSIS

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## THE F COEFFICIENT -- Continued

Data Table from above				linest					
score #	Method				m	b			
1	65	75	59	4 slope m	0.008781	0	-0.0508	-0.1236	0
2	87	69	78	94 standard error se	0	0	0	0	0
3	73	83	67	89 R Square, $r_2$	1	0	#N/A	#N/A	#N/A
4	79	81	62	80 chance relation F	#NUM!	0	#N/A	#N/A	#N/A
5	81	72	83	88 SS Regression	5	0	#N/A	#N/A	#N/A
6	69	79	76	0	the chance relation F in this linest is not valid				
7	0	90	0	0	linest must have 0's as place holders				
	6	7	6	4 slope m	-0.0566	-0.124712	0.12109	0.1367	-3.9531
	75.7	78.4	70.8	87.8 standard error se	0.011377	0.064868	0.06152	0.06516	5.63671
				R Square, $r_2$	0.971371	0.633097	#N/A	#N/A	#N/A
				chance relation F	16.96454	2	#N/A	#N/A	#N/A
				SS Regression	27.19838	0.801624	#N/A	#N/A	#N/A

Sort each group in ascending order before using linest

score #	1	2	3	4	1	2	3	4				
1	65	69	59	80	61	0.156	66	0.276105	55	0.44606	80	0.84615
2	69	72	62	88	95	7.908	90	7.467074	95	8.16128	95	4.04715
3	73	75	67	89								
4	79	79	76	94								
5	81	81	78									
6	87	83	83									
7		90										
	7	6	7	6	4							
	3.0	75.8	65.9	71.3	88.8							

Group	linest	
Group 1	slope m	0.228 -13.752
	standard error se	0.011358 0.86357
	R Square, $r_2$	0.990171 0.20736
	chance relation F	402.9767 4
	SS Regression	17.328 0.172
Group 2	slope m	0.299624 -19.499
	standard error se	0.021989 1.73062
	R Square, $r_2$	0.973777 0.38321
	chance relation F	185.6726 5
	SS Regression	27.26576 0.73424
Group 3	slope m	0.19288 -10.162
	standard error se	0.015308 1.09
	R Square, $r_2$	0.975424 0.33
	chance relation F	158.7618 4.00
	SS Regression	17.06992 0.43
Group 4	slope m	0.2134 -16.226
	standard error se	0.045213 3.97393
	R Square, $r_2$	0.917618 0.45
	chance relation F	22.27711 2
	SS Regression	4.588089 0.41191

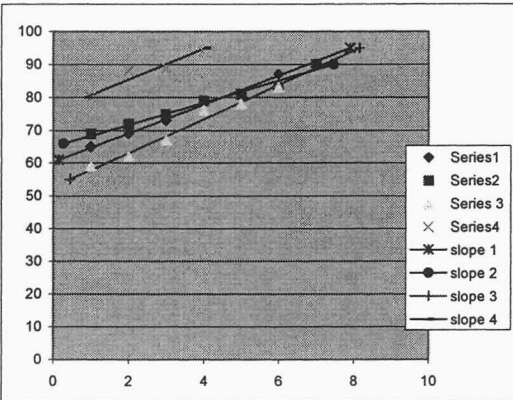


Figure 14-16 A comparison of methods.

### CURVILINEAR REGRESSION ANALYSIS

And now, for the real reason that I got into this essay.

Record the readings of a string gage at about 0.25 inch intervals. This string gage uses a linear potentiometer but the readings from linear potentiometers and LVDT's are never quite linear. To interpret readings from the gage between the calibration measurements, we create the equation that can plot a straight line through the scatter of points and give fairly accurate results.

The creation of an equation to fit these points is fitted essentially by hand. We use the **linest** function to help us fit this curve. **Linest** is dynamic – as you change your values, **linest** re-computes its value.

The  $r^2$  value is of critical value.

String 1	Distance					
$x_1$	$x_2 = x_1^{1.01}$	y	curve	$x_1$ mean	y mean	
4010	4357	0.00	4011	3627	0	
2863	3100	0.25	2861	1578	0.75	
1783	1921	0.50	1782	-471	1.5	
1097	1176	0.75	1098			
682	728	1.00	683			
399	424	1.25	400			
213	225	1.50	212			

power of 1.01  
n 7

**linest  $x_1$**   
m -0.0003661 1.3276942  
se 5.117E-05 0.1047367  
 $r^2$  0.9110075 0.1764862  
F 51.184493 5  
SS<sub>reg</sub> 1.5942631 0.1557369

**linest  $x_1 + x_1^{power of}$**   
m 0.0326723 -0.0359284 1.7598648  
se 0.0045917 0.0049979 0.068505  
 $r^2$  0.993484 0.0533924 #N/A  
F 304.93727 4 #N/A  
SS<sub>reg</sub> 1.738597 0.011403 #N/A

This plot can be also be fitted with Excel's add trendline feature in the graph pop up menu. Click on the curve of actual values and select add trendline. You have the option of displaying the formula and the value for  $r^2$  on the graph.

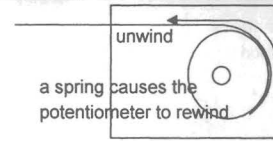


Figure 14-17 A diagram of the string gage.

$r^2$  the correlation of estimated and actual y values

Note: an  $r^2$  greater than 0.95 is usually acceptable

LVDT linear voltage displacement transducer an instrument which uses a power supply to create and AC voltage. The measurement is made by the position of a plunger within a coil whose voltage changes as the plunger moves. Measurements must be "normalized" to be truly accurate.

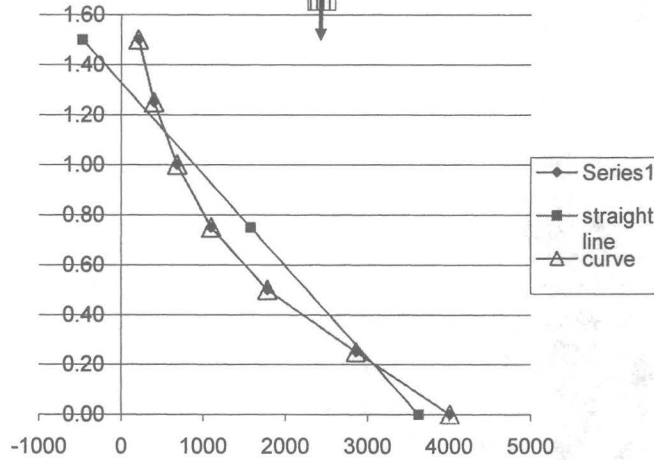


Figure 14-18 The straight line approximation of a curve.

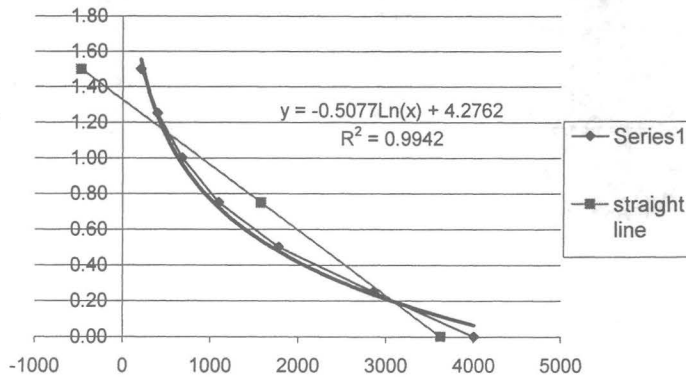


Figure 14-19 Using Excel's add trendline function to fit a curve.

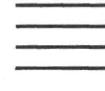


# TAKEDOWN

Kraft Pulping Building Modifications

**15**

Christy  
17:39  
12/20/05



15 Takedown.xls

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A B C D E F G H I J K L M N

**KRAFT PULPING** 24 May 84

This is a sample from an actual job.  
Loads must be tallied and factored for column and foundation design.

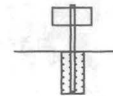
Column A2 Loads Take Down

	A2	DL	LL	New Piping	Existing Piping	Sum	
Roof		6.45		0	0	6.45	
		2	wall			2	
Conveyor flr		21.5	floor	2.6	9.4	33.5	8.45
		2	21.5	conveyor		23.5	row 20
			8.6	8.4		17	
Operating flr		21.5			6.6	28.1	82.45
		2	wall			2	
Mezzanine		6.5			36.4	42.9	112.55
		31	at ES			31	
Ground floor					9.6	9.6	196.05
							row 30
<b>Figure 15-1 Structure Elevation</b>		92.95	30.1	11	62	196.05	196.05

row 40

row 50

row 60



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**POLE FOUNDATION -- LATERAL BEARING TYPE FOUNDATION**

This template uses the "shooting method" of converging two equations which depend upon each other for values.

P	0.5 k	Applied lateral force, kips
h	4.0 ft	distance from ground surface to P, ft
q	266 psf/ft	allowable soil-brg UBC Table 18-I-A / IBC Table 1804.2 / psf/ft
b	1.00 ft 12"	diameter or diagonal dimension of a 0.71' square post, ft

**Constrained**

$$S_3 = q * d$$

$$d^2 = 4.25 * P * 1000 * h / (S_3 * b)$$

$$d^2 = 4.25 * P * 1000 * h / (q * d * b)$$

$$d^3 = 4.25 * P * 1000 * h / (q * b)$$

$$d = (4.25 * P * 1000 * h / (q * b))^{1/3}$$

d	3.19 ft	$(4.25 * P * 1000 * h / (q * b))^{1/3}$ $(4.25 * 0.5 * 1000 * 4.0 / (266 * 1.00))^{1/3}$
	0.376 k	weight $(1.00 / 2)^2 * \pi * 3.19 * 0.150$
	0.093 cy	concrete $(1.00 / 2)^2 * \pi * 3.19 / 27$

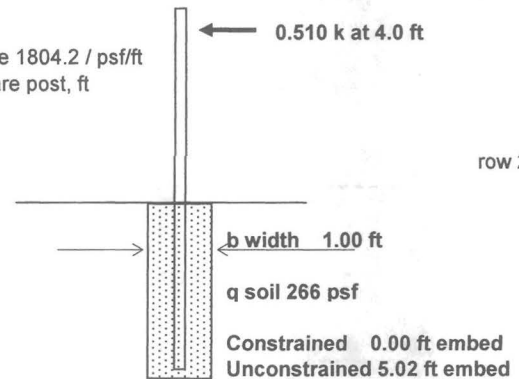


Figure 16-1 POLE FOUNDATION ELEVATION

**Unconstrained at Top**

S <sub>1</sub>	445 psf	q * d <sub>est</sub> / 3
A	3 ft	2.34 * P * 1000 / (S <sub>1</sub> * b)
d <sub>u</sub>	5.02 ft	A / 2 * (1 + (1 + 4.36 * h / A) <sup>1/2</sup> )
converge	100.0 %	the difference in d <sub>u</sub> for the last 2 iterative calculations = 0.00 ft 100 - 0.00
	0.591 k	weight $(1.00 / 2)^2 * \pi * 5.02 * 0.150$
	0.146 cy	concrete $(1.00 / 2)^2 * \pi * 5.02 / 27$

**NOTES**

See UBC 1806.7.2.1 equation 6-1 NonConstrained, 6-2 Constrained / IBC 1805.7.2.1 equations 18-1, 2, and 3 / and Table 18-I-A / IBC 1804.2 / Allowable Foundation and Lateral Pressure for typical allowable lateral pressures.

The solution for this answer is iterative. Typically -- vary the estimated depth d<sub>est</sub> to be greater than the required depth for constrained or unconstrained conditions. If you have a maximum depth which must not be exceeded, vary the width b.

Width b is the diameter of a round post or the diagonal dimension of a square post (or footing). Hence, b for a 3'-0" round footing is 3.0 but for a 3'-0" square footing b is  $(3^2 + 3^2)^{0.5} = 4.24'$

P \* h = moment to overturn the foundation

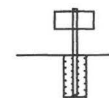
UBC 1806.7.2.1 d / IBC Table 1804.2 footnote d / states that allowable stresses and soil-bearing values may be increased 33% when combining vertical loads with wind/earthquake loads or when lateral loads are acting alone. Footnote 3 in Table 18-I-A / IBC 1804.3.1 / allows a 100% lateral bearing increase for poles not adversely affected by a 1/2" lateral translation at the top of the footing. Use judgement when increasing the 2x multiplier by another 33%.

Depth d<sub>est</sub> is the depth of embedment in the earth not to exceed 12 ft when computing lateral pressures S<sub>1</sub> or S<sub>3</sub>.

UBC Table 18-I-A note 3 / IBC 1804.3.1 / limits lateral bearing value increase to 15 x designated value. Current designated value = 266 psf/ft. Max value = 3990 psf. However, depth "d" used for computing lateral pressure is limited to 12'. Hence, lateral pressure is limited to 3192 psf.



# EMBEDDED POLE AN EXAMPLE OF THE SHOOTING METHOD



16 Pole.xls

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## THE SHOOTING METHOD

### ITERATIVE CALCULATIONS FOR UNCONSTRAINED FOOTING

d\_est 5.00 ft ESTIMATED embedment, 5.00 ft. for pressure

443.33	445.70	444.89	444.36	444.82	444.84	444.68	444.73	444.77	445	445	445	445	444.74
2.69	2.68	2.68	2.69	2.68	2.68	2.68	2.68	2.68	2.7	2.7	2.7	2.7	2.68
5.03	5.01	5.01	5.02	5.02	5.02	5.02	5.02	5.02	5.0	5.0	5.0	5.0	5.02
$\frac{\$q * \text{MINA}(D\_EST, 12)}{266 * \text{MINA}(5.00, 12)} \quad \frac{\$q * \text{MINA}(A91, 12)}{266 * \text{MINA}(5.03, 12)} \quad \frac{\$q * \text{MINA}((A91 + B91) / 2, 12)}{266 * \text{MINA}((5.03 + 5.01) / 2, 12)}$													row 80
$2.34 * \$P * 1000 / (A89 * \$B) \quad 2.34 * \$P * 1000 / (B89 * \$B) \quad 2.34 * \$P * 1000 / (A89 * \$B)$													
$2.34 * 0.51 * 1000 / (443.33 * 1.00) \quad 2.34 * 0.51 * 1000 / (445.70 * 1.00) \quad 2.34 * 0.51 * 1000 / (444.89 * 1.00)$													
$A90 / 2 * (1 + (1 + 4.36 * \$H / A90)^{0.5}) \quad B90 / 2 * (1 + (1 + 4.36 * \$H / B90)^{0.5}) \quad \text{in this row, a new depth of embedment is calculated}$													
$2.69 / 2 * (1 + (1 + 4.36 * 4.00 / 2.69)^{0.5}) \quad 2.68 / 2 * (1 + (1 + 4.36 * 4.00 / 2.68)^{0.5})$													

No convergence factor is applied to the math in these equations. Other equation sets require some sort of adjustment/convergence factor to achieve convergence.

row 90

The notes below the inputs are not meant to represent the code. You will want to edit them to reflect your understanding of the code and soils engineering. They are included in the printout as an aid to the building department in reviewing these calculations.

Also, the code can be complicated at times and these notes help to bring all of the design issues together in one place. Otherwise, some of the fine but important points may be forgotten such as the 12' embedment limit.

## WORKSHEET

row 100

Values for a lamp pole:

	Weights	h	cg	Seismic	area	cg	Wind
lamps	90	2	32.33	2910	3	32.33	97
brackets	42	0	31.33	1316	1	31.33	31
spar	100	1.33	30.665	3067	5	30.665	153
pole	558	30	15	8370	15	15	225
sum	790	33.33		15662			506.645
			M seismic 0.5	7831 lb-ft	M wind 18		9120 lb-ft

row 110

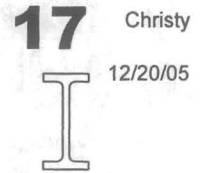
relative P 282.08 k  
relative h 32.33 ft

row 120

row 130



# NUMERICAL INTEGRATION



ENGINEERING with the SPREADSHEET

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17 Numerical Integration.xls

A B C D E F G H I J K L M N O P Q R S T U V W X Y  
**OVERVIEW**

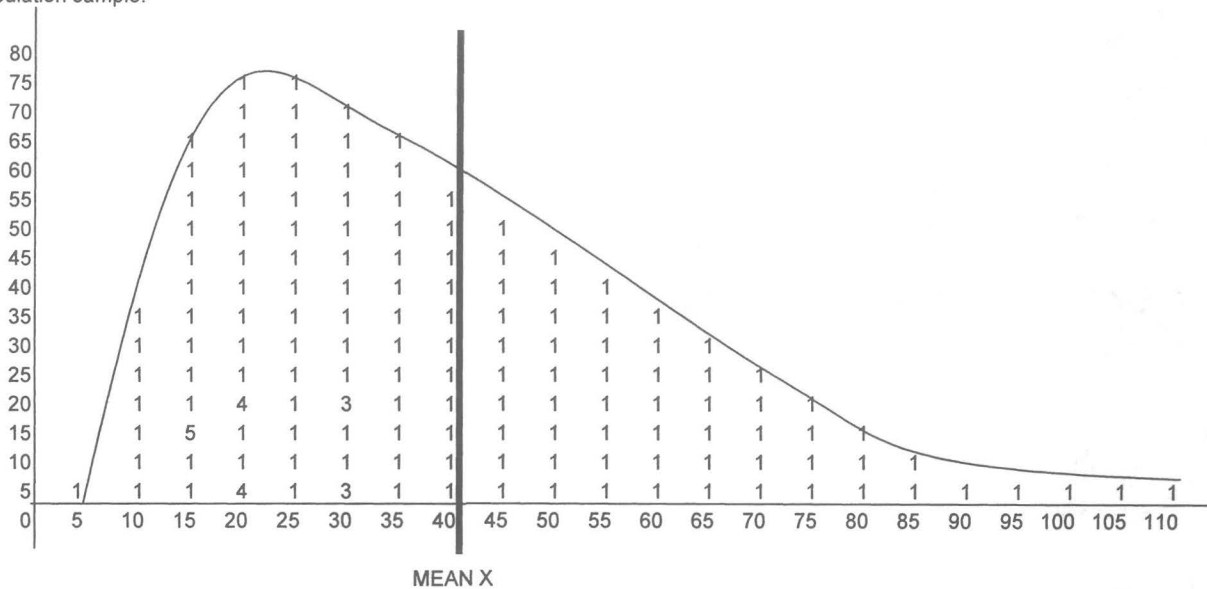
This template was originally created to design irregular footings. It calculates  $I_{xx}$ ,  $I_{yy}$ ,  $I_{xy}$  and the centers of gravity.

Many engineering designs do not submit themselves to logic. They require numerical integration. Most of us do a rough type of numerical integration when we're balancing a fry pan on an uneven burner.

What is numerical integration? Well, for example, draw a curve on quadrule paper and a straight line below the curve. Now, determine the area below the curve. Count the squares between the curve and the straight line. Counting the squares is numerical integration.

row 20

The following figure is a printout from the numerical integration template. It's for a skewed population sample.



row 30

row 40

Figure 17-1 Numerical integration of a population sample.

The area or population size is simply the number of filled cells. The center of gravity (or mean) is the balance point. It is calculated as the sum of all the individuals times their respective distances from the X or Y axis divided by the area (population).

row 50

For the distance from the Y axis  
 Sum (each value \* respective arm) /number of samples

value \* 5 70 255 420 375 540 455 440 450 450 440 420 390 350 300 240 170 90 95 100 105 110  
 sum 162 =SUM(B28:W42)

Mean  $\bar{x}$  39 =SUM(B56:W56)/B57

row 60



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17 Numerical Integration.xls

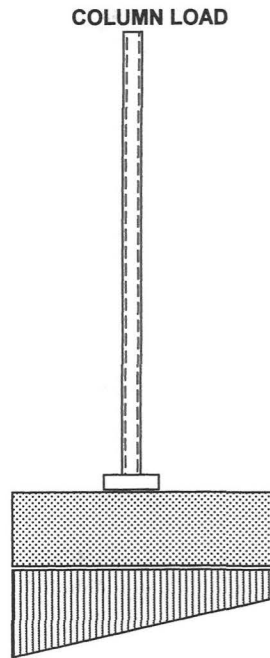
A B C D E F G H I J K L M N O P Q R S T U V W X Y

**FOOTING DESIGN**

That's the first step. The template was actually created to analyze irregularly shaped footings with eccentric loads. In real life, not all populations fit the bell shaped curve, nor can all footings be square or rectangular with the load in the middle.

In the template, the footing's shape is described by filling in a field of cells. Each spreadsheet cell represents an element which has a width, length, and center of gravity. The contribution from each element to the footing is calculated in several different formulas in rows below the field and compiled into values for other calculations. The end result is a close approximation to the formal calculus answer and it will work for our footing.

row 70



row 80

row 90

The sum of soil resistance = column load + footing dead load (DL)

Figure 17-2 An elevation view of the column and footing.

The soil pressure that resists the footing will vary. The simple form of the equation that describes this resistance at a given location beneath a rectangular footing is:

$$q \text{ lbs/ft}^2 = \frac{P \text{ lbs}}{\text{area ft}^2} \pm \frac{M \text{ lb-ft} * c \text{ ft}}{I \text{ ft}^4}$$

c the distance from the extreme fiber to the center of gravity in the direction in question

CG center of gravity

Ad<sup>2</sup> spreadsheet notation is Ad<sup>2</sup>

The interesting part of this equation is the variable I, the moment of inertia. This is the resistance to moment, the twisting force that tries to tip the footing into the soil. For this design, you won't find I in a book somewhere. You have to derive it.

row 110



A B C D E F G H I J K L M N O P Q R S T U V W X Y  
**FOOTING DESIGN -- Continued**

You can explain this concept as analogous to a bicycle tire where the fat tire is harder to get going than the thin tire. The fat tire has more area of rubber out at the rim and, therefore, more moment of inertia, I.

Calculating I requires two equations that work with the field of cells shown. The first formula is:

$$I = \text{Area} * \text{distance}^2$$

This is a way of multiplying each element times the square of its distance from the footing's center of gravity. Here, the element essentially rotates about the footing's center of gravity.

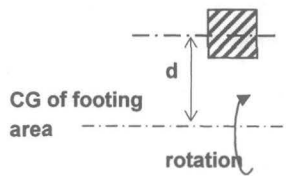


Figure 17-3 Rotation around the footing's center of gravity

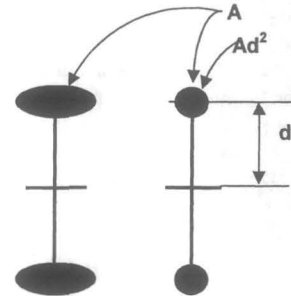


Figure 17-4 Bicycle tire profiles for a moment of inertia comparison.

row 120

This calculates a value of I for each element where the element rotates about its own axis.

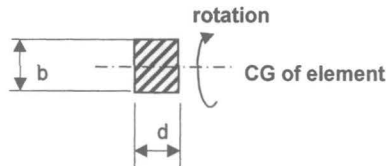


Figure 17-5 Rotation of an element around its own center of gravity.

row 130

The value of I for a rectangular element is:

$$I = b d^3 / 12$$

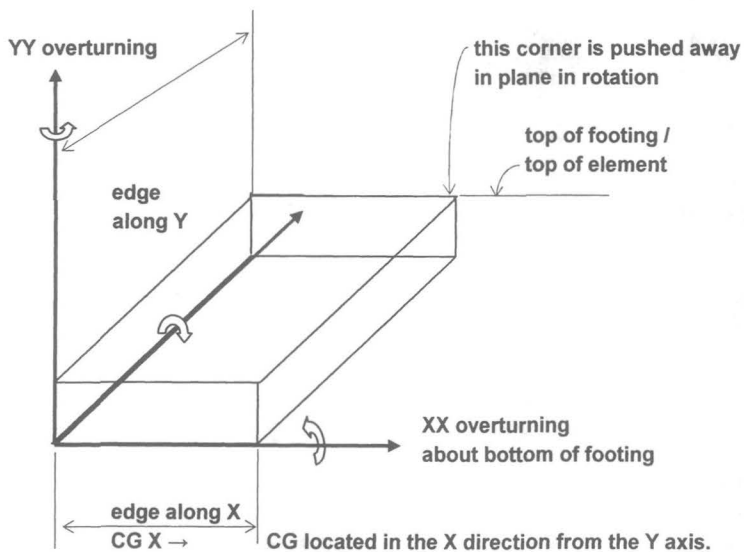


Figure 17-6 3D view of the footing.

row 140

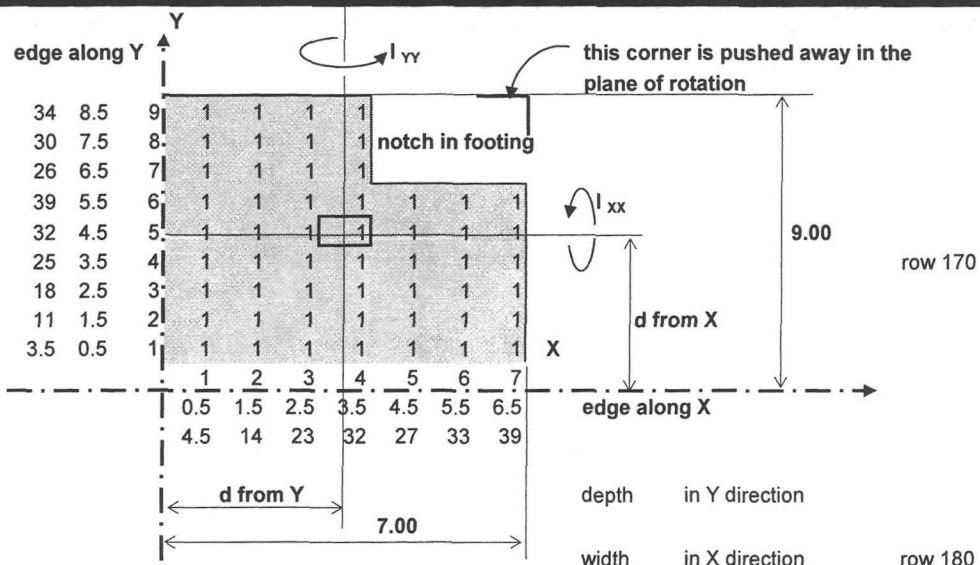
row 150

row 160



A B C D E F G H I J K L M N O P Q R S T U V W X Y  
**FOOTING DESIGN -- Continued**

This is easy to model with the spreadsheet. The two I's for a column of cells are computed in two rows of cells below the field. The values in those rows are summed in a convenient spot to the right of the rows. In this way, the values for all of the squares are counted like the squares on quadrule paper.



unit depth 1.00 ft  
 unit width 1.00 ft  
 Area 54 ft<sup>2</sup>  
 sum X\*d 171 ft-ft<sup>2</sup>

Figure 17-7 FOOTING PLAN VIEW

CG X → 3.17 ft CG about Y axis  
 sum Y\*d 216 ft-ft<sup>2</sup>  
 CG Y ↑ 4.00 ft CG about X axis

$d_x$  could be the distance from the X axis or Y axis. Use descriptive range names and descriptions. This works better for you and others using your work.

$I_{xx}$ about X	$d$	$Ad^2$	4	16	16	16	16	0	0	0	$bd^3/12$	0.1	0.1	0.1	0.1	0	0	0
$A d_x^2$			3	9	9	9	9	0	0	0		0.1	0.1	0.1	0.1	0	0	0
			2	4	4	4	4	0	0	0		0.1	0.1	0.1	0.1	0	0	0
			1	1	1	1	1	1	1	1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
			0	0	0	0	0	0	0	0		0.1	0.1	0.1	0.1	0.1	0.1	0.1
			-1	1	1	1	1	1	1	1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
$I_{xx}$ about X			-2	4	4	4	4	4	4	4		0.1	0.1	0.1	0.1	0.1	0.1	0.1
sum $I_{xx}$	338 ft <sup>4</sup>		-3	9	9	9	9	9	9	9		0.1	0.1	0.1	0.1	0.1	0.1	0.1
about CG <sub>x</sub>		333	-4	16	16	16	16	16	16	16	4.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1

$I_{yy}$ about Y	$d$	-2.7	-1.7	-0.7	0.33	1.33	2.33	3.33										
$A d_y^2$	$Ad^2$	7.1	2.8	0.4	0.1	0	0	0	$b^3d/12$	0.1	0.1	0.1	0.1	0	0	0	0	
		7.1	2.8	0.4	0.1	0	0	0		0.1	0.1	0.1	0.1	0	0	0	0	
		7.1	2.8	0.4	0.1	1.8	5.4	11		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
		7.1	2.8	0.4	0.1	1.8	5.4	11		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
		7.1	2.8	0.4	0.1	1.8	5.4	11		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
$I_{yy}$ about Y		7.1	2.8	0.4	0.1	1.8	5.4	11		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
sum $I_{yy}$	209 ft <sup>4</sup>	7.1	2.8	0.4	0.1	1.8	5.4	11		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
about CG <sub>y</sub>		204	7.1	2.8	0.4	0.1	1.8	5.4	11	4.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

A B C D E F G H I J K L M N O P Q R S T U V W X Y  
**FOOTING DESIGN -- Continued**

d from X **4.5 ft** location of column from the X axis ↑  
d from Y **4 ft** location of column from the Y axis →  
P **24 k**

M<sub>x</sub> -12.0 k-ft moment about CG from X axis  
M<sub>y</sub> -20.0 k-ft

c<sub>x</sub> can also be d from X distance from the CG load to the extreme fiber in question at the top or bottom of the plan view

Keeping everything sorted out is easier with descriptive range names.

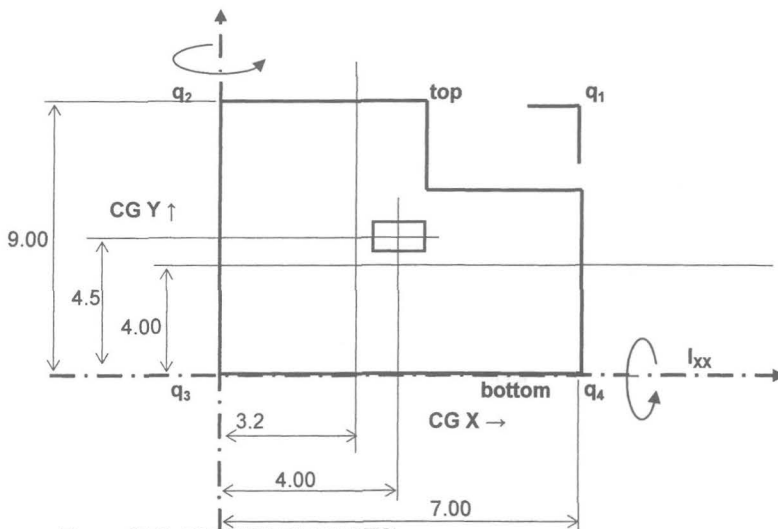


Figure 17-9 FOOTING PLAN VIEW

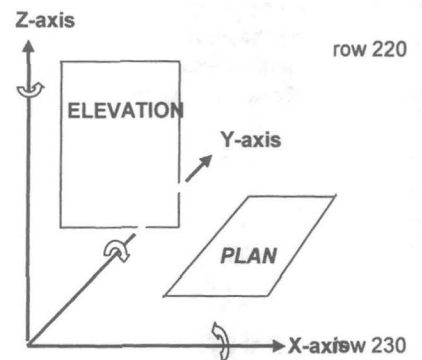


Figure 17-8 The right-hand rule.

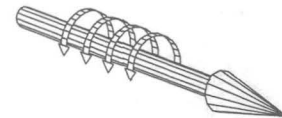


Figure 17-10 Simple view of the right-hand rule.

Wrap the fingers of your right hand 240 around the arrow. Your thumb will point in the positive direction of the axis.

This rule is handy for installing screws, nuts, and bolts. Remember to use your right hand, point your thumb in the direction you want the bolt to go, and turn the bolt in the direction that your fingers point.

q k/ft <sup>2</sup>	P k	±	M <sub>x</sub> k-ft * c <sub>y</sub> ft	±	M <sub>y</sub> k-ft * c <sub>x</sub> ft	
	area ft <sup>2</sup>		I <sub>xx</sub> ft <sup>4</sup>		I <sub>yy</sub> ft <sup>4</sup>	
	24	-	-12 4.5	+	-20 3.00	
	54		338		209	
q <sub>1</sub>	0.4	-	-0.2	+	-0.3	= 0.3
					-20 4.00	
					209	
q <sub>2</sub>	0.4	-	-0.2	-	-0.4	= 1
			+ -12 4.5			
			338			
q <sub>3</sub>	0.4	+	-0.2	-	-0.4	= 0.67
q <sub>4</sub>	0.4	+	-0.2	+	-0.3	= 0.00

Other numerical integration applications can become more complex but the approach is much the same. Generally, fields of formulas calculate values which are compiled into an answer.

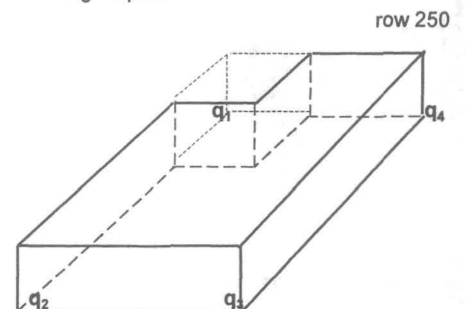


Figure 17-11 View of the footing. row 250  
row 260



**NUMERICAL INTEGRATION for W8 X 31**

Scale factors of 0.5 inch and 0.5 inch were selected for the X and Y-axes. The flange thickness (0.435 inch) is divided by the scale factor so that the correct area of the flange for that segment of the flange length will be used by the model.

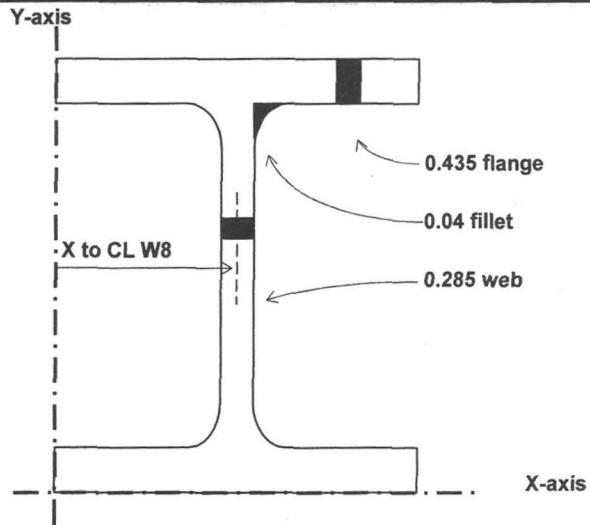
Note that the fillets are also approximated.

These values compare favorably with the values in the Eighth Edition AISC Handbook.

The template also calculates the stress at a chosen point.

Item **W8 X 31**

X Scale **0.5** adjust axis scales to fit as many areas  
 Y Scale **0.5** (rectangles) in to the model as possible



row 270

Figure 17-12 The profile of a wide flange beam.

row 280

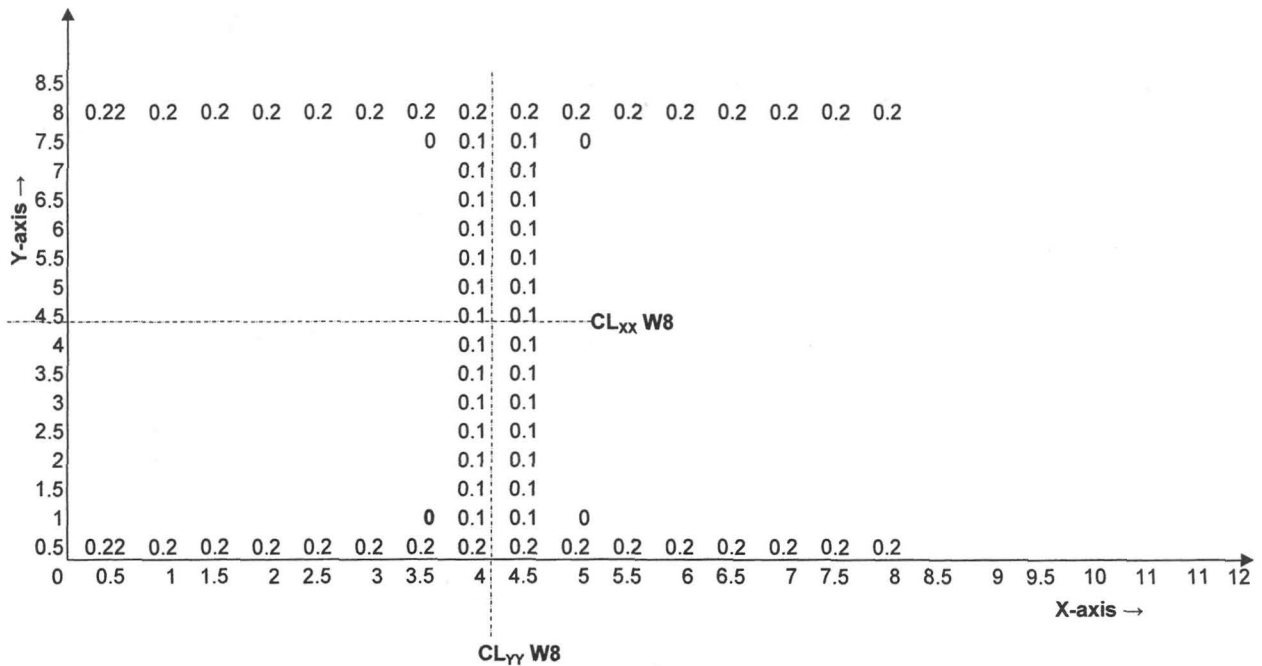
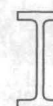


Figure 17-13 The profile of a wide flange beam.

row 310



# NUMERICAL INTEGRATION



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A B C D E F G H I J K L M N O P Q R S T U V W X Y

**NUMERICAL INTEGRATION for W8 X 31 For  $I_{YY}$  about the Y axis**

A sum **9.12 in<sup>2</sup>**

X to CL

elements	0.25	0.8	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8	5.3	5.8	6.3	6.8	7.3	7.8	8.3	8.8	9.3	9.8	10	11	11
A elements	0.44	0.4	0.4	0.4	0.4	0.4	0.5	1.4	1.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0	0	0	0	0	0	0
AX	0.11	0.3	0.5	0.8	1	1.2	1.7	5.4	6.1	2.4	2.3	2.5	2.7	2.9	3.2	3.4	0	0	0	0	0	0	0
sum AX	36.5																						

CG from Y **4 in**

Ad <sup>2</sup> YY	0.03	0.2	0.7	1.3	2.2	3.3	5.4	20	26	12	12	14	17	20	23	26	0	0	0	0	0	0	0
	183																						
CG - X = d	3.75	3.3	2.8	2.3	1.8	1.3	0.8	0.3	-0.2	-0.7	-1.3	-1.8	-2.3	-2.8	-3.3	-3.8	-4.3	-4.8	-5.3	-5.8	-6.3	-6.8	-7
	6.12	4.6	3.3	2.2	1.3	0.7	0.3	0.1	0.1	0.3	0.7	1.3	2.2	3.3	4.6	6.1	0	0	0	0	0	0	0
bd <sup>3</sup> /12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	0	0	0	0	0	0	0
	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	100	100	100	100	100	100	100

I edge<sub>YY</sub> **183 in<sup>4</sup>**



Ad<sup>2</sup> NA **37.2**

I<sub>YY</sub> **37.3 in<sup>4</sup>**

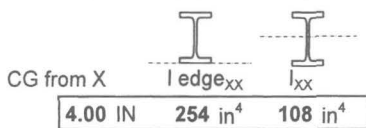


$I_{YY}$  moment of inertia about the weak axis of a wide flange shape.

**NUMERICAL INTEGRATION for W8 X 31 For  $I_{XX}$  about the X axis**

Oriented vertically for rotation about the X-axis

A elements				I edge <sub>xx</sub>		bd <sup>3</sup> /12			
Y to CL elements	Y	sum AY	Ad <sup>2</sup> XX	Ad <sup>2</sup> NA					
8.5	8.25	0	0	0	-4.3	0	0	100	
8	7.75	3.5	27	209	-3.8	49	0	8	8
7.5	7.25	0.2	1.6	12	-3.3	2.4	0	7.5	7.5
7	6.75	0.1	1	6.5	-2.8	1.1	0	7	7
6.5	6.25	0.1	0.9	5.6	-2.3	0.7	0	6.5	6.5
6	5.75	0.1	0.8	4.7	-1.8	0.4	0	6	6
5.5	5.25	0.1	0.7	3.9	-1.3	0.2	0	5.5	5.5
5	4.75	0.1	0.7	3.2	-0.8	0.1	0	5	5
4.5	4.25	0.1	0.6	2.6	-0.3	0	0	4.5	4.5
4	3.75	0.1	0.5	2	0.2	0	0	4	4
3.5	3.25	0.1	0.5	1.5	0.7	0.1	0	3.5	3.5
3	2.75	0.1	0.4	1.1	1.3	0.2	0	3	3
2.5	2.25	0.1	0.3	0.7	1.8	0.4	0	2.5	2.5
2	1.75	0.1	0.2	0.4	2.3	0.7	0	2	2
1.5	1.25	0.1	0.2	0.2	2.8	1.1	0	1.5	1.5
1	0.75	0.2	0.2	0.1	3.3	2.4	0	1	1
0.5	0.25	3.5	0.9	0.2	3.8	49	0	0.5	0.5
		9.1	36			108			



generally, taken as the moment to rotate a shape around the vertical, Y-axis

d usually, the distance from the neutral axis to the center of a finite element

$I_{XX}$  moment of inertia about the strong axis of a wide flange shape generally, taken as the moment to rotate a shape around the horizontal, X-axis

row 350

row 360

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
	NUMERICAL INTEGRATION for W8 X 31 For $I_{xy}$ about $NA_x$ and $NA_y$																								
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.22	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
6.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
5.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
4.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
3.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.5	0.22	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	11	11	12	

Figure 17-14 An example of conditional formatting.

This is a good example of conditional formatting. It makes this table/calculation easier to read and troubleshoot. Conditional formatting is discussed on the next page and is used in several of the other templates in this manual.

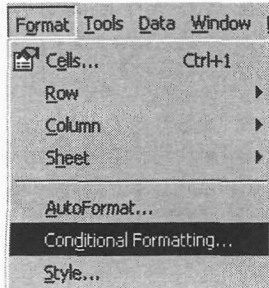
### CONDITIONAL FORMATTING

1	0	0
0.5	0.22	0.2
0	0	0

The 0 values have been formatted to be gray in color which may or may not show well on the printout.  
The non-zero values have been formatted as black, bold on a yellow background which shows well on our HP LaserJet 6P.

row 390

To apply conditional formatting, click on Format and Conditional formatting...



to get →

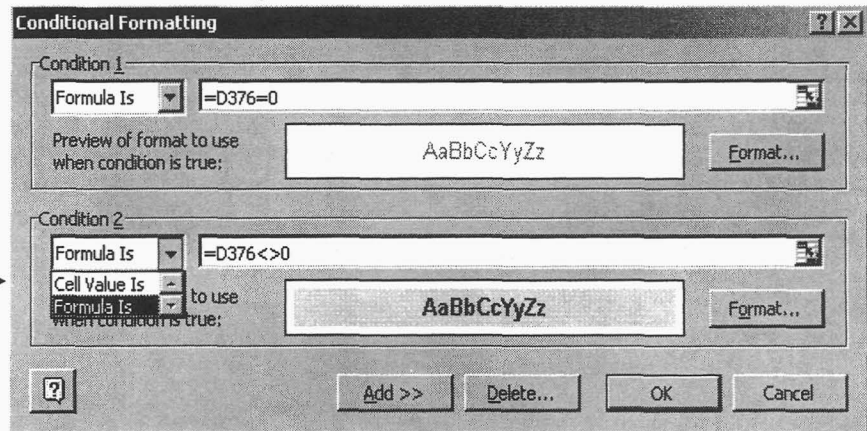


Figure 17-15 Drop down menu.


Figure 17-16 Cascading menu.

row 410

A B C D E F G H I J K L M N O P Q R S T U V W X Y

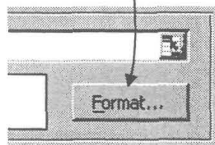
**CONDITIONAL FORMATTING -- Continued**

The cells in the wide flange profile above were formatted using two of the three possible formats in Conditional Formatting. Press **Add>>** for each additional condition and format.

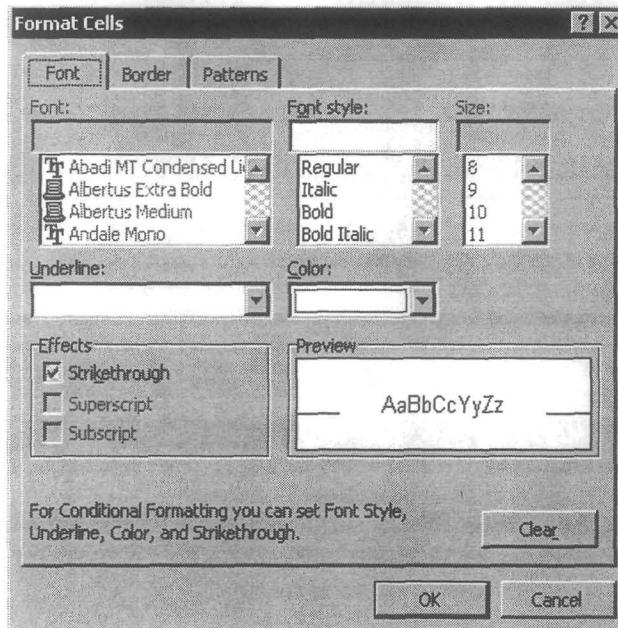
Entering the formula is the tricky part. Click on the  icon and then click on a cell. The values returned will be automatically absolutely referenced. To make these operate as relative references, use your mouse pointer to highlight the spot in front of the \$ and press the **[Backspace]** key.

row 420

To format the cell, press the format button



to get →



row 430

This menu operates more or less like the regular format menu.

row 440

**Figure 17-17** The conditional formatting menu.

row 450

row 460





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A B C D E F G H I J K L M N O P Q R S T U V W X Y AutoCAD MASS PROPERTIES

In AutoCAD, draw the profile of the shape. When done, this must be a closed pline.

Next, use the region command and click on the pline.

Then, use the massprop command to analyze the region.

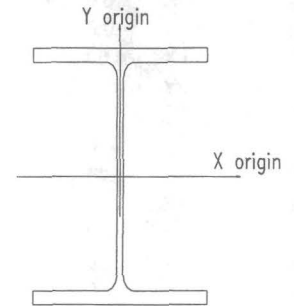


Figure 17-20 The wide-flange profile.

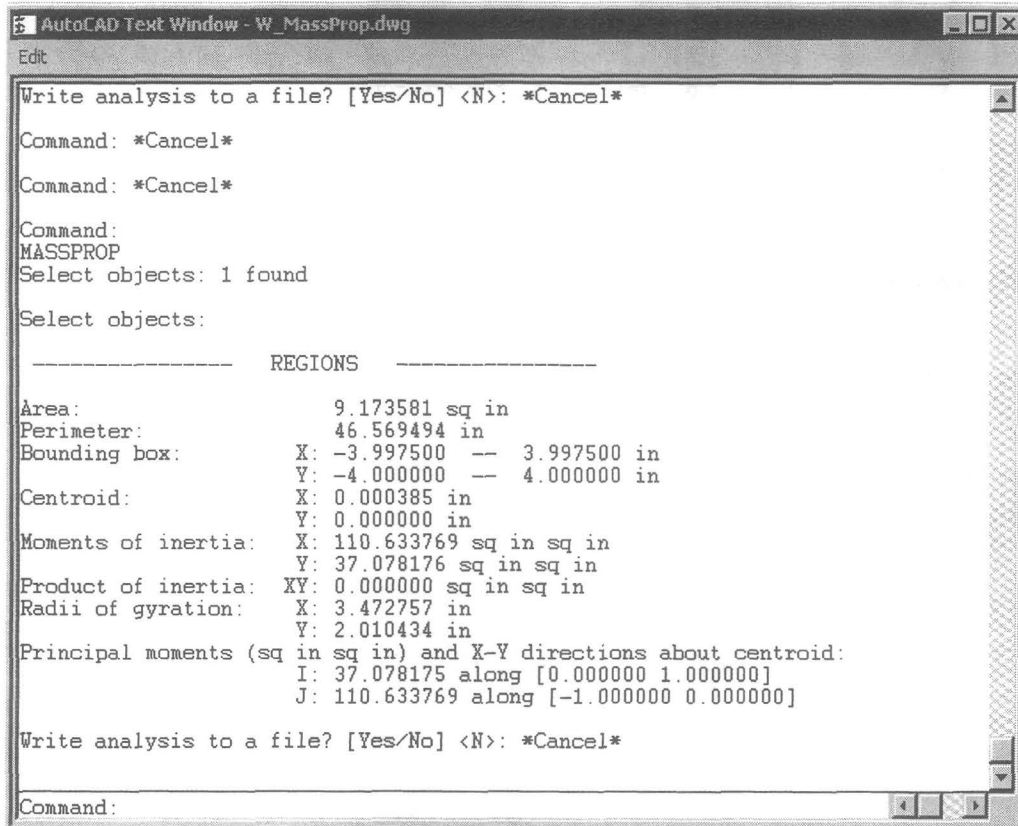


Figure 17-21 The AutoCAD command input window.

You can write the results to an .mpr file.



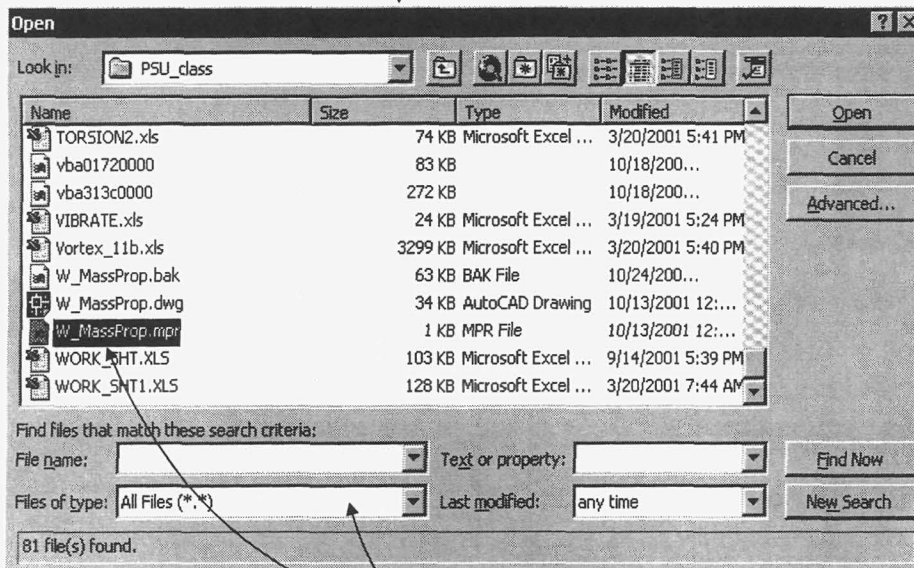
row 530

row 540

row 550

row 560

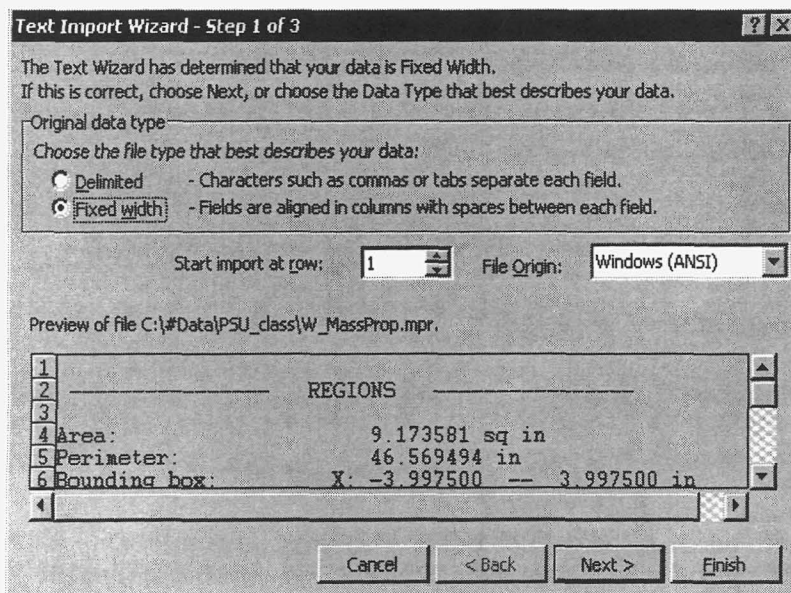
A B C D E F G H I J K L M N O P Q R S T U V W X Y  
AutoCad MASS PROPERTIES -- Continued



- region AutoCad function -- 2D enclosed area
- pline AutoCAD contiguous line made up of straight line and curves
- .mpr filename extension for an AutoCAD ASCII file
- centroid the point upon which a shape can be balanced

row 580

**Figure 17-22** Open the Excel file menu.  
Open the file in Excel under the All Files option.



row 590

row 600

**Figure 17-23** This is the Excel "Text Import Wizard."

row 610

A B C D E F G H I J K L M N O P Q R S T U V W X Y  
AutoCad MASS PROPERTIES -- Continued

Deselect the Tab box

**Text Import Wizard - Step 2 of 3**

This screen lets you set the delimiters your data contains. You can see how your text is affected in the preview below.

Delimiters:  Tab  Semicolon  Comma  Space  Other:

Treat consecutive delimiters as one

Text Qualifier:

Data preview

```

----- REGIONS -----
Area:                9.173581 sq in
Perimeter:           46.569494 in
Bounding box:        X: -3.997500 -- 3.997500 in
    
```

Cancel < Back Next > Finish

**Text Import Wizard - Step 3 of 3**

This screen lets you select each column and set the Data Format.

'General' converts numeric values to numbers, date values to dates, and all remaining values to text.

Column data format:

General  
 Text  
 Date: MDY  
 Do not import column (Skip)

Data preview

```

General
----- REGIONS -----
Area:                9.173581 sq in
Perimeter:           46.569494 in
Bounding box:        X: -3.997500 -- 3.997500 in
    
```

Cancel < Back Next > Finish

Figure 17-24 The step-by-step process.

row 620

row 630

row 640

row 650

row 660



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A B C D E F G H I J K L M N O P Q R S T U V W X Y  
 AutoCad MASS PROPERTIES -- Continued

	A	B	C	D	E	F	G
4	Area:	9.173581 sq in					
5	Perimeter:	46.569494 in					
6	Bounding box:	X: -3.997500 -- 3.997500 in					
7		Y: -4.000000 -- 4.000000 in					
8	Centroid:	X: 0.000385 in					
9		Y: 0.000000 in					
10	Moments of inertia:	X: 110.633769 sq in sq in					
11		Y: 37.078176 sq in sq in					
12	Product of inertia:	XY: 0.000000 sq in sq in					
13	Radii of gyration:	X: 3.472757 in					
14		Y: 2.010434 in					
15	Principal moments (sq in sq in) and X-Y directions about centroid:						
16		I: 37.078175 along [0.000000 1.000000]					
17		J: 110.633769 along [-1.000000 0.000000]					
18							
19							

row 670

row 680

Figure 17-25 Importing text -- this is the resulting spread sheet.

You can save this as an .mpr file or you can copy clip it into your spread sheet to get this result:

```

----- REGIONS -----
Area:                9.173581 sq in
Perimeter:           46.569494 in
Bounding box:        X: -3.997500 -- 3.997500 in
                    Y: -4.000000 -- 4.000000 in
Centroid:            X: 0.000385 in
                    Y: 0.000000 in
Moments of inertia:  X: 110.633769 sq in sq in
                    Y: 37.078176 sq in sq in
Product of inertia:  XY: 0.000000 sq in sq in
Radii of gyration:   X: 3.472757 in
                    Y: 2.010434 in
Principal moments (sq in sq in) and X-Y directions about centroid:
                    I: 37.078175 along [0.000000 1.000000]
                    J: 110.633769 along [-1.000000 0.000000]
  
```

row 690

row 700

Alternatively, you can copy-clip the AutoCAD text window into your spreadsheet.

If your shape is asymmetrical, do a massprop on the region and check the Centroid: values. Move the shape with the move command to the 0, 0 origin of your drawing and do another massprop. If your Centroid: reads 0 and 0 then your values for I<sub>xx</sub> and I<sub>yy</sub> will be about the neutral axes.

row 710

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

**MATRIX MATH**

**In the Beginning**

Solve three equations with three unknowns.

$$\begin{aligned} 2x + 3y - 1z &= -1 && \text{line 1} \\ -1x + 5y + 3z &= -10 && \text{line 2} \\ 3x - 1y - 6z &= 5 && \text{line 3} \end{aligned}$$

Eliminate one of the unknowns:

$$\begin{aligned} 2x + 3y - 1z &= -1 && * 1 \rightarrow 2x + 3y - 1z = -1 \\ -1x + 5y + 3z &= -10 && * 2 \rightarrow -2x + 10y + 6z = -20 \\ 3x - 1y - 6z &= 5 && \\ \hline &&& \text{add to get: } 13y + 5z = -21 \end{aligned}$$

Get another equation and eliminate x again:

$$\begin{aligned} 2x + 3y - 1z &= -1 && \\ -1x + 5y + 3z &= -10 && * 3 \rightarrow -3x + 15y + 9z = -30 \\ 3x - 1y - 6z &= 5 && * 1 \rightarrow 3x - 1y - 6z = 5 \\ \hline &&& \text{add to get: } 14y + 3z = -25 \end{aligned}$$

Combine the two equations with two unknowns:

$$\begin{aligned} 13y + 5z &= -21 && * 3 \rightarrow 39y + 15z = -63 \\ 14y + 3z &= -25 && * 5 \rightarrow 70y + 15z = -125 \\ \hline &&& \text{subtract to get: } 31y = -62 \\ &&& \text{and: } y = -2 \end{aligned}$$

Solve for z:

$$13y + 5z = -21 \rightarrow 13 * -2 + 5z = -21 \rightarrow \text{and: } z = 1$$

To get x:

$$2x + 3y - 1z = -1 \rightarrow 2x + 3 * -2 - 1 * 1 = -1 \rightarrow \text{to get: } x = 3$$

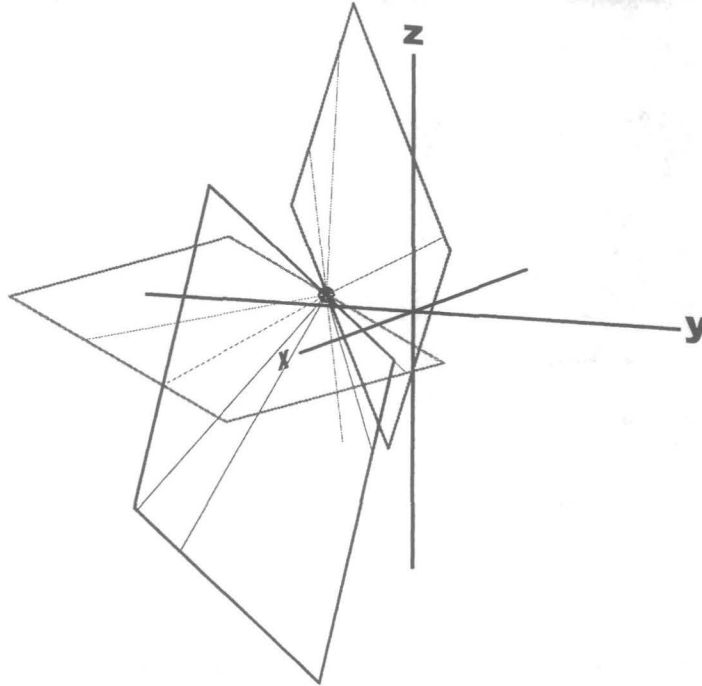


Figure 18-1 The common point of intersecting planes.

These equations each create a family of lines. All of the lines lay within a single plane as determined by that particular equation. The three planes created by the equations intersect at a single, finite point.

The following calculations are used to plot the equations in AutoCad.

				plane 1			plane 2			plane 3		
-1	x	y	z	0.5	x = -0.5	x = -1.5	x = 1.6	x = 10	y = 18	x = -0.67	x = 1.67	y = 4
		-1	-1	y = -1	y = 0	y = 1	y = -1	y = 0	y = 1	y = -1	y = 0	y = 1
3		-1	-6	z = -1	z = 0	z = 1	z = -1	z = 0	z = 1	z = -1	z = 0	z = 1
		1	6									
			-2	x = -1	x = 0	x = 1	x = -1	x = 0	x = 1	x = -1	x = 0	x = 1
			<b>x -0.666667</b>	y = 0	y = -0.33	y = -0.67	y = -1.6	y = -2	y = -2.4	y = -2	y = -5	y = -8
				z = -1	z = 0	z = 1	z = -1	z = 0	z = 1	z = -1	z = 0	z = 1
	x	y	z	x = -1	x = 0	x = 1	x = -1	x = 0	x = 1	x = -1	x = 0	x = 1
	-1	-1	-1	y = -1	y = 0	y = 1	y = -1	y = 0	y = 1	y = -1	y = 0	y = 1
	3	-1	-6	z = -4	z = 1	z = 6	z = -2	z = -3.33	z = -4.67	z = -1.17	z = -0.8	z = -0.5
	-3	1	6									
			2									
			<b>y -2</b>									
	x	y	z									
	-1	-1	-1									
	3	-1	-6									
	-3	1	6									
			7									
			<b>z -1.166667</b>									



# MATRIX MATH

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$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

18 Matrix Math.xls

**MATRIX SOLUTION**

Note that the equations take the form of:

$$\begin{matrix} & \text{matrix} & & \text{constants vector} \\ \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} & \times & \begin{bmatrix} A \\ B \\ C \end{bmatrix} & = & \end{matrix}$$

This matrix is of order 3 x 3.

This matrix is of order 3 x 3.

$$\begin{bmatrix} 2 & 3 & -1 \\ -1 & 5 & 3 \\ 3 & -1 & -6 \end{bmatrix} \times \begin{bmatrix} -1 \\ -10 \\ 5 \end{bmatrix} =$$

To enter a matrix array: use your cursor to outline an area in the shape of the array you want. Enter a formula such as **=minverse(B89:D91)** and press **[Ctrl] [Shift] [Enter]** all at the same time to get **{=MINVERSE(B89:D97)}** in the array of cells. multiply the invert \* constants vector

row 90

The quick solution, as explained below, is:

$$\begin{bmatrix} 0.87097 & -0.61290 & -0.45161 \\ -0.09677 & 0.29032 & 0.16129 \\ 0.45161 & -0.35484 & -0.41935 \end{bmatrix} \times \begin{bmatrix} -1 \\ -10 \\ 5 \end{bmatrix} = \begin{bmatrix} 3x \\ -2y \\ 1z \end{bmatrix}$$

A matrix is a rectangular array of numbers which are called elements. Rows are the first number, columns the second number. Brackets are sometimes omitted.

row 100

A single row matrix is referred to as a "row" or vector matrix. A single column matrix is referred to as a "column" or vector matrix.

Matrices can be multiplied if matrix A has the same number of rows as matrix B has columns.

Note that:  $AB \neq BA$        $AB = C$        $BA \neq C$        $ABC = (AB)C = A(BC)$        $A(B + C) = AB + AC$

**A**  $\times$  **B** = **AB**

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \times \begin{bmatrix} 2 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix} = \begin{bmatrix} 15 & 32 \\ 36 & 77 \end{bmatrix}$$

Calculations:  
 $1 \times 2 + 2 \times 2 + 3 \times 3 = 15$   
 $1 \times 4 + 2 \times 5 + 3 \times 6 = 32$   
 $4 \times 2 + 5 \times 5 + 6 \times 6 = 77$   
 $4 \times 2 + 5 \times 2 + 6 \times 3 = 36$

**B**  $\times$  **A** = **BA**

$$\begin{bmatrix} 2 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix} \times \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} = \begin{bmatrix} 18 & 24 \\ 22 & 29 \\ 27 & 36 \end{bmatrix}$$

Calculations:  
 $2 \times 1 + 4 \times 4 = 18$   
 $30 \times 2 + 4 \times 5 = 24$   
 $36 \times 2 + 3 + 4 \times 6 = 30$   
 $45 \times 2 + 1 + 5 \times 4 = 22$   
 $2 \times 2 + 5 \times 5 = 29$   
 $2 \times 3 + 5 \times 6 = 36$   
 $3 \times 1 + 6 \times 4 = 27$   
 $3 \times 2 + 6 \times 5 = 36$   
 $3 \times 3 + 6 \times 6 = 45$

**A'** the transpose of matrix A

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \times \begin{bmatrix} 1 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix} = \begin{bmatrix} 10 & 32 & 45 \\ 17 & 29 & 36 \end{bmatrix}$$

Calculations:  
 $1 \times 1 + 2 \times 2 + 3 \times 3 = 10$   
 $1 \times 4 + 2 \times 5 + 3 \times 6 = 32$   
 $4 \times 1 + 5 \times 2 + 6 \times 3 = 45$   
 $4 \times 4 + 5 \times 5 + 6 \times 6 = 77$   
 $2 \times 1 + 5 \times 2 + 6 \times 3 = 36$   
 $2 \times 2 + 5 \times 5 + 6 \times 6 = 77$

**A<sup>-1</sup>** the invert of matrix A

$$\begin{bmatrix} 20 & 4 & 6 \\ 4 & 34 & -20 \\ 6 & -20 & 31 \end{bmatrix} \times \begin{bmatrix} 0.063 & -0.023 & -0.027 \\ -0.023 & 0.056 & 0.041 \\ -0.027 & 0.041 & 0.064 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$A^{-1}A = AA^{-1} = I$  unitary matrix

Square Matrix

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

row 130

Symmetrical Matrix

$$\begin{bmatrix} 5 & -1 & -2 \\ -1 & 4 & -6 \\ -2 & -6 & 3 \end{bmatrix}$$

Symmetrical Matrix also shown as

$$\begin{bmatrix} 5 & -1 & -2 \\ -1 & 4 & -6 \\ -2 & -6 & 3 \end{bmatrix}$$

Diagonal Matrix

$$\begin{bmatrix} 5 & 0 & 0 \\ 0 & 6 & 0 \\ 0 & 0 & 7 \end{bmatrix}$$

Unit Matrix

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Note: A' is often denoted as A<sub>1</sub> in this manual because the range name for A' appears as A<sub>1</sub> in Excel. Another notation for A' is At.

row 140

row 150

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

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18 Matrix Math.xls

### 3 x 3 MATRIX -- Circuit Analysis, Longhand Matrix Solution

See the chapter Quadratic and Cubic Equations for the 2 x 2 matrix solution of two straight lines.

This example includes the longhand solution as well as Excel's **inverse** and **mmult** functions.

Determine the current flow in each of the three loops.

The typical use for this application is n equations with n unknowns.

After designating the loop currents, we set up voltage equations around each loop. The current in R<sub>5</sub> is I<sub>1</sub> + I<sub>2</sub> whereas the current in R<sub>6</sub> is I<sub>2</sub> - I<sub>3</sub> when referred to loop 2.

In this model we'll use Maxwell's Method.

- $R_1 * I_1 + R_5 * (I_1 + I_2) + R_4 * (I_1 + I_2) = E_1$
- $R_2 * I_2 + R_5 * (I_3 + I_2) + R_6 * (I_3 + I_2) = E_2$
- $R_3 * I_3 + R_6 * (I_3 + I_2) + R_4 * (I_3 + I_1) = E_3$

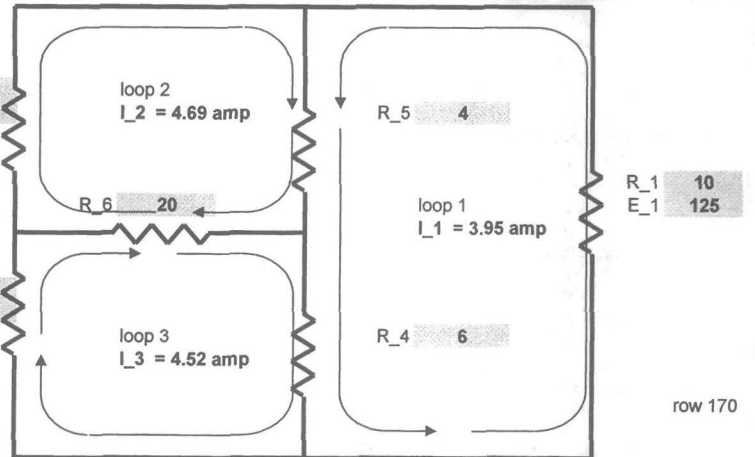


Figure 18-2 Circuit analysis with a 3 x 3 matrix.

**Note:** the underbar    in R<sub>1</sub> is an easy way to show the symbol as a three character variable and makes it easy to create range names with Insert Name Create. Using the symbols R2 or R2, will create range names that are also cell addresses -- not good.

Collect the coefficients of unknowns.

- loop 1  $(R_1 + R_4 + R_5) * I_1 + R_5 * I_2 + R_4 * I_3 = E_1$   
 loop 2  $R_5 * I_1 + (R_2 + R_5 + R_6) * I_2 - R_6 * I_3 = E_2$   
 loop 3  $R_4 * I_1 - R_6 * I_2 + (R_3 + R_4 + R_6) * I_3 = E_3$

The cells in a matrix array may contain equations which reference other inputs or equations.

The matrix for these equations is:

	$(R_1 + R_4 + R_5) * I_1$	+	$R_5 * I_2$	+	$R_4 * I_3$	=	$E_1$								
	$R_5 * I_1$	+	$(R_2 + R_5 + R_6) * I_2$	+	$-R_6 * I_3$	=	$E_2$								
	$R_4 * I_1$	+	$-R_6 * I_2$	+	$(R_3 + R_4 + R_6) * I_3$	=	$E_3$								
loop 1	20 ohms	+	4 ohms	+	6 ohms	=	125 volts								
loop 2	4	+	34	+	-20	=	85								
loop 3	6	+	-20	+	31	=	70								
Laplace expansion	20		34		-20	4		4		-20	6		4		34
			-20		31			6		31			6		-20
+	20	654				4	244				6			-284	
sum	13080					976					-1704				

sum 10400 determinant

Cramer's rule	E	I <sub>2</sub>	I <sub>3</sub>	I <sub>1</sub>	E	I <sub>3</sub>	I <sub>1</sub>	I <sub>2</sub>	E
	125	4	6	20	125	6	20	4	125
	85	34	-20	4	85	-20	4	34	85
	70	-20	31	6	70	31	6	-20	70
		10400 determinant			10400			10400	
+	125	654 = 34 * 31 - 20 * -20		20	4035		20	4080	
		85	-20		4	-20		4	85
		70	31		6	31		6	70
-	4	4035		125	244		4	-230	
		85	34		4	85		4	34
		70	-20		6	70		6	-20
+	6	-4080		6	-230		125	-284	
sum I 1	3.95 amps			sum I 2	4.69 amps		sum I 3	4.52 amps	

where  $3.95 = (125 * 654 - 4 * 4,035 + 6 * -4,080) / 10,400$



$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

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18 Matrix Math.xls

**3 x 3 MATRIX MINVERSE and MMULT Excel Method**

1.  $R_1 \cdot I_1 + R_5 \cdot (I_1 + I_2) + R_4 \cdot (I_1 + I_2)$  E\_1
2.  $R_2 \cdot I_2 + R_5 \cdot (I_3 + I_2) + R_6 \cdot (I_3 + I_2)$  E\_2
3.  $R_3 \cdot I_3 + R_6 \cdot (I_3 + I_2) + R_4 \cdot (I_3 + I_1)$  E\_3

Collect the coefficients of unknowns.

- loop 1  $(R_1 + R_4 + R_5) \cdot I_1 + R_5 \cdot I_2 + R_4 \cdot I_3$  E\_1  
loop 2  $R_5 \cdot I_1 + (R_2 + R_5 + R_6) \cdot I_2 - R_6 \cdot I_3$  E\_2  
loop 3  $R_4 \cdot I_1 - R_6 \cdot I_2 + (R_3 + R_4 + R_6) \cdot I_3$  E\_3

matrix				constants vector	minverse		
20	4	6		125	0.063	-0.023	-0.027
4	34	-20		85	-0.023	0.056	0.041
6	-20	31		70	-0.027	0.041	0.064

mmult
3.95 amps
4.69 amps
4.52 amps

row 230

**4 x 4 MATRIX MODEL Longhand Solution -- not the equation above**

x1	20	4	6	3	125
x2	4	34	-20	14	85
x3	6	-20	31	-26	70
x4	3	25	9	18	6

row 240

Laplace expansion

20	34	-20	14					
	-20	31	-26					
	25	9	18					
34	31	-26	-20	-20	-26	14	-20	31
	9	18		25	18		25	9
+	34	792	-	-20	290	+	14	-955
	26928			-5800			-13370	
20	19358	=	387160					
4	4	-20	14					
	6	31	-26					
	3	9	18					
4	31	-26	-20	6	-26	14	6	31
	9	18		3	18		3	9
+	4	792	-	-20	186	+	14	-39
	3168			-3720			-546	
4	6342	=	25368					
6	4	34	14					
	6	-20	-26					
	3	25	18					
4	-20	-26	34	6	-26	14	6	-20
	25	18		3	18		3	25
+	4	290	-	34	186	+	14	210
	1160			6324			2940	
6	-2224	=	-13344					
3	4	34	-20					
	6	-20	31					
	3	25	9					
4	-20	31	34	6	31	-20	6	-20
	25	9		3	9		3	25
+	4	-955	-	34	-39	+	-20	210
	-3820			-1326			-4200	
3	-6694	=	-20082					

row 250

row 260

row 270

row 280

sum 368530 determinant

sum 368530 using MDETERM() to solve for the determinate of square matrices

row 290



MATRIX MATH

18

Christy  
17:55  
12/20/05

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

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18 Matrix Math.xls

A B C D E F G H I J K L M N  
4 x 4 MATRIX MODEL Longhand Solution -- Continued

Cramer's rule

125	4	6	3
85	34	-20	14
70	-20	31	-26
6	25	9	18

368530 determinant

20	125	6	3
4	85	-20	14
6	70	31	-26
3	6	9	18

368530

row 300

20	4	125	3
4	34	85	14
6	-20	70	-26
3	25	6	18

368530

20	4	6	125
4	34	-20	85
6	-20	31	70
3	25	9	6

368530

		34	-20	14
		-20	31	-26
		25	9	18
+	125	19358		

		85	-20	14
		70	31	-26
		6	9	18
20	101856			

row 310

		85	-20	14
		70	31	-26
		6	9	18
-	4	101856		

		4	-20	14
		6	31	-26
		3	9	18
125	6342			

row 320

		85	34	14
		70	-20	-26
		6	25	18
+	6	2686		

		4	85	14
		6	70	-26
		3	6	18
6	-12582			

		85	34	-20
		70	-20	31
		6	25	9
-	3	-133671		

		4	85	-20
		6	70	31
		3	6	9
3	8571			

sum x1 6.59

sum x2 3.10

row 330

		34	85	14
		-20	70	-26
		25	6	18
20	-2686			

		34	-20	85
		-20	31	70
		25	9	6
20	-133671			

row 340

		4	85	14
		6	70	-26
		3	6	18
4	-12582			

		4	-20	85
		6	31	70
		3	9	6
4	-8571			

row 350

		4	34	14
		6	-20	-26
		3	25	18
125	-2224			

		4	34	85
		6	-20	70
		3	25	6
6	16286			

sum x3 -0.90

sum x4 -4.63

row 360



$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} -4.0 \\ 4.5 \end{bmatrix}$$

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18 Matrix Math.xls

**4 x 4 MATRIX MODEL Using MDETERM**

x1	20	4	6	3	125
x2	4	34	-20	14	85
x3	6	-20	31	-26	70
x4	3	25	9	18	6

determ 368530

34	-20	14	85	-20	14	34	85	14	34	-20	85	row 370
-20	31	-26	70	31	-26	-20	70	-26	-20	31	70	
25	9	18	6	9	18	25	6	18	25	9	6	
125	19358	6.57	20	101856	5.53	20	-2686	-0.15	20	-133671	-7.25	
85	-20	14	4	-20	14	4	85	14	4	-20	85	
70	31	-26	6	31	-26	6	70	-26	6	31	70	
6	9	18	3	9	18	3	6	18	3	9	6	
4	101856	1.11	125	6342	2.15	4	-12582	-0.14	4	-8571	-0.09	
85	34	14	4	85	14	4	34	14	4	34	85	row 380
70	-20	-26	6	70	-26	6	-20	-26	6	-20	70	
6	25	18	3	6	18	3	25	18	3	25	6	
6	2686	0.04	6	-12582	-0.20	125	-2224	-0.75	6	16286	0.27	
85	34	-20	4	85	-20	4	34	85	4	34	-20	
70	-20	31	6	70	31	6	-20	70	6	-20	31	
6	25	9	3	6	9	3	25	6	3	25	9	
3	-133671	-1.09	3	8571	0.07	3	16286	0.13	125	-6694	-2.27	

6.59	3.10	-0.90	-4.63	row 390
------	------	-------	-------	---------

**4 x 4 MATRIX MINVERSE and MMULT Excel Method**

20	4	6	3	125
4	34	-20	14	85
6	-20	31	-26	70
3	25	9	18	6

minverse	0.0525	0.0039	-0.0030	-0.0161	6.59
	-0.0172	0.0396	0.0261	0.0097	3.10
	-0.0060	-0.0154	0.0139	0.0331	-0.90
	0.0182	-0.0480	-0.0427	0.0282	-4.63

20 year old reference books refer to inverting a matrix as computer intensive. row 400  
Now, on a common personal computer, the inversion process is transparent.

row 410

row 420

row 430



**PART 3:**

**RETIREMENT HOME**

**EXHAUST STACK**



# COMMENTS ON CALCULATIONS AND DRAWINGS

Not included on the CD-ROM

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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>COMMENTS</b>													

## Spiral Binder

Keep a spiral binder. Write down notes on your conversations and phone calls and at what time they occurred. Use a date stamp for each day's notes.

Lawyers will tell you that this type of note keeping may be dangerous but, on the other hand, how can you run your life without some sort of record. Remember that your notes and other documents may end up in a hearing or courtroom and write accordingly. You can record personal issues as well. In most jurisdictions, personal notes and notes about other clients can be redacted. Redact items not pertinent to the job by placing a white piece of paper over just the area in question when you are making copies.

row 20

No flip or sarcastic comments should occur in your notes, transmittals, drawings, and calculations. This looks bad to your coworkers and will make you look foolish in a hearing.

## Calculations

You can inundate a plans examiner with too much information. Pare your calculations and organize them for review. This includes creating a table of contents.

If you are designing several columns, you may want to include a comprehensive calculation for the worst case column and summaries for the others.

row 30

## Hate Mail

Keep your language polite. Use the term "in my opinion" or "I believe that --" or other terms that don't commit you to making a statement of fact.

For instance, the contractor's registered engineer has stated that some action of yours has caused a serious delay in construction. This professional engineer is, however, lying to cover his/her own shortcomings and you can prove it. Your letter to the owner will include copies of the appropriate documents with a cover letter that states, "It is my opinion that things are not going well for so-and-so and that some of his comments may be a little out-of-line. Please see my documentation."

row 40

Don't refer to so-and-so as a damned liar who blew it. If the problem ends up in a hearing, and you are wrong, you haven't slandered anyone. Also, you have softened your stance leaving a way for the contractor and the engineer to drop his/her position and get on with the project.

## Documents

Send drawings and calculations in Adobe .PDF format. The program must be purchased from Adobe. This limits the recipient's ability to alter documents and drawings. <http://www.adobe.com>

Some authorities recognize Verisign as an electronic signature. This costs about \$12/year and applies to only one computer which provides a fair amount of certainty that the document was signed by you.

<http://www.verisign.com>

Sometimes a set of of calculations or a spreadsheet template will look good and logical. A few weeks later they may not look good at all. And even if they do, other people may not be able to follow them.

They look good at the moment and sometimes later because you are the one who made them. The information is still in your head or, you're so familiar with certain concepts that you forget that other people may need more explanation.

Know your audience and try to address their needs. Put your creation down for a few hours or days and then review it. It will look different and you will want to edit for clarity and accuracy -- this helps others who must also review or rely on your work.

row 60

If you don't lie, you'll never have to remember exactly what you said to someone.

row 70

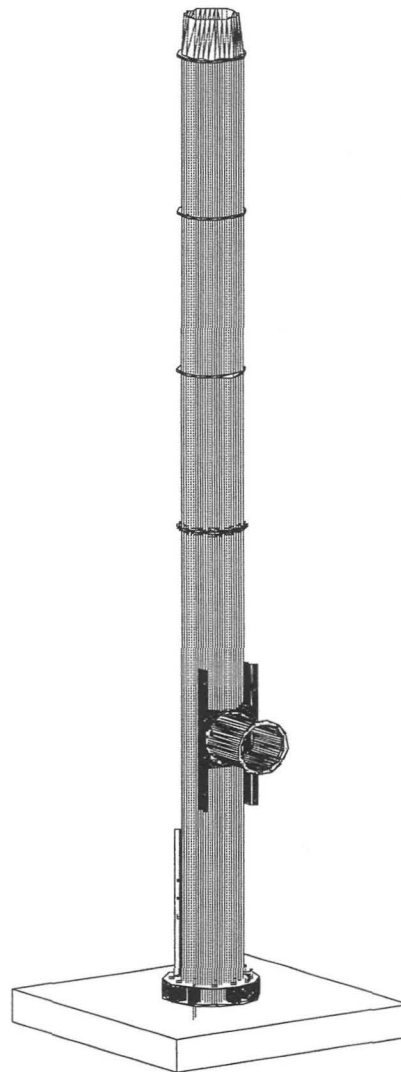
# STRUCTURAL CALCULATIONS

for

# RETIREMENT HOME EXHAUST STACK

Prepared by:  
Craig T. Christy, P.E.  
July 19, 2002

**CONSULTING COMPANY**





# RETIREMENT HOME EXHAUST STACK



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**Note:** Calculations for vortex shedding are adopted from several sources and give varying answers. These calculations bracket the wind speed at which the stack oscillates and the force of those oscillations.



**SEISMIC CALCULATION '97 UBC  
EXHAUST STACK**

**20** Christy

17:55  
12/20/05



20 Seismic.xls

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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>SEISMIC CALCULATION WORKSHEET</b>										V = 0.409 W <sub>Ultimate</sub> = 0.292 W <sub>working stress</sub>			
Z	0.3	unit	← seismic zone factor	Copy clip [Ctrl] [c],		ZONE	1	2A	2B	3	4		
soil	S <sub>D</sub>	← soil profile type	[Ctrl] [v] these values		← Z	0.075	0.15	0.2	0.3	0.4			

into the inputs

Copy clip table values to reduce transcription errors.

Note:  
This worksheet operates in a similar manner to the old fashioned checklist. It uses conditional formatting to highlight the results of your inputs from the logic sieves to guide you and provide documentation for the reviewer.

Remove this logo in the upper left corner and replace it with your own.

SOIL PROFILE TYPE	blows/ft	logic
S <sub>A</sub> Hard rock		0
S <sub>B</sub> Rock	>50	0
S <sub>C</sub> Very dense soil & soft rock	15 to 5	0 row 20
S <sub>D</sub> Stiff soil	<15	5
S <sub>E</sub> Soft soil		0
S <sub>F</sub> Soil requiring evaluation		0
		5

**SEISMIC COEFFICIENT C<sub>A</sub> UBC TABLE 16 Q**

SOIL TYPE	SEISMIC ZONE FACTOR, Z				
	0.075	0.150	0.200	0.300	0.400
S <sub>A</sub>	0.06	0.12	0.16	0.24	0.32
S <sub>B</sub>	0.08	0.15	0.20	0.30	0.40
S <sub>C</sub>	0.09	0.18	0.24	0.33	0.40
S <sub>D</sub>	0.12	0.22	0.28	0.36	0.44
S <sub>E</sub>	0.19	0.30	0.34	0.36	0.36
S <sub>F</sub>	Soil requiring evaluation				

NOTE: C<sub>a</sub> and C<sub>v</sub> are no longer used in the IBC or ASCE 7-02 row 30

C<sub>a</sub> 0.36 unitless

C<sub>a</sub> The coefficient that defines the short period ground motion for structures with a fundamental period < C<sub>v</sub> / 2.5 C<sub>a</sub> . row 40

**SEISMIC COEFFICIENT C<sub>v</sub> 97 UBC TABLE 16 R**

SOIL TYPE	SEISMIC ZONE FACTOR, Z				
	0.075	0.150	0.200	0.300	0.400
S <sub>A</sub>	0.06	0.12	0.16	0.24	0.32
S <sub>B</sub>	0.08	0.15	0.20	0.30	0.40
S <sub>C</sub>	0.13	0.25	0.32	0.45	0.56
S <sub>D</sub>	0.18	0.32	0.40	0.54	0.64
S <sub>E</sub>	0.26	0.50	0.64	0.84	0.96
S <sub>F</sub>	Soil requiring evaluation				

logic  
0  
0  
0  
5  
0 row 50  
0  
5

C<sub>v</sub> 0.54

C<sub>v</sub> The coefficient that defines the longer period constant velocity ground motion.

The first five soil profile types are based upon soil shear wave velocity. Values for S<sub>F</sub> require a soil specific evaluation to establish site coefficients.

row 60

row 70



# SEISMIC CALCULATION '97 UBC EXHAUST STACK

**20** Christy

17:55  
12/20/05



20 Seismic.xls

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**NEAR-SOURCE FACTOR  $N_a$  97 UBC TABLE 16 S ZONE 4 CALCULATION**  $V = 0.409 W_{Ultimate} = 0.292 W_{working stress}$

Distance **5** Km 3.11 miles -- Closest distance to known seismic source in Km  
type **C** Seismic source type

The Zone 4 calculations are not used in this design but are included in this calculation set for future reference.

The near source factors  $N_a$  and  $N_v$  apply to Zone 4 calculations UBC 1628 Symbols and Notations

SEISMIC SOURCE TYPE	CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE (Km)			
	2.00	5.00	10.00	and greater
A	0	1	1	
B	1	0	0	
C	0	1	0	
A	1.50	1.20	1.00	1.00
B	1.30	1.00	1.00	1.00
C	1.00	1.00	1.00	1.00

$N_a$  1.00

**SEISMIC SOURCE TYPE 97 UBC TABLE 16 U**

**A** Faults that can produce large magnitude events and have a high rate of activity

**B** All faults other than A or C

**C** Faults that are not capable of producing large magnitude events and have a low rate of activity

NOTE:  $N_a$  and  $N_v$  are no longer used in the IBC or ASCE 7-02

$N_a$  The acceleration based factor for short period structures

row 80

logic

0

0

4

4

choose

5

10

5

lookup

1

1

5

1

**NEAR-SOURCE FACTOR  $N_v$  97 UBC TABLE 16 T ZONE 4 APPLICATION**

Distance **5** Km 3.11 miles -- Closest distance to known seismic source in Km  
type **C** Seismic source type

SEISMIC SOURCE TYPE	CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE (Km)			
	2.00	5.00	10.00	15.00 and greater
A	0	1	1	1
B	1	0	0	0
C	0	1	0	0
A	2.00	1.60	1.20	1.00
B	1.60	1.20	1.00	1.00
C	1.00	1.00	1.00	1.00

$N_v$  1.00

$N_v$  The velocity based factor for ground motion periods > 1 second

row 100

logic

0

0

4

4

choose

5

10

5

lookup

1

1

5

1

**NEAR-SOURCE CALCULATIONS**

$C_a$  0.36 unitless soil type factor 97 UBC Table 16Q  
 $N_a$  1.00 unitless near source factor from above  
 $C_a * N_a$  0.36 unitless  $C_a * N_a$  in Zone 4 UBC 1628 Symbols  
IF(0.3 zone = 0.4 , 1.00 \* 0.36 , 0.36 )

Check with the local Building Official as to which seismic zone and near source factors may be required.

row 120

$C_v$  0.54 unitless seismic coefficient 97 UBC Table 16R  
 $N_v$  1.00 unitless near source factor from above  
 $C_v * N_v$  0.54 unitless near source factor  $N_v$  used in Zone 4  
IF(0.3 = 0.4 , 0.54 \* 1.00  $N_v$  , 0.54 )  
see UBC 1628 Symbols and Notations

Parts of the Oregon coast have been reclassified to Zone 4. More of western Oregon and Washington may be reclassified to Zone 4 in the future.

row 130



# SEISMIC CALCULATION '97 UBC EXHAUST STACK

**20** Christy

17:55  
12/20/05



20 Seismic.xls

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## SEISMIC CALCULATION WORKSHEET

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Z	soil	0.3	unitless	zone acceleration factor from above				R						
		SD	alpha	soil type	Stiff soil									
R		2.2	unitless	<b>Tanks, vessels or pressurized spheres on braced or unbraced legs</b>										
I		1	unitless	importance factor										
h <sub>n</sub>		75	ft	building height										
C <sub>t</sub>		0.020	unitless	building period factor based upon construction style 97 UBC 1630.2.2				I						
T		0.510	seconds	C <sub>t</sub> * h <sub>n</sub> <sup>0.75</sup> . (30-8) natural period ..										
				0.020 * (75.0 <sup>0.75</sup> )										
V rigid		0.252	*W	0.7 * C <sub>a</sub> * I * W (34-1)				V						
				0.7 * 0.36 * 1.00 * W										
V flexible		0.482	*W	C <sub>v</sub> * I / (R * T) * W (30-4)										
				0.54 * 1.00 / (2.2 * 0.510) * W										
V		0.482	*W	flexible structure ..										
Vmax		0.409	*W	2.5 * C <sub>a</sub> * I / R * W (30-5)										
				2.5 * 0.36 * 1.00 / 2.2 * W										
Vmin		0.040	*W	0.11 * C <sub>a</sub> * I * W (30-6)										
				0.11 * 0.36 * 1.00 * W										
Structure		1	input	0 = building structure 0.8 in (30-7), 1 = non building structure 1.6 in (34-3)										
Vmin_4a		0.202	*W	0.56 * C <sub>a</sub> * I * W (34-2)										
				0.56 * 0.36 * 1.00 * W										
				1 logic										
				for flexible nonbuilding structures 1634.5										
N <sub>v</sub>		1.00	unitless	near source factor for Zone 4 calculations										
Vmin_4b		0.218	*W	0.8 in (30-7), 1.6 in (34-3) * Z * N <sub>v</sub> * I / R * W (34-3)										
				1.6 * 0.30 * 1.00 * 1.00 / 2.2 * W										
zone		0	logic	0.3 = 0.4 is not Zone 4 ..										
V_applied <sub>u</sub>		0.409	*W_ultimate strength	T > 0.06 Flexible nonbuilding structure ..										
V_applied <sub>w</sub>		0.292	*W_working stress	T > 0.06 Flexible nonbuilding structure ..										

Highlight callouts that change frequently

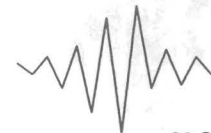
Write out the actual equation maximum lateral force

This concatenated string displays the actual values used

this value sets the lower bounds for long period structures C<sub>a</sub> is multiplied by N<sub>a</sub> in Zone 4 calculations

for non-building structures C<sub>a</sub> is multiplied by N<sub>a</sub> in Zone 4 calculations

Highlight the results in a way that will be eye catching in print. It also helps to include your hand checking in the white space (areas free of print)



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A	B	C	D	E	F	G	H	I	J	K	L	M	N
UBC 1634 Non-Building Structures at Grade										V = 0.409 W_Ultimate = 0.292 W_working stress			
V	0.292 *W applied												

For nonbuilding structures at / or below grade

weight	60000 lbs	gross weight of item
CG	480 in	mass center of gravity
M_ot	8415584 in-lbs	0.292 g * 480.00" * 60,000 lbs
bolt_brg	90 in	bolt to bearing to resist overturning
CG_rt	30.00 in	arm in plan view to cg of gross weight
M_rt	1530000 in-lbs	0.85 * 60,000 lbs* 30.00 in
Bolts t	2	
tension	38253 lbs	( 8,415,584 - 1,530,000 ) in-lbs / 90.00 in / 2 bolts
Bolts v	4	
shear	4383 lbs	0.292 * 60,000 lbs / 4 bolts

For initial estimate of forces on anchor bolts and foundation.

Use a diagram, picture, or drawing to explain something that may not be readily apparent

In this case, most designers don't realize that a large, three legged tank is a flexible structure

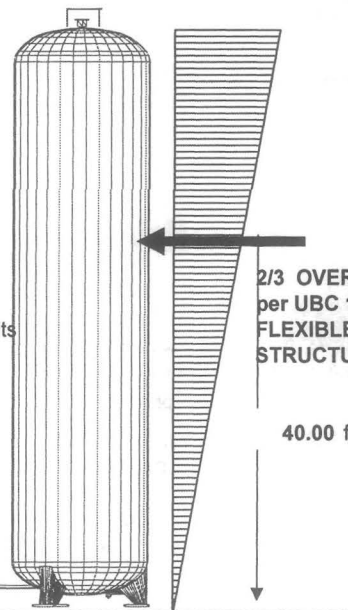


Figure 20-1 FLEXIBLE STRUCTURE

row 200

row 210

row 220

row 230

row 240

row 250

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21 Wind.xls

**WIND '97 UBC**

V<sub>basic</sub> 36 mph basic wind speed per customer specifications  
 Exposure B 2 Exposure and gust factor coefficient B or C 16-G  
 I 1 unitless importance factor 16-K  
 C<sub>q</sub> 0.80 unitless pressure coefficient from Table 16-H  
 h<sub>slab</sub> 2.00 ft from grade to foundation interface to top of foundation

$$P = C_e * C_q * q_s * I$$

**16-F q<sub>s</sub> WIND STAGNATION PRESSURE at STANDARD HEIGHT of 33'**

row 20

Speed mph	70.0	80.0	90.0	100.0	110.0	120.0	130.0	150.0	175.0	basic wind speed
q <sub>s</sub> psf	12.6	16.4	20.8	25.6	31.0	36.9	43.3	57.6	78.4	0.00256 * basic_wind_speed <sup>2</sup> mph

q<sub>s</sub> 3.3 psf wind stagnation pressure, std ht 33', 16-G

**16-K OCCUPANCY CATEGORY**

	I <sub>E</sub>	I <sub>Ep</sub>	I <sub>Wind</sub>
1. ESSENTIAL FACILITIES	1.25	1.5	1.15
2. HAZARDOUS FACILITIES	1.25	1.5	1.15
3. SPECIAL OCCUPANCY	1.0	1.0	1.0
4. STANDARD OCCUPANCY	1.0	1.0	1.0
5. GROUP U	1.0	1.0	1.0

Hydrogen, oxygen, nitrogen, and carbon dioxide all qualify as hazardous materials. This requires a higher importance factor.

**16-H C<sub>q</sub> PRESSURE COEFFICIENTS**

Chimneys, tanks, solid towers

Square or Rectangular	1.4
Hexagonal or octagonal	1.1
Round or elliptical	0.8

**16-G C<sub>e</sub> COMBINED HEIGHT, EXPOSURE, and GUST FACTOR COEFFICIENT**

HEIGHT	Exp_D	Exp_C	Exp_B	w/o C <sub>q</sub>	with C <sub>q</sub>
400	2.34	2.19	1.80	6.0	4.8
300	2.23	2.05	1.63	5.4	4.3
200	2.10	1.87	1.42	4.7	3.8
160	2.02	1.79	1.31	4.4	3.5
120	1.93	1.67	1.20	4.0	3.2
100	1.88	1.61	1.13	3.8	3.0
80	1.81	1.53	1.04	3.5	2.8
60	1.73	1.43	0.95	3.2	2.5
40	1.62	1.31	0.84	2.8	2.2
30	1.54	1.23	0.76	2.5	2.0
25	1.50	1.19	0.72	2.4	1.9
20	1.45	1.13	0.67	2.2	1.8
15	1.39	1.06	0.62	2.1	1.7

top of foundation  
 anchor bolt interface  
 bottom of foundation  
 soil/foundation interface

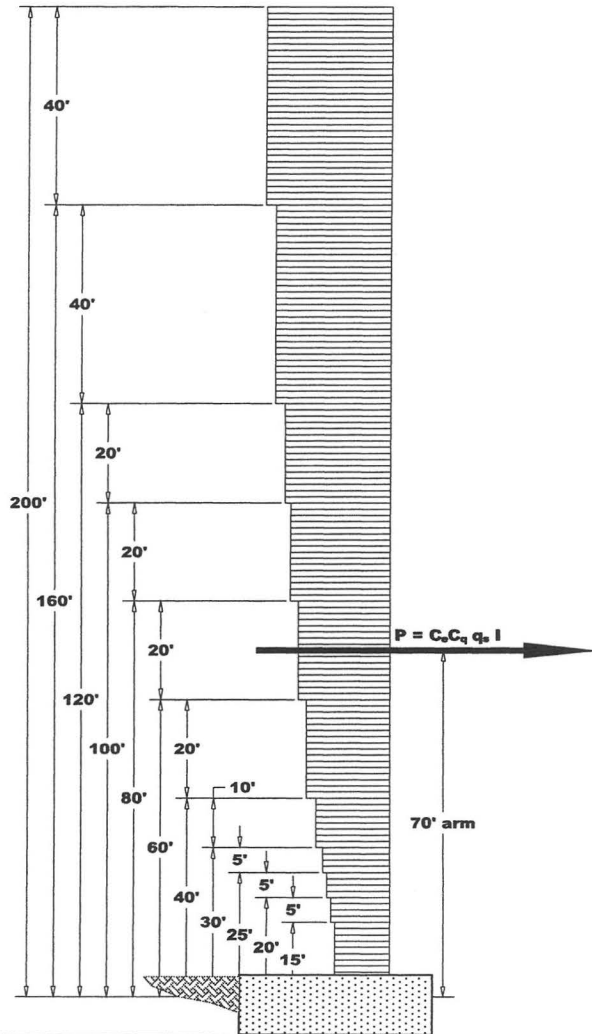


Figure 21-1 Graduated wind force acting on a structure.

row 70



# Wind EXHAUST STACK



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## WIND OVERTURNING -- INCREMENTAL MOMENTS

Heights are taken from the top of the footing

HEIGHT	q psf	ABOUT X-Axis ↑			To the TOP of the footing ↑			To the BOTTOM of the footing ↑	
		ht 1	ht 2	width	force	arm	Mot	arm	Mot
		from bot	to top	along X	about x	about x	about x	about x	about x
400	4.8	300	400	0	0.00	350.00	0.0	352.00	0.0
300	4.3	200	300	0	0.00	250.00	0.0	252.00	0.0
200	3.8	160	200	0	0.00	180.00	0.0	182.00	0.0
160	3.5	120	160	0	0.00	140.00	0.0	142.00	0.0
120	3.2	100	120	0	0.00	110.00	0.0	112.00	0.0
100	3.0	80	100	0	0.00	90.00	0.0	92.00	0.0
80	2.8	60	80	3.5	0.19	70.00	13.6	72.00	14.0
60	2.5	40	60	3.5	0.18	50.00	8.9	52.00	9.2
40	2.2	30	40	3.5	0.08	35.00	2.7	37.00	2.9
30	2.0	25	30	3.5	0.04	27.50	1.0	29.50	1.0
25	1.9	20	25	3.5	0.03	22.50	0.8	24.50	0.8
20	1.8	15	20	3.5	0.03	17.50	0.5	19.50	0.6
15	1.7	0	15	3.5	0.09	7.50	0.7	9.50	0.8

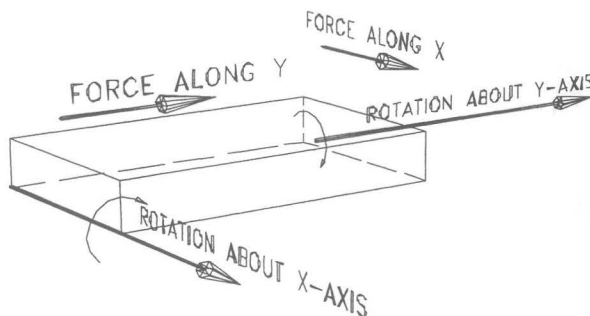
row 80

0.64 k	28.1 k-ft top	1376.00	29.4 k-ft bottom
--------	---------------	---------	------------------

HEIGHT	q psf	ABOUT Y-Axis →			To the TOP of the footing →			To the BOTTOM of the footing →	
		ht 1	ht 2	width	force	arm	Mot	arm	Mot
		from bot	to top	along X	about x	about x	about x	about x	about x
400	4.8	300	400	0	0.00	350.00	0.0	352.00	0.0
300	4.3	200	300	0	0.00	250.00	0.0	252.00	0.0
200	3.8	160	200	0	0.00	180.00	0.0	182.00	0.0
160	3.5	120	160	0	0.00	140.00	0.0	142.00	0.0
120	3.2	100	120	0	0.00	110.00	0.0	112.00	0.0
100	3.0	80	100	0	0.00	90.00	0.0	92.00	0.0
80	2.8	60	80	3.5	0.19	70.00	13.6	72.00	14.0
60	2.5	40	60	3.5	0.18	50.00	8.9	52.00	9.2
40	2.2	30	40	3.5	0.08	35.00	2.7	37.00	2.9
30	2.0	25	30	3.5	0.04	27.50	1.0	29.50	1.0
25	1.9	20	25	3.5	0.03	22.50	0.8	24.50	0.8
20	1.8	15	20	3.5	0.03	17.50	0.5	19.50	0.6
15	1.7	0	15	3.5	0.09	7.50	0.7	9.50	0.8

row 110

0.64 k	28.1 k-ft top	1376.00	29.4 k-ft bottom
--------	---------------	---------	------------------



row 120

Figure 21-2 FOUNDATION SIGNS

row 130



# Wind EXHAUST STACK

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21 Wind.xls

## VERIFICATION OF TABLE VALUES

Determine if published coefficients of  $C_e$  create a smooth line and if these values can generate a formula.

### Published Table Values

Gust Factor Coefficient  $C_e$

HEIGHT	Exp_D	Exp_C	Exp_B
400	2.34	2.19	1.80
300	2.23	2.05	1.63
200	2.10	1.87	1.42
160	2.02	1.79	1.31
120	1.93	1.67	1.20
100	1.88	1.61	1.13
80	1.81	1.53	1.04
60	1.73	1.43	0.95
40	1.62	1.31	0.84
30	1.54	1.23	0.76
25	1.50	1.19	0.72
20	1.45	1.13	0.67
15	1.39	1.06	0.62

$$y = 0.8987x^{0.1597}$$

$$R^2 = 0.9998 =$$

$$y = 0.5824x^{0.2206}$$

$$R^2 = 0.9998 =$$

$$y = 0.252x^{0.3262}$$

$$R^2 = 0.9995 =$$

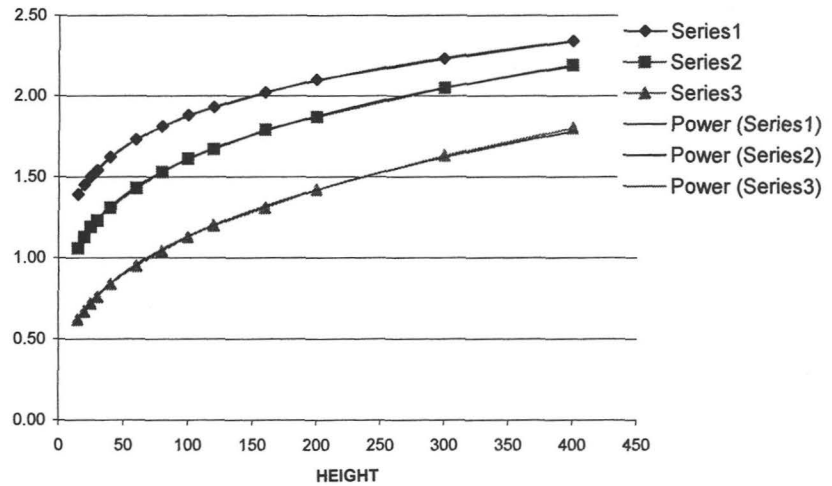


Figure 21-3 TABLE VALUES

### Calculation: Wind Pressure versus Velocity

V	35.6 mph	
P wind	3.3 lb/ft <sup>2</sup>	0.00257 * (V miles/hour) <sup>2</sup>

- $C_e$  Gust Factor Coefficient
- $C_q$  pressure coefficient
- V wind velocity of wind, miles/hour
- P wind pressure of wind, Lbs./ft<sup>2</sup> row 170
- $Q_s$  wind stagnation pressure at standard height
- $q_s$  wind pressure at a designated height, Lbs./ft<sup>2</sup>
- I importance factor
- V\_basic basic wind speed, miles/hour
- Exposure Exposure and gust factor coefficient B, C, or D

row 180

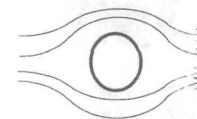
row 190



# VORTEX SHEDDING INTRODUCTION EXHAUST STACK

# 22

Christy  
15:31  
12/20/05



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22 Vortex Intro.xls

## VORTEX SHEDDING INTRODUCTION

A	B	C	D	E	F	G	H	I	J	K	L	M	N
weight	485 lb/ft <sup>3</sup>		weight of steel										
Coefficient of expansion e	6.5E-06 unitless		at 70 to 100 degrees Fahrenheit										
	6.50E-06												
	(6.1 + 0.0019 * t) x 10 <sup>-6</sup>												
t	500 deg F												
e	7.05E-06												row 20
Modulus of elasticity E for carbon steels with C < 0.30%	29000 ksi		at 70 degrees F										
	22400 ksi		at 900 degrees F -- varies linearly and drops off rapidly after 900 degrees F										
E heat	26099 ksi		at 500 degrees F										

F<sub>y</sub> is generally constant from -20 to 650 degrees F

### Suggested Damping

5 %	concrete chimneys	input as:	0.05
3 to 5 %	lined steel stacks		0.03 to 0.05
1 to 2 %	unlined steel stacks		0.01 to 0.02

### Table 1 -- PLATE VALUES

Plate used in fabrication of vessels

per API 620 2002 Table R-4 and  
2.2.3.2 ASTM Specifications

	F <sub>y</sub> yeild ksi	F <sub>t</sub> tensile, ksi	allowable tensile, ksi
A36 modification 2 manganese content to have a range of 0.80 to 1.20% Material shall not be rimmed or capped steel	36	58	16.0
A131 structural quality only	34	58	14.0
A283 grade C maximum thickness of 3/4"	30	55	14.0
A283 grade D maximum thickness of 3/4"	33	60	14.0
A285 grade C only maximum thickness of 3/4"	30	55	16.5
A442	30	55	16.5
A516 grade 55 modification 1 max carbon content 0.20%, max manganese content of 1.50%	32	60	18.0
A516 modification 2 max carbon content 0.20%, max manganese content of 0.70 to 1.40%, max silicon 0.50%, steel shall be normalized			
A537 carbon 0.20%, manganese 0.85 to 1.60%, max thickness 1 1/2"	50	70	21.0
A573 grade 58	32	58	16.0
A633 grades C and D	50	70	17.8
A662 grade B	40	65	19.5
A662 grade C	43	70	21.0
A678 grade A max thickness 1 1/2"	50	70	17.8
A678 grade B max thickness 2 1/2"	60	80	20.3
A737 grade B max thickness 2 1/2"	50	70	21.0

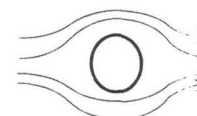
Where API note 4 includes a 0.92 quality factor for plate used as structural material.  
Use 20 plf additional weight for ladders and stiffeners.



# VORTEX SHEDDING INTRODUCTION EXHAUST STACK

# 22

Christy  
15:31  
12/20/05



22 Vortex Intro.xls

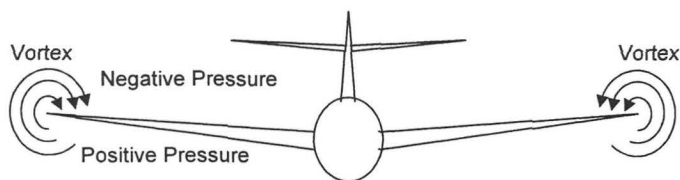
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A	B	C	D	E	F	G	H	I	J	K	L	M	N
---	---	---	---	---	---	---	---	---	---	---	---	---	---

**Reference**

<p><i>PRESSURE VESSEL DESIGN HANDBOOK</i> Copyright 1986 reprinted 1991 Krieger Publishing 2nd ed. PVDH</p>	<p>Before you design a tall stack or process vessel, you must secure your own references.</p>
<p><i>GUIDE FOR STEEL STACK DESIGN AND CONSTRUCTION</i> Sheet Metal and Air Conditioning Contractors' National Association Inc. SMACNA 1996 <a href="http://www.smacna.org">http://www.smacna.org</a></p>	<p>With the assistance of this template, you will need two to five days to design a stack with a critical aspect ratio. This time includes your learning curve. This estimate may be optimistic.</p>
<p><i>DESIGN of PROCESS EQUIPMENT</i> Pressure Vessel Handbook Publishing, Inc. Kanti K. Mahajan 1990 DPE</p>	<p>If you breeze through this process you risk leaving 10,000 to 20,000 lbs of material on the ground. <span style="float: right;">row 80</span></p>
<p><i>DESIGN and CONSTRUCTION of LARGE, WELDED, LOW-PRESSURE STORAGE TANKS</i> API Standard 620, Tenth Edition, February 2002 American Petroleum Institute API</p>	<p>Stacks typically fail at 15 to 30 mph of wind which provides a steady-state flow so that the stack can vibrate like a reed in the wind. Winds above 60 mph usually blow as gusts.</p>
<p><i>Formulas for Stress and Strain</i> Fifth Edition Raymond J. Roark, Warren C. Young McGraw-Hill Book Company</p>	<p>The different references in this template reflect different philosophies, research, and experience. No reference will generate an exact, guaranteed answer. The best approach is to bracket your answers. The calculations in this template will provide comparisons, where to look in your references, and some assurance that your design is reasonable. <span style="float: right;">row 90</span></p>
	<p>In designing anchor bolts and bolt rings, a conservative, shotgun approach saves design time by using more concrete and steel. This is an economical trade-off. The body of the stack, however, is a different matter. Design with care. <span style="float: right;">row 100</span></p>



This is the type of vortex that most of us are familiar with.

Figure 22-1 Vortex created at aircraft wingtips.

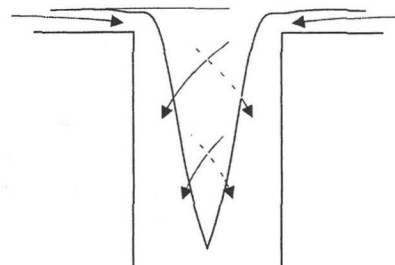


Figure 22-2 Vortex created by water down the drain.

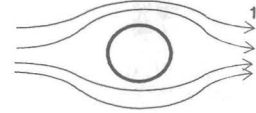
row 110

row 120

row 130



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK



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23 Vortex Shedding.xls

A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>SUMMARY</b>													

Wind	150 mph	per the customer
Seismic	0.511 g <sub>ult</sub>	zone 3, importance factor 1.25 E/ 1.15 W, R 2.2, C <sub>a</sub> 0.36
	0.365 g <sub>working</sub>	
soil	2000 psf	estimated
L	62.5 ft	height of stack/structure from TANK inputs
D	3.500 ft	max stack diameter at CL of plate
E	26099 ksi	modulus of elasticity at operating temperature
corrosion	1/16 inch	corrosion allowance per ICE and NTS
t	500 deg F	
e	7.05E-06	coefficient of expansion, unitless
E heat	26099 ksi	at 500 degrees F

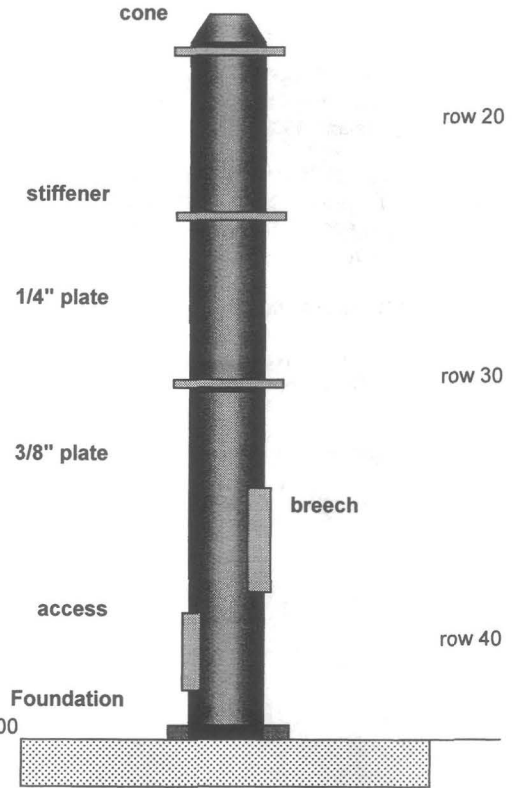


Figure 23-1 ELEVATION VIEW

**Results Following PVDH Guidelines**

W	6.944 k	gross weight of structure
Using method of superposition and incremental moments		
M wind	344.7 k-ft	
d wind	4.27 in	
M seismic	124.3 k-ft wk'g	
d seismic	1.22 inch	
T <sub>n</sub>	0.334 cycles/sec	natural, resonant frequency of structure
f <sub>n</sub>	2.991 Hz	1 / T <sub>n</sub> frequency
V <sub>wind</sub>	15.0 mph	possible vortex shedding wind speed where R <sub>e</sub> < 50,000
V <sub>wind</sub>	35.6 mph	vortex shedding per resonant frequency of structure
M <sub>res1</sub>	536.1 k-ft	vortex induced moment at 35.6 mph and foundation magnification factor of 60 at 1 ft above base / top of bolting ring <b>USE THIS MOMENT IN DESIGN</b>

**Results Following DPE Guidelines**

W <sub>s</sub>	5.208 k	corroded weight of stack
K <sub>1'</sub>	0.136 unitless	ratio of force to structure weight
K <sub>1''</sub>	13.320 unitless	ratio of force to structure weight and modulus 13.320 > 1/15 CHECK CANTILEVER VIBRATION
D <sub>cantilever</sub>	2.03 inch	amplified deflection
M vortex	165.0 k-ft	vortex induced moment

**Ovaling**

f <sub>n</sub>	4.33 cycle/sec	SMACNA	<a href="http://www.smacna.org">http://www.smacna.org</a>
f <sub>oval</sub>	13.66 cycle/sec	PVDH	
fr <sub>oval</sub>	10.29 cycle/sec	DPE	

row 50

row 60

row 70



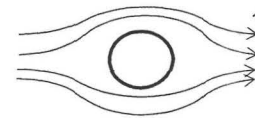
# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK

# 23

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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>TANK / STACK DESIGN PVDH</b>													
L	62.5 ft	height of stack/structure from TANK inputs		PVDH pg 120									
D	3.500 ft	max stack diameter at CL of plate											
E	29500 ksi	modulus of elasticity											
Aspect	17.9 !!!	L/D for unlined steel stack <= 13 vibrational analysis not required											
		L/D for lined steel stack <= 15 vibrational analysis not required											
		L/D for process columns <= 15 vibrational analysis not required											
W <sub>DL+LL</sub>	6.944 k	estimated total weight -- this value used in calculations											
factor	9.1 !!!	W / (h * D <sup>2</sup> ) * 1000											
		W / (h * D <sup>2</sup> ) <= 20 vibration analysis MUST be performed											
		20 < W / (h * D <sup>2</sup> ) <= 25 vibration analysis SHOULD BE PERFORMED											
		25 < W / (h * D <sup>2</sup> ) * 1000 vibration analysis NEED NOT be performed											
W <sub>DL only</sub>	6.944 k												
	9.1 !!!												
corrosion	0.063 inch	corrosion allowance											

**METHOD OF SUPERPOSITION FOR WIND DEFLECTION PVDH PAGE 103**

unit wt	0.111 k/ft		for reference		running		M_Wind	
	ht 1	ht 2	width	t_PL	wind	sum	sum	k-ft
	from bot	to top	ft	inch	psf	k	k	
k	120	150	0	0	0.0	0.000	0.000	0.0
j	100	120	0	0	0.0	0.000	0.000	0.0
i	80	100	0	0	0.0	0.000	0.000	0.0
h	60	80	0	0	0.0	0.000	0.000	0.0
g	40	62.5	3.5	0.25	54.9	4.326	4.326	221.7
f	30	40	3.5	0.25	48.6	1.700	6.026	59.5
e	25	30	3.5	0.375	43.9	0.769	6.795	21.1
d	20	25	3.5	0.375	41.6	0.729	7.524	16.4
c	15	20	3.5	0.375	38.7	0.678	8.202	11.9
b	1	15	3.5	0.375	35.9	1.757	9.958	14.1
a	0	1	3.5	0.375	35.9	0.125	10.084	0.1
						<b>10.084</b>		<b>345</b>
								<b>k-ft</b>
								<b>working</b>

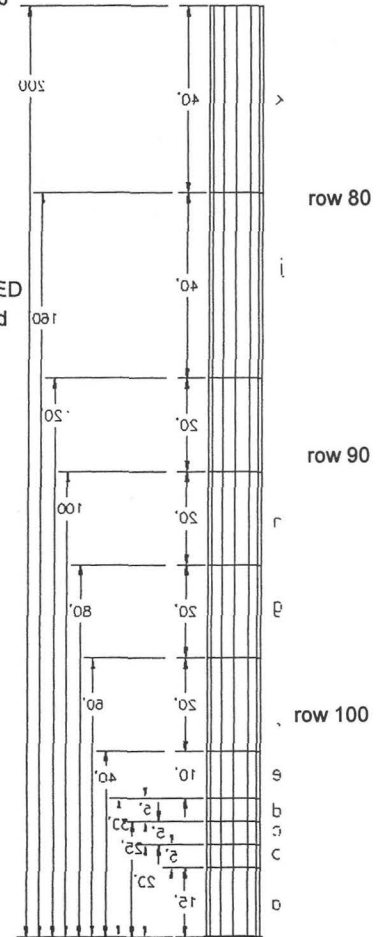


Figure 23-2 ELEVATION VIEW

**WIND Incremental Moments**

Wind	150 mph		maximum wind speed							sum row
	ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft
k	0	0.0								0.0
j	0	0.0	0.0							0.0
i	0	0.0	0.0	0.0						0.0
h	0	0.0	0.0	0.0	0.0					0.0
g	22.5	48.7	0.0	0.0	0.0	0.0				48.7
f	10	8.5	91.9	0.0	0.0	0.0	0.0			100.4
e	5	1.9	17.0	113.6	0.0	0.0	0.0	0.0		132.5
d	5	1.8	5.8	25.5	135.2	0.0	0.0	0.0		168.3
c	5	1.7	5.5	9.6	34.0	156.8	0.0	0.0	0	207.6
b	14	12.3	11.2	15.7	20.4	57.8	161.1	0.0	0	278.5
a at base	1	0.1	14.1	11.9	16.4	21.1	61.2	221.7	0.0	346.4
footing	2.00	0	0.2	17.6	13.2	17.9	21.1	62.9	230.4	363.2
L structure	62.5 ft									k-ft

row 130



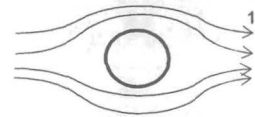
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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>WIND Lateral Deflections</b>														
		corrosion allowance	Area	segment <sup>2</sup> l	y_incr EI	d_W	d_Q	d_M	delta	theta	theta	theta	theta	
		inch	ft <sup>2</sup>	ft <sup>4</sup>	1/k	ft	ft	ft	sum 1	theta W	theta Q	theta M	theta sum 2	
										1/k	ft	ft	ft	
k		0.0625	0.00	0.00	0	0.0000	0.0000	0.0000	0.000	0	0	0	0	0
j		0.0625	0.00	0.00	0	0.0000	0.0000	0.0000	0.000	0	0	0.00	0	0
i		0.0625	0.00	0.00	0	0.0000	0.0000	0.0000	0.000	0	0	0.00	0	0
h		0.0625	0.00	0.00	0	0.0000	0.0000	0.0000	0.000	0	0	0.00	0	0
g		0.0625	0.17	0.26	0.000453	0.0055	0.0147	0.0110	0.031	0.000453	0.007	0.01	0.022	0.04355
f		0.0625	0.17	0.26	8.95E-05	0.0002	0.0018	0.0045	0.006	0.000291	8E-04	0.00	0.029	0.03306
e		0.0625	0.29	0.44	1.34E-05	0.0000	0.0002	0.0009	0.001	0.000101	6E-05	0.00	0.013	0.01534
d		0.0625	0.29	0.44	1.34E-05	0.0000	0.0002	0.0011	0.001	0.000114	7E-05	0.00	0.019	0.02167
c		0.0625	0.29	0.44	1.34E-05	0.0000	0.0002	0.0014	0.002	0.000128	7E-05	0.01	0.026	0.03602
b		0.0625	0.29	0.44	0.000105	0.0003	0.0049	0.0147	0.020	0.000462	0.002	0.00	0.129	0.13296
a		0.0625	0.29	0.44	5.37E-07	0.0000	0.0000	0.0001	0.000	3.36E-05	7E-07	0.00	0.012	0.01163
									0.062 ft				sum 2	0.29423

I used in the following calculations

sum 1 + sum 2 **0.36 ft**  
**4.27 in**

**METHOD OF SUPERPOSITION for SEISMIC DEFLECTION PVDH pg 103**

Seismic	0.511 g_ultimate	
E <sub>ASD</sub>	0.365 g_working	Seismic /1.4
t	0.1875 in	corroded plate thickness
W <sub>DL+LL</sub>	6.944 k	estimated total weight from above -- this value used in calculations
w	0.111 k/ft	W <sub>DL+LL</sub> / height
T <sub>n</sub>	0.380 sec/cycle	0.00000765 * (Height / d) <sup>2</sup> * (w * d / t) <sup>0.5</sup> DPE value
V	2.5 k	E <sub>ASD</sub> * W <sub>DL+LL</sub>
	0.041 k/ft	V / L
F <sub>t</sub>	0.1 k	0.07 * T <sub>n</sub> * V
F	2.5 k	V - F <sub>t</sub>
	0.039 k/ft	F / L

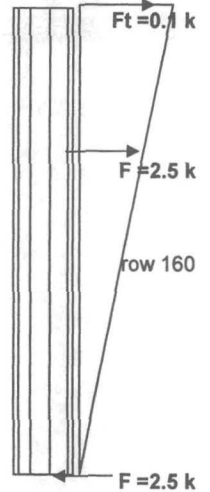


Figure 23-3 SEISMIC LOADING

	ht 1	ht 2	mean width	t_PL	Seismic mass	wh	wh	sum	running sum	M_Seismic		
	from bot	to top	ft	inch	w	k-ft	unitless	k	k-ft	k-ft		
F <sub>t</sub>								0.1	0.1	10.12		
k	120	150	0	0	0.000	0.0	0.000	0.0	0.1	0	0	0
j	100	120	0	0	0.000	0.0	0.000	0.0	0.1	0	0	0
i	80	100	0	0	0.000	0.0	0.000	0.0	0.1	0	0	0
h	60	80	0	0	0.000	0.0	0.000	0.0	0.1	0	0	0
g	40	62.5	3.5	0.25	2.500	128.1	0.529	1.3	1.4	66.94	22.5	78.75
f	30	40	3.5	0.25	1.111	38.9	0.161	0.4	1.8	13.9	10	35
e	25	30	3.5	0.375	0.833	22.9	0.095	0.2	2.0	6.4	5	17.5
d	20	25	3.5	0.375	0.833	18.7	0.077	0.2	2.2	4.3	5	17.5
c	15	20	3.5	0.375	0.833	14.6	0.060	0.1	2.3	2.6	5	17.5
b	1	15	3.5	0.375	2.333	18.7	0.077	0.2	2.5	1.5	14	49
a	0	1	3.5	0.375	0.167	0.1	0.000	0.0	2.5	0.0	1	3.5
					8.610	242.0	1.000	2.5				

mean diameter  
**106 k-ft ult**  
**76 k-ft wk'g**

row 190



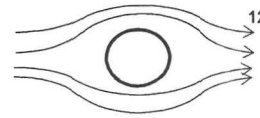
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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>SEISMIC Incremental Moments</b>														
		ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft	k-ft				k-ft
F <sub>t</sub>			0.0											0.0
k		0	0.0	0.0										0.0
j		0	0.0	0.0	0.0									0.0
i		0	0.0	0.0	0.0	0.0								0.0
h		0	0.0	0.0	0.0	0.0	0.0							0.0
g		22.5	14.7	0.0	0.0	0.0	0.0	1.5						16.2
f		10	2.0	27.8	0.0	0.0	0.0	0.0	2.2					31.9
e		5	0.6	4.0	34.3	0.0	0.0	0.0	0.0	2.5				41.4
d		5	0.5	1.8	5.9	40.8	0.0	0.0	0.0	0.0	2.87			51.9
c		5	0.4	1.4	2.9	7.9	47.3	0.0	0.0	0.0	0	3.21		63.2
b		14	1.3	2.5	4.1	6.2	13.5	48.7	0.0	0.0	0	0	4.15	80.4
a		1	0.0	1.5	2.6	4.3	6.4	38.3	66.9	0.0	0	0	0	124.3
		62.5												4.22

<b>SEISMIC Lateral Deflections</b>													row 210
	Area	I corroded	segment <sup>2</sup>	y_incr	d_W	d_Q	d_M	delta	theta	theta	theta	theta	
	ft <sup>2</sup>	ft <sup>4</sup>	1/k	ft	ft	ft	ft	sum	1/k	W	Q	M	sum
F <sub>t</sub>	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0000	0.00	0.00	0
k	0.00	0.00	0	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0000	0.00	0.00	0
j	0.00	0.00	0	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0000	0.00	0.00	0
i	0.00	0.00	0	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0000	0.00	0.00	0
h	0.00	0.00	0	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0000	0.00	0.00	0
g	0.23	0.26	0.000453	0.0017	0.0044	0.0037	0.0098	0.000453	0.0022	0.00	0.01	0.014	
f	0.23	0.26	8.95E-05	0.0000	0.0001	0.0014	0.0016	0.000291	0.0002	0.00	0.01	0.01	row 220
e	0.34	0.44	1.34E-05	0.0000	0.0000	0.0003	0.0003	0.000101	0.0000	0.00	0.00	0.004	
d	0.34	0.44	1.34E-05	0.0000	0.0000	0.0003	0.0004	0.000114	0.0000	0.00	0.01	0.006	
c	0.34	0.44	1.34E-05	0.0000	0.0000	0.0004	0.0004	0.000128	0.0000	0.00	0.01	0.008	
b	0.34	0.44	0.000105	0.0000	0.0001	0.0042	0.0044	0.000462	0.0002	0.00	0.04	0.037	
a	0.34	0.44	5.37E-07	0.0000	0.0000	0.0000	0.0000	3.36E-05	0.0000	0.00	0.00	0.004	
						sum 1		0.0168 ft					0.085 ft
													0.101 ft
													1.218 in
													row 230

row 240

row 250



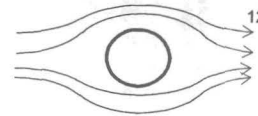
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## THE NATURAL FREQUENCY $T_n$ OF A STRUCTURE .....

W\_input 1 0 = default, 1 = input

Conjugate Beam Method for calculating  $T_n$   
PVDH pg 123

	volume in <sup>3</sup>	default	W input	weight
k	0	0.0	0.0	0.000
j	0	0.0	0.0	0.000
i	0	0.0	0.0	0.000
h	0	0.0	0.0	0.000
g	8906	2.5	1.8	1.801
f	3958	1.1	0.8	0.789
e	2969	0.8	0.6	0.645
d	2969	0.8	0.6	0.645
c	2969	0.8	0.6	0.645
b	8313	2.4	2.0	1.965
a	594	0.2	0.2	0.200
base		8.7	6.7	6.690 k

row 260

	dx ft	M k-ft											sum M's		
k	0	0											0		
j	0	0											0		
i	0	0	0										0		
h	0	0	0	0									0		
g	11.25	0	0	0	0						0				
f	16.25	25	0	0	0	0					25				
e	7.5	9	46	0	0	0	0				56				
d	5	4	14	57	0	0	0	0				76			
c	5	3	7	18	66	0	0	0	0			95			
b	9.5	5	8	12	24	79	0	0	0	0			128		
a	7.5	17	10	13	17	31	95	0	0	0	0			183	
base	1.5	1	26	13	16	20	34	103	0	0	0	0			213

	I corroded plate		segment	dx	M dx/l k/ft <sup>2</sup>	running sum	M dx <sup>2</sup> /l k/ft	running sum	Wy		Wy <sup>2</sup> k-in <sup>2</sup>
	from above ft <sup>4</sup>	M/l k/ft <sup>3</sup>							y ft	k-in	
k	0.00	0	0					627509.7	0.000	0	0
j	0.00	0	0	0	0	13454	0	627509.7	0.000	0	0
i	0.00	0	0	0	0	13454	0	627510	0.000	0	0
h	0.00	0	0	0	0	13454	0	627510	0.000	1.399	0
g	0.26	94	22.5	11.25	530	13454	151360	627510	0.148	0.867	2.48034
f	0.26	211	10	16.25	2480	12925	214328	476150	0.112	0.477	1.16634
e	0.44	173	5	7.5	1439	10445	87636	261822	0.062	0.317	0.35265
d	0.44	217	5	5	974	9006	48627	174185	0.041	0.697	0.15609
c	0.44	292	5	5	1272	8031	42592	125559	0.030	0.047	0.24721
b	0.44	418	14	9.5	3370	6759	70255	82966	0.020	0.24	0.01099
a	0.44	486	1	7.5	3390	3390	12711	12711	0.003		0.00862
base									sum Wy 4.044		

$T_n$	0.334 sec/cycle	$2 * \pi * (\text{sumWy}^2 / (g * \text{sumWy}))^{0.5}$
$f_n$	2.991 Hz	

sum Wy<sup>2</sup> 4.42224

Check  $T_n$  Against Simple Formula .....

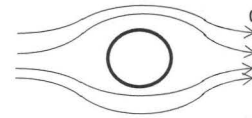
$t$	0.1875 in	plate thickness from row 156 above
$w$	0.111 k/ft	

$T_n$	0.380 sec/cycle	$0.0000027 * (\text{Height} / d)^2 * (w / t)^{0.5}$
-------	-----------------	---

simplified calculation for uniform shell  
PVDH pg 121

$f_n$	2.629 Hz	to compare with 2.991 above
-------	----------	-----------------------------

row 310



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**VORTEX SHEDDING and FORCES on the CYLINDER PVDH**

Note: the drag coefficient varies from 0.9 to 1.1 at low  $R_e$  values.  
At  $R_e$  values greater than  $5 \times 10^5$  the drag coefficient drops to 0.3 to 0.5.

$R_e$  = Reynolds number  
first critical velocity -- consider winds below 60 mph only  
0.20 is the dimensionless Strouhal number for  
 $R_e$  between  $10^3$  to  $10^5$   
PVDH pg 112 & DPE pg 246

**First Check**

V_wind	15.0 mph	velocity of air
V_wind	22 ft/sec	
$\rho_{air}$	2.40E-03 lb-sec <sup>2</sup> /ft <sup>4</sup>	air mass density
d_mean	3.5 ft	diameter of cylinder
m_air	3.80E-07 lb-sec/ft <sup>2</sup>	viscosity of air
$R_e$	4.86E+05 unitless	$r_{air} * V_{wind} * d_{mean} / m_{air}$

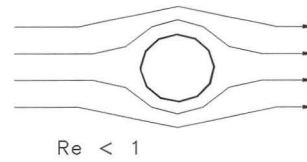
where  $R_e < 5 \times 10^5$  is critical in vortex shedding

**!!! vortex shedding at 15.0 mph per Re**

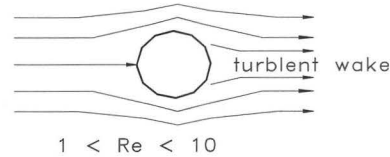
**Second Check**

V_wind	30.0 mph	
V_wind	44 ft/sec	
$R_e$	9.73E+05 unitless	not critical at 30.0 mph per Re

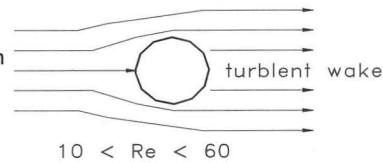
V applied	15.0 mph	velocity of air
$q_{wind}$	0.58 lb/ft <sup>2</sup>	$0.00257 * (V \text{ mph})^2$ generic wind pressure calculation
q	0.58 lb/ft <sup>2</sup>	$\rho_{air} * V^2 / 2$ acting on the front of the stack
$C_D$	1.0	coefficient of drag drops to about 0.5 at $R_e > 10^5$
D	0.58 lb/ft <sup>2</sup>	$C_D * \rho_{air} * V^2 / 2$ parallel to air flow
$C_L$	0.6	coefficient of lift
$L_-$	0.35 lb/ft <sup>2</sup>	$C_L * \rho_{air} * V^2 / 2$ force on stack at critical wind velocity



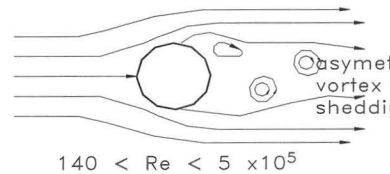
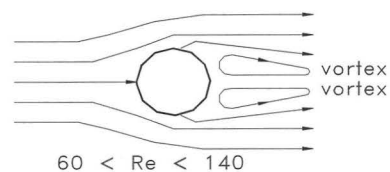
row 320



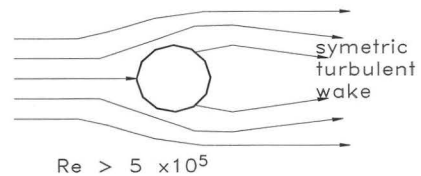
row 330



row 340



row 350



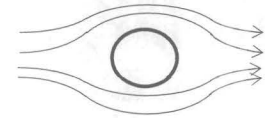
row 360

**Figure 23-4 Vortex shedding and Reynolds numbers; vortex periodicity vanishes at  $R_e > 5 \times 10^5$**

PVDH page 117 and DPE page 246  
M.F. Table 4.3 PVDH

row 370

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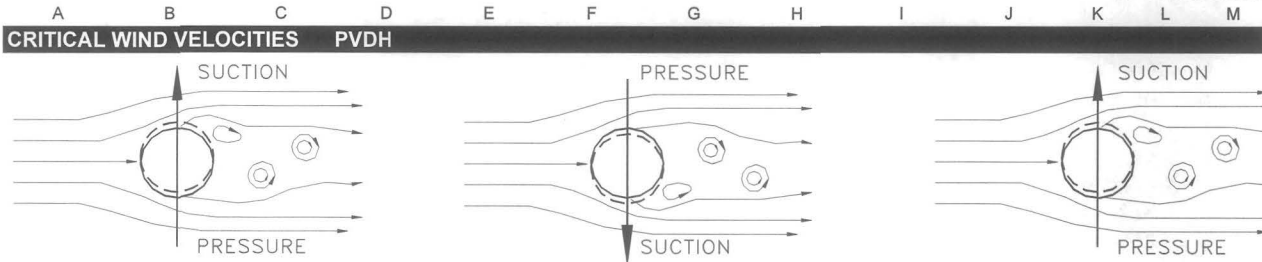


Figure 23-5 VORTEX SHEDDING -- TRANSVERSE VIBRATION

$S = f_v d / V$                       Strouhal number  
 substitute  $f = 1/T_n$  for  $f_v$   
 $S = f T_n d / V$   
 $V = d / T_n / S$

For values of  $R_e$  of 140 to 50000 and  $S = 0.18$  to  $0.21$ ,  
 the first critical velocity is:  
 $V = d / T_n / 0.2 = 5 d / T_n$  fps  
 $V = 3600 \text{ sec/hour} / 5280 \text{ ft/mile} * 5 d / T_n = 3.41 d / T_n$  miles/hour

- d logarithmic decrement for damping
- M.F. magnification factor, conservatively  $p / d$
- S dimensionless parameter, Strouhal number
- $f_v$  shedding frequency of vortices, Hz
- d diameter of cylinder perpendicular to wind flow, ft
- V wind velocity, ft/sec
- V\_1 first critical velocity at which vortex shedding frequency equals the natural frequency of the structure

d_mean	3.50 ft	mean stack diameter from row 187 above
V_1	35.6 mph	$3.4 * d\_mean / T_n$ ←
	52.2 ft/sec	$3.4 * 3.50 / 0.334$
	35.6 < 60 mph by -69 %	
	35.6 < 150 mph by -322 %	

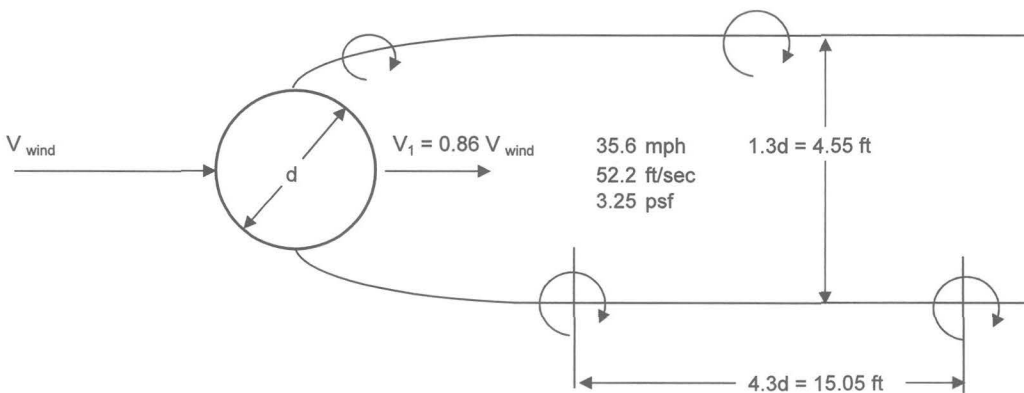


Figure 23-6 VORTEX SHEDDING

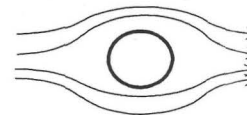
**V\_2**                      **222.4 mph**                       $6.25 * V_1$  second critical velocity  
 222.4 > 60 mph by 73 %  
 222.4 > 150 mph by 33 %



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK

# 23

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## OVERTURNING MOMENT with FOUNDATION MAGNIFICATION FACTOR

### Table 23 - 1 -- DAMPING AND MAGNIFICATION FACTORS

#### Footing Average Values

	Soft Soils		Stiff Soils		PVDH Rock, Very Stiff Soils	
	d	M.F. max	d	M.F. max	d	M.F. max
Tall Process Columns	0.126	25	0.080	39	0.052	60
Unlined Stacks	0.105	30	0.052	60	0.035	90
Lined Stacks	0.314	10	0.105	30	0.070	45

row 440

Height **62.5 ft** from row 72 above  
M.F. **60** foundation magnification factor  
 $C_L$  **0.6** coefficient of lift

L 117.63 lb/ft<sup>2</sup>  $C_L * M.F. * \rho_{air} * (V_1 * 5280/3600)^2 / 2$   
for  $V_1$  in mph

$F_1$  **8.58 k**  $L * d * Height / 3 / 1000$  lb/k  
force acting at top of stack

$M_{res1}$  **536.1 k-ft** Height \*  $F_1$  at 35.6 mph  
 $M_{wind} 345 < M_{Resonance} 536$  k-ft **GOVERNS**

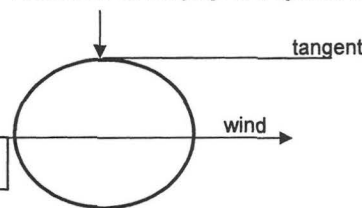
$h$  **2.00 ft** depth of footing from input above  
 $M_{res1 ftg}$  **553 k-ft**

$F_2$  335 k  
 $M_{res2}$  20940 k-ft Height \*  $F_2$  at 222.4 mph  
This is not of interest when  $V_2$  is above 60 mph

A substantial amount of force is generated perpendicular to the direction of the wind. You can observe this in your car's solid radio antenna. At various speeds the antenna will wave side to side and sometimes the motion will be circular which is a combination of back and forth whipping and side to side whipping.

$C_L$  coefficient of lift generally 0.4 to 0.6 where 0.6 is conservative

L pressure transverse to the wind direction at resonance on the projected cylinder area, psf



row 450

Figure 23-7 TRANSVERSE FORCE

row 460

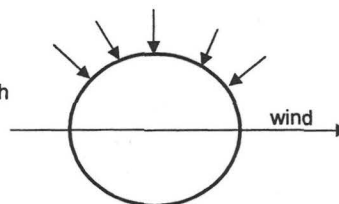


Figure 23-8 NORMAL FORCE

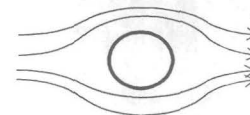
row 470

row 480

row 490



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK



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## CANTILEVER VIBRATION DPE

Ovaling calculations and vortex shedding are based upon the plate thickness at the top of the stack. Shell thickness is determined at locations where plate thickness changes with the appropriate moments and loads at those levels.

f	2.991 Hertz	natural frequency from calculations above
V <sub>c</sub>	35.59 mph	3.41 * f * D <sub>r</sub> 3.41 * 2.991 Hz * 3.490 ft

DPE page 246

V <sub>30</sub>	150 mph	from above
L <sub>effective</sub>	62.5 ft	from above
V <sub>w</sub>	167 mph	V <sub>30</sub> * (L/30) <sup>0.143</sup>
V <sub>w</sub> max	195 mph	1.3 * V <sub>30</sub>
V <sub>w</sub>	167 mph	minimum (V <sub>w</sub> , V <sub>w</sub> max)

For values of R<sub>e</sub> of 140 to 50000 and S = 0.18 to 0.21, the first critical velocity is: row 500  
 $V = d / T_n / 0.2 = 5 d / T_n$  fps  
 $V = 3600 \text{ sec/hour} / 5280 \text{ ft/mile} * 5 d / T_n = 3.41 d / T_n$ , miles/hour

The weight of the stack should be equal to or greater than the corroded weight of the stack plus refractory lining (which reduces vibration frequency) DPE 247.

V<sub>c</sub> critical wind velocity, mph  
V<sub>w</sub> maximum wind velocity, mph  
V<sub>30</sub> wind velocity at 30 ft above grade, mph

D <sub>r</sub>	3.49 ft	average diameter at the top of the stack
W <sub>s</sub>	5.208 k	weight of corroded stack including attachments say 3/4 * 6.944 k

K<sub>1</sub> ratio of critical wind velocity to weight of stack, unitless row 510  
Use refractory lining as part of weight to help reduce vibration.

Q <sub>critical</sub>	3.3 lb/ft <sup>2</sup>	0.00257 * V <sub>c</sub> <sup>2</sup> 0.029884
-----------------------	------------------------	---

L<sub>e</sub> effective length of stack  
E Youngs modulus of elasticity, ksi  
Q<sub>critical</sub> P<sub>critical</sub> in DPE, pressure at critical wind velocity, psf

K <sub>1</sub> '	0.136 unitless	Q <sub>critical</sub> * D <sub>r</sub> * L <sub>e</sub> / W <sub>s</sub> / 1000 lb/k 3.3 * 3.49 * 62.5 / 5.208 / 1000
E	29500 ksi	from above
K <sub>1</sub> ''	13.320 unitless	0.0077 * D <sub>r</sub> <sup>5</sup> * E / (L <sub>e</sub> <sup>3</sup> * W <sub>s</sub> ) * 144 in <sup>2</sup> / ft <sup>2</sup> 0.0077 * 3.49 <sup>5</sup> * 29,500 / (62.5 <sup>3</sup> * 5.208) * 144

unit analysis

lb	ft	ft	1000	k
ft <sup>2</sup>		k		lb
ft <sup>5</sup>	k	1	1	144 in <sup>2</sup>
	in <sup>2</sup>	ft <sup>3</sup>	k	ft <sup>2</sup>

K <sub>1</sub> limit	13.320 unitless	1/15 ratio
----------------------	-----------------	------------

**13.320 > 1/15 CHECK CANTILEVER VIBRATION**

row 530

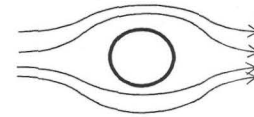
NOTE: This flag operates using IF statements.

row 540

row 550



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK



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**DEFLECTION CALCULATED AS STATIC DEFLECTION DPE**

$I_s$       **0.260** ft<sup>4</sup>      see calculations at row 135 above  
moment at top half of stack

$D_s$       0.034 in       $q_{critical} * D_r * L_e^4 / (8 * E * 1000 \text{ lb/k} * I_{top}) * 12 / 1000$  static deflection  
 $3.26 * 3.49 * 62.5^4 / (8 * 29,500 * 1000 * 0.260) * 12 / 1000$

unit analysis

$$\frac{\text{lb/ft}^2 \cdot \text{ft}}{\text{k/in}^2} \cdot \frac{\text{ft}^4}{\text{ft}^4} = \frac{\text{lb}}{\text{ft}^2} \cdot \frac{\text{in}^2}{\text{k}} \cdot \frac{\text{ft}}{\text{ft}^4}$$

row 560

$$= \frac{\text{lb}}{\text{k}} \cdot \frac{\text{in}^2}{\text{ft}} \cdot \frac{\text{k}}{1000 \text{ lb}} \cdot \frac{\text{ft}}{12 \text{ in}} = \frac{\text{in}}{1000} \cdot \frac{12}{1000} = \text{in}$$

M.F.      60 unitless      magnification factor from Table 23-1 above.

$D_{cantilever}$	<b>2.03</b> inch	amplitude of vibration	←	$D_{cantilever} w L^4 / (8 E I)$
------------------	------------------	------------------------	---	----------------------------------

Ratio PDVH wind incremental deflection to DPE resonant deflection and multiply PDVH incremental wind moment. row 570

M vortex	<b>165.0</b> k-ft	2.03" / 4.27" * 346.4 k-ft
----------	-------------------	----------------------------

**Damping Stability**

Table 23 - 2 – LOGARITHMIC DECREMENTS FOR DIFFERENT TYPES OF STRUCTURES

Type of Construction	Lining	Decrement d		
Welded	None	0.03		
Welded	Gunite	0.05		
Welded	Tower Full of Water	0.07		
Riveted	Brick	0.05		

row 580

$\epsilon_{damping}$       **0.03** unitless      damping factor for type of structure      DPE page 264

$D_r$       **3.490** ft      average internal diameter of top half of stack

$W$       **6.9** k      from above row 590

$L$       **62.5** ft      over all height

$D_F$       **0.27 !!!**       $We / (LD_r^2)$        $D_F < 0.75$  unstable  
 $6.9 \text{ k} * 1000 * 0.03 / (62.5 \text{ ft} * 3.490^2)$        $0.75 < D_F < 0.95$   
 $D_F > 0.95$

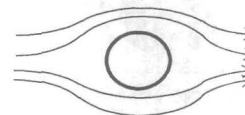
$$\frac{\text{k}}{\text{k}} \cdot \frac{1000 \text{ lb}}{\text{k}} \cdot \text{unitless} \cdot \frac{1}{\text{ft}} \cdot \frac{1}{\text{ft}^2}$$

row 600

row 610



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK



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## ALLOWABLE SHELL BUCKLING STRESS Bottom Shell

E_heat	26099 ksi	E approximated for heat	
Fy_heat	36 ksi	Fy approximated for heat	
Sc_1	18.00 ksi	Fy /2	DPE page 242
D_Mean	3.500 ft	mean stack diameter from row 187 above	
t_shell	0.3125 in	t shell for corroded plate	
ratio_c	0.00446	t_shell /D_Mean	
	0 logic	t_shell /D_Mean < 0.00425	row 620
ratio_c	0.00425		
Sc_2	15.93 ksi	0.56 * ratio_c * E' / (1+ 0.004 * E' /Fy')	where ratio_c = min(t_shell /D_Mean, 0.00425)
limit compression stress to (0.85 weld efficiency) * (Fy at temperature) / (FS = 2)			
Sc_3	15.30 ksi	0.85 * Fy' /2	
Sc	15.30 ksi	allowable shell stress	

## Required Shell Thickness

Wt	6.690 k		DPE page 242
M	536.1 k-ft	vortex shedding	
tr	0.3068 in	(Wt * D_mean + 48 * M) / (p * D_mean <sup>2</sup> * Sc)	Required plate thickness to resist DL + LL + M wind or seismic

## Check Against P/A + Mc/I .....

W_sum	6.690 k	P	
M_wind	346.4 k-ft	wind calculated per traditional method above	row 640
M_vortex	536.1 k-ft		
M_gov	536.1 k-ft	M_wind 345 < M_Resonance 536 k-ft	
D_sect	41.625 in	diameter at centerline of shell plate	
t_shell	0.3125 in	PL 3/8 corroded plate at base	
A_sect	40.87 in <sup>2</sup>		
I_sect	0.43 ft <sup>4</sup>		
q	P/A	Mc/I	15.290 ksi
	0.164	15.127	-14.963 ksi
	1 logic		
	Sc > q OK		row 650
	Sc 15.30 > q 15.290 ksi required OK...		

## Vibration Analysis for the Life of the Structure

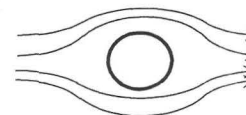
Fu	60 ksi		PVDH page 118
n	5		
K	780000		
SR	36 ksi	SR = 2 S	row 660

## Table 23 - 3 -- TYPE of CONSTRUCTION b FACTOR

β	1.20	shell with a smooth finish	
β	1.80	butt-weld joints	
β	3.00	fillet weld or incomplete penetration groove weld with root unsealed	
N	9.24E+35 cycles	(K /b SR) <sup>n</sup>	
Tn	0.380 sec/cycle		
Le	9.76E+31 hours	N * Tn /3600 seconds /hour	
	1.11E+28 years		row 670



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**ALLOWABLE SHELL BUCKLING STRESS Top Shell**

A	B	C	D	E	F	G	H	I	J	K	L	M	N
E_heat	26099	ksi	E	approximated for heat									
Fy_heat	36	ksi	Fy	approximated for heat									
Sc_1	18.00	ksi	Fy / 2	DPE page 242									
D_Mean	3.500	ft	mean stack diameter from row 247 above										
t_shell	0.1875	in	t shell for corroded plate										
ratio_c	0.05357		t_shell / D_Mean										
	0	logic	t_shell / D_Mean < 0.00425	row 680									
ratio_c	0.00425												
Sc_2	15.93	ksi	0.56 * ratio_c * E' / (1 + 0.004 * E' / Fy') where ratio_c = min(t_shell / D_Mean, 0.00425)										
limit compression stress to (0.85 weld efficiency) * (Fy at temperature) / (FS = 2)													
Sc_3	15.30	ksi	0.85 * Fy' / 2										
Sc	15.30	ksi	allowable shell stress										

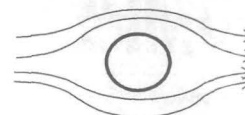
**Check Against P/A + Mc/l .....** row 690

W_sum	6.690	k	P										
M_wind	132	k-ft	wind calculated per traditional method above										
M_vortex	205.0	k-ft	M_wind 0 < M_Resonance 536 k-ft										
M_gov	205.0	k-ft											
D_sect	41.75	in	diameter at centerline of shell plate										
t_shell	0.3125	in	PL 3/8 corroded plate at base										
A_sect	40.99	in <sup>2</sup>											
I_sect	0.43	ft <sup>4</sup>											
q	P/A	Mc/l	5.913	ksi									
	0.163	5.750	-5.587	ksi									
	1 logic												
	Sc > q OK												
	Sc 15.30 > q 5.913 ksi required OK...												

row 710

row 720

row 730



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### OVALING SMACNA

The SMACNA calculation is a fundamental calculation demonstrating the roots of the ovaling calculations. Other calculations do not include the units or background for some of the numbers used. This may be because some of these calculations are empirical or the factors are a series of calculations that have been boiled down for ease of use.

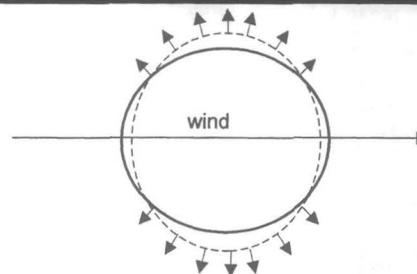


Figure 23-9 OVALING

The entire SMACNA calculation is:

$$f_n = \frac{2n(n^2 - 1)}{p D^2 \sqrt{r(n^2 + 1)}} \sqrt{\frac{E I}{A}}$$

This calculation is broken up for construction and trouble shooting purposes.

$$f = 1 / 2p (k * g / W)^{0.5} \text{ for a mass on the free end of a spring, other end fixed}$$

$$T = 1/f$$

Unit analysis is used here to document the results.

n	2 unitless	mode of vibration		
t_x	0.1875 in	corroded plate thickness		
b	10 in	arbitrary starting point for the estimation of a built-up member compression flange		

A PL	1.875 in <sup>2</sup>			
I PL	0.001030 in <sup>4</sup>	10 * 0.1875 * 0.1875 <sup>3</sup> / 12		
E heat	26099 k/in <sup>2</sup>			
num <sub>2</sub>	119.74 lb <sup>0.5</sup>	$(\frac{E\_heat\_ * 1000 * I\_Plate}{A\_PL})^{0.5}$	$\frac{26099 \text{ k}}{\text{in}^2} \frac{1000 \text{ lb}}{\text{k}} 0.00103 \text{ in}^4$	$\frac{1}{1.875 \text{ in}^2}$

r	15.06 lb-sec <sup>2</sup> / ft <sup>4</sup>	$\frac{485 \text{ lb}}{\text{ft}^3} \frac{\text{sec}^2 \text{ mass}}{32.2 \text{ ft}}$		
r <sup>0.5</sup>	3.88 lb <sup>0.5</sup> -sec / ft <sup>2</sup>			
d_mean	3.490 ft	diameter of section under consideration from above		
d_mean <sup>2</sup>	12.180 ft <sup>2</sup>			

num <sub>1</sub>	1.708 unitless	$\frac{2 * n * (n^2 - 1)}{2 * 2 * (2^2 - 1)}$	$\frac{1}{(PI() * (n^2 + 1)^{0.5})}$	$\frac{1}{(PI() * (2^2 + 1)^{0.5})}$
f <sub>n</sub>	4.33 cycle/sec	1.708 num <sub>1</sub> unit	$\frac{1}{12.180 \text{ ft}^2}$	$\frac{119.74 \text{ num}_2 \text{ lb}^{0.5}}{3.88 \text{ lb}^{0.5}\text{-sec}}$

k	spring constant, lb/in
g	gravity, 386 in/sec <sup>2</sup> , 32.2 ft/sec <sup>2</sup>
W	weight, lbs
mass	W / g, lb-sec <sup>2</sup> / in
f	frequency, cycle/sec, Hertz
T	period, seconds/cycle
p	pi, pi(), 3.14 unitless
num	numerator
den	denominator



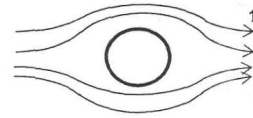
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A B C D E F G H I J K L M N

**OVALING PVDH**

t PL **0.1875** in corroded shell thickness PVDH page 119  
m 0.000136 lb-sec<sup>2</sup>/in /in = lb-sec<sup>2</sup>/in<sup>2</sup> mass lb-sec<sup>2</sup>/in  
mass per unit length of ring  
485 lb/in<sup>3</sup> /1728 in<sup>3</sup>/ft<sup>3</sup> \* 0.1875 /386 in/sec<sup>2</sup>

R 20.94 in radius to centerline of shell

T\_oval 0.073 sec/cycle  $2 * \pi / 2.68 * (m * R^4 / (E_{heat} * 1000 * I_{Plate}))^{0.5}$  row 800  
 $2 * \pi / 2.68 * (0.000136 * 20.94^4 / (26,099 * 1000 * 0.001030))^{0.5}$   
 $\left( \begin{matrix} \text{lb-sec}^2 & \text{in}^4 & \text{in}^2 & \text{k} & 1 \\ \text{in}^2 & & & 1000 \text{ lb} & \text{in}^4 \end{matrix} \right)^{1/2}$

f oval 13.66 Hz 1 / T\_oval

V\_1oval **81.0** mph  $3.4 * d_{mean} / (2 * T_{oval})$

V\_1oval' **60.2** mph  $1120 * t_x / d_{mean}$

row 810

**OVALING DPE**

fr\_oval **10.29** Hz  $7.85 * t_x * E_{heat}^{0.5} / (60 * D_{mean}^2)$  DPE page 249  
 $7.85 * 0.1875 * 26,099^{0.5} / (60 * 3.50^2)$

T 0.097 sec/cycle

Design to 66 fps = 45 mph

fv **3.782** Hz  $0.2 * (V = 66 \text{ fps}) / D_{mean}$

T 0.264 sec/cycle

row 820

critical 1 logic fv < 2 \* fr\_oval  
**!!! Stiffening rings required**

S dimensionless parameter, Strouhal number usually 0.18 to 0.22 in this range of Reynolds (Re) numbers

V<sub>o</sub> 5386.4 fpm  $60 * f_r * D / (2 * S)$   
89.8 fps  
61.2 mph

H<sub>r</sub> spacing between rings, ft  
V<sub>o</sub> critical ovaling velocity, fpm, feet/minute

H<sub>r</sub> **16.00** ft spacing between rings

S<sub>t</sub> 15.30 ksi from above

S<sub>m</sub> **0.259** in<sup>3</sup> required section modulus at ring

row 830

b 11.25 in  $60 * t_x$  rule of thumb for plate deck

S<sub>plate</sub> **0.066** in<sup>3</sup>  
critical 1 logic S<sub>plate</sub> < S<sub>m</sub>  
**!!! Stiffening rings required**

**OVALING**

V design **45** mph

q 5.20 lb/ft<sup>2</sup>  $0.00257 * V^2 / 2$

row 840

Radius 1.745 ft

M max 4.98 lb-ft/ft  $0.314 * q * \text{Radius}^2$

S req'd **0.062** in<sup>3</sup> for stiffener spacing = 16.0 ft

ROARK -- APPROXIMATE A PARTIALLY LOADED RING

row 850



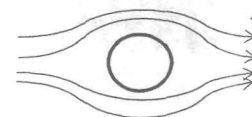
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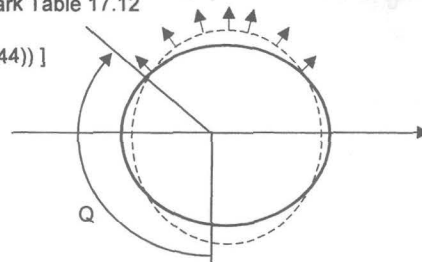
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**ROARK -- APPROXIMATE A PARTIALLY LOADED RING**

Θ	2.44 radians													
	140 degrees	Q / p 180												
M	7.21 lb-ft/ft	$2.5 * 5.20 * 1.745^2 * [ 2.44 / \text{PI}() * (1 + \text{COS}(2.44)) ]$												
S req'd	0.090 in <sup>3</sup>	$7.21 * 12 / 15.30 / 1000 * 16.00$ for stiffener spacing = 16.0 ft												

Roark Table 17.12



wind

row 860

Figure 23-10 OVALING ESTIMATE

**STIFFENER DESIGN**

t'	0.1875 in	corroded thickness
f'	15.3 ksi	

shooting method to achieve convergence for b

row 870

where  $b = 253 * t / f^{0.5} * (1 - 50.3 / ((be / t) * f^{0.5}))$  as in the flange of a rectangular section

be	1.875	2.765	2.967	3.083	3.156	3.205	3.239	3.262	3.278
b	-3.468	1.554	2.273	2.643	2.863	3.005	3.099	3.163	3.208

Calculate L without accounting for fillet and rounded toes -- values will be the same as AISC

L t	0.125
L Length	2 in
L Flange	2 in
L A	0.484375 in <sup>2</sup>

	arm	area	q
Length	1.0000	0.250	0.250
Flange	1.9375	0.234	0.454
		q sum	0.704
CG x	1.454 in	from left fiber of L vertical leg	

	A	d	d <sup>2</sup>	Ad <sup>2</sup>	I
Length	0.250	0.454	0.206	0.051	0.083
Flange	0.234	0.484	0.234	0.055	0.000
			sum I	0.190 in <sup>4</sup>	

	A	cg x	I	A cg	d	A d <sup>2</sup>
L	0.484	1.454	0.190	0.795	0.857	0.584
PL	0.602	0.09375	0.001762	0.056	0.690	0.027
Area	1.086 in <sup>2</sup>		cg	0.784 in		
				I sum	0.803 in <sup>4</sup>	

S tension	0.936 in <sup>3</sup>	I / d right
S_compr	-1.163 in <sup>3</sup>	I / d left

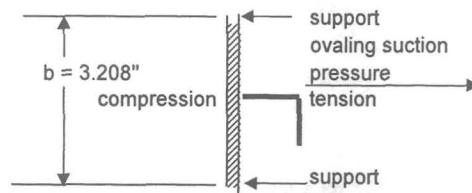
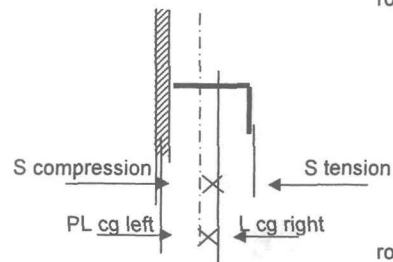


Figure 23-11 COMPRESSION FLANGE

row 890

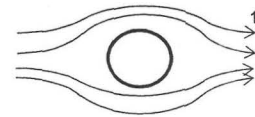


row 900

Figure 23-12 STIFFENER RING

T_oval	0.003 sec/cycle	$2 * \text{p} / 2.68 * (m * R^4 / (E_{\text{heat}} * 1000 * I_{\text{Plate}}))^{0.5}$
f oval	381.304 Hz	$2 * \text{pi}() / 2.68 * (0.000136 * 20.94^4 / (26,099 * 1000 * 0.803))^{0.5}$
V_1oval	2262 mph	$3.4 * d_{\text{mean}} / (2 * T_{\text{oval}})$

row 910



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### BREECHING

#### Manhole Access

General rules for openings per SMACNA.

For arc of shell removed

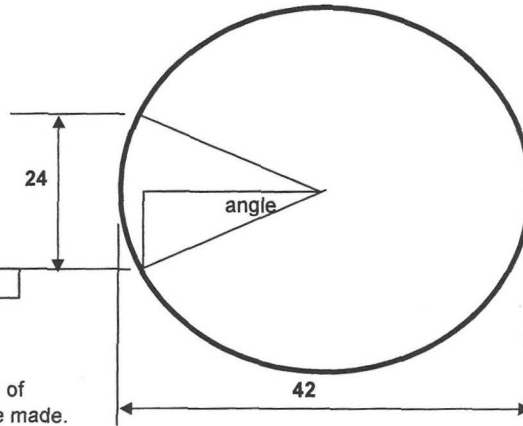
diameter **42 in**  
chord **24 in**

angle 0.6082 radians  
chord 1.2165 radians  
arc 25.5463 in

PL t **0.375**

PL area **9.58 in<sup>2</sup>** in cross-section

Replace this area with vertical stiffeners to assure a shell structure with as much or a greater Ixx. This applies until the opening width is greater than 2/3 of the stack diameter. Then, a detailed analysis must be made.



row 920

Figure 23-13 PLAN VIEW AT MANHOLE IN SHELL

row 930

**Use L 4 x 4 x 3/4 on each side of opening. A = 10.88 in<sup>2</sup>.**

Stiffeners to extend a minimum of 3/4 the width of the opening above and below the opening.

#### Intake Breaching

For shell minus arc

dia breach **42 in**  
chord **36 in**

angle 1.0297 radians  
58.9973 degrees  
chord 2.0594 radians  
arc 43.0542 in

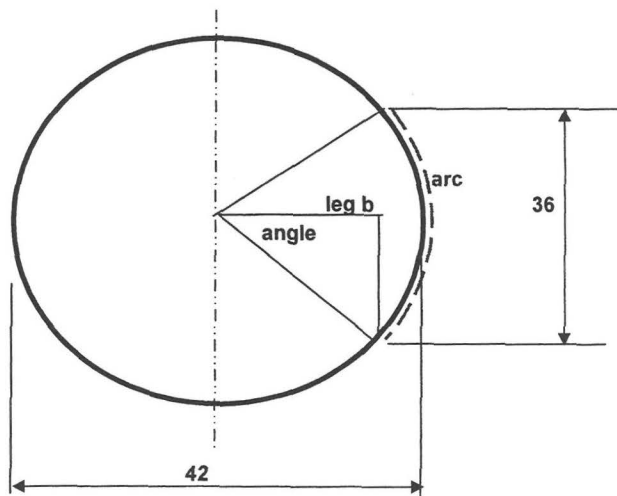
PL t **0.375 in**

PL area **16.08 in<sup>2</sup>** arc in cross-section

yc	0	zc	17.3248 in
Ixx arc	1989	Iyy arc	4974 in <sup>4</sup>
area	49.04	area	49.04 in <sup>2</sup>
Ixx circle	10622	Iyy circle	10622 in <sup>4</sup>
cg y	0.0000	cg x	-8.4487
Ixx shell	<b>8633</b>		

arc	16.08	17.3248	278.50
circle	49.04	0	0
			-278.50

a shell 32.9633  
cg x -8.4487



row 950

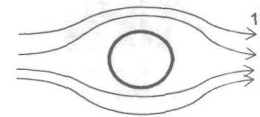
Figure 23-14 PLAN VIEW AT BREECHING IN SHELL

	Iyy	a	dx	adx <sup>2</sup>
arc	4974	16.08	17.1373	275.482
circle	10622	32.96	-8.4487	-278.496
			sum Iyy	<b>3279 in<sup>4</sup></b>

row 970



# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK



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23 Vortex Shedding.xls

A B C D E F G H I J K L M N

**BREECHING -- Continued**

AutoCAD Mass Properties of Shell Minus Arc

Area: 32.9654  
Perimeter: 176.5653  
Bounding box: X: -21.0000 -- 10.8166  
Y: -21.0000 -- 21.0000  
Centroid: X: -8.4473  
Y: 0.0000  
Moments of inertia: X: 8632.8991  
Y: 5647.5443  
Product of inertia: XY: 0.0000  
Radii of gyration: X: 16.1826  
Y: 13.0888  
Principal moments and X-Y directions about centroid:  
I: 3295.2498 along [0.0000 -1.0000]  
J: 8632.8991 along [1.0000 0.0000]

AutoCAD Mass Properties of Arc

Area: 16.0729  
Perimeter: 86.4723  
Bounding box: X: 10.6235 -- 21.0000  
Y: -18.0000 -- 18.0000  
Centroid: X: 17.3253  
Y: 0.0000  
Moments of inertia: X: 1988.6813  
Y: 4974.0361  
Product of inertia: XY: 0.0000  
Radii of gyration: X: 11.1233  
Y: 17.5917  
Principal moments and X-Y directions about centroid:  
I: 149.5106 along [0.0000 -1.0000]  
J: 1988.6813 along [1.0000 0.0000]

row 980

row 990

**L Reinforcing**

leg b 10.6235 in

Calculate L without accounting for fillet and rounded toes -- values will be the same as AISC

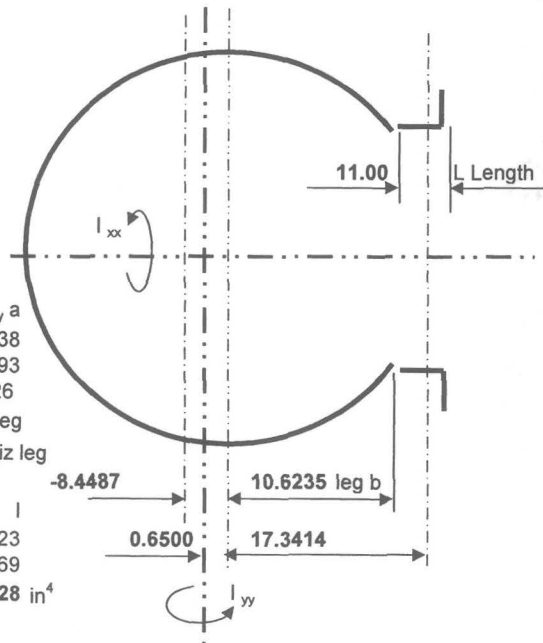
L t 0.625  
L Length 11 in  
L Flange 4 in  
L Area 8.984 in<sup>2</sup>

**L cg calculations**

	arm <sub>x</sub>	area q = arm <sub>x</sub> a		arm <sub>y</sub> q = arm <sub>y</sub> a	
Length	5.5000	6.875	37.813	0.3125	2.148438
Flange	10.6875	2.109	22.544	2.3125	4.87793
		q sum	60.356		7.026

L cg<sub>x</sub> 6.718 in from left fiber of L horizontal leg  
L cg<sub>y</sub> 0.782 in from the bottom fiber of L horiz leg

L I <sub>yy</sub>	A	d	d <sup>2</sup>	Ad <sup>2</sup>	I
Length	6.875	1.218	1.483	10.198	69.323
Flange	2.109	3.970	15.757	33.238	0.069
sum A	8.984 in <sup>2</sup>			sum I <sub>yy</sub>	112.828 in <sup>4</sup>



row 1000

row 1010

Figure 23-15 PLAN VIEW REINFORCING AT BREECHING

row 1020

row 1030



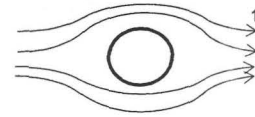
# VORTEX SHEDDING IN TALL STACKS AND VESSELS EXHAUST STACK

# 23

Christy

18:02

12/20/05



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23 Vortex Shedding.xls

**BREECHING -- Continued**

	arm <sub>x</sub>	area		
L's cg x	17.3414	17.97		311.6
Shell cg x	-8.4487	32.96		-278.5
	sum A	50.93	q sum	33.108
comp x	<b>0.6500 in</b>			

	$I_{yy}$	A	d	$Ad^2$	
2 - L's	226	17.97	16.8846	303.39	5123
Shell	3279	32.96	-9.0987	-299.92	2729
		50.93		sum $I_{yy}$	11356 in <sup>4</sup>
	-5.8887				

AutoCAD Mass Properties of Shell Composite Profile

Area: 40.4654  
Perimeter: 208.5653  
Bounding box: X: -16.7363 -- 20.1387  
Y: -21.0000 -- 21.0000  
Centroid: X: 0.0000  
Y: 0.0000

row 1040

	A	d	$d^2$	$Ad^2$	I
L $I_{xx}$	6.875	0.470	0.220	1.516	0.224
Length	2.109	-1.530	2.342	4.941	2.002
Flange	sum A <b>8.984 in<sup>2</sup></b>				
	sum $I_{xx}$ <b>8.683 in<sup>4</sup></b>				

Moments of inertia: X: 11274.7741

Y: 6427.2093  
Product of inertia: XY: 0.0000  
Radii of gyration: X: 16.6921  
Y: 12.6029

row 1050

	$I_{xx}$	A	d	$Ad^2$
2 - L's	17.365	17.969	18.78207	6339
Shell	sum $I_{yy}$ <b>14989 in<sup>4</sup></b>			

Principal moments and X-Y directions about centroid:  
I: 11274.7741 along [1.0000 0.0000]  
J: 6427.2093 along [0.0000 1.0000]

For Comparison

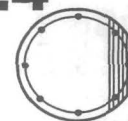
Circle	10622 in <sup>4</sup>
Shell $I_{xx}$ ↑	11356 in <sup>4</sup>
Shell $I_{yy}$ →	14989 in <sup>4</sup>

row 1060

row 1070

row 1080

row 1090



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24 Bolt Patterns.xls

A	B	C	D	E	F	G	H	I	J	K	L	M	N
---	---	---	---	---	---	---	---	---	---	---	---	---	---

BOLT CIRCLE		
Bolts	12 unit	number of bolts
d_bolt	1.75 inch	gross diameter of bolt
n_bolt	5 unit	threads per inch
A_threaded	1.8995 in <sup>2</sup>	threaded portion of bolt in tension and shear $0.7854 * (1.75 - 0.9743 / 5)^2$
BC	54.00 inch	diameter of bolt circle through bolt CL's
Base PL	66.00 inch	diameter of base plate / bolt ring
F bearing	0.750 ksi	bearing working stress max
d bearing	7.500 in	estimated depth in the direction of the FORCE <i>iterate manually</i>
leg a	20.95 in	$((66.000/2)^2 - (66.000/2 - 7.500)^2)^{0.5}$
angle	0.8214 radians	$20.95 / (66.000/2 - 7.500)$
A bearing	351.4 in <sup>2</sup>	$(66.000/2)^2 * (0.8214 - \sin(0.8214)) * \cos(0.8214)$

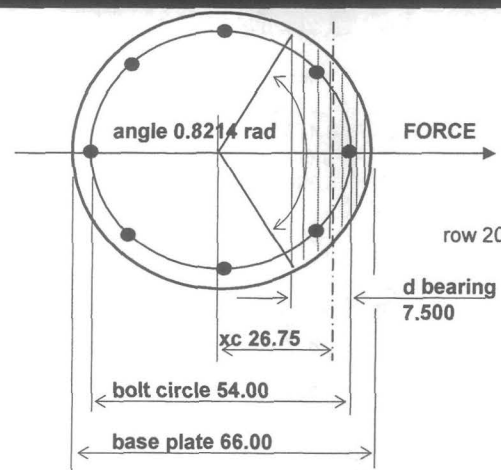


Figure 24-1 PLAN VIEW OF BOLT CIRCLE

xc	26.75 in	cg of bearing area
----	----------	--------------------

F <sub>u</sub> bolt	105 ksi	ultimate tension value of bolt material
E bolt	29000 ksi	young's modulus of elasticity
F <sub>t</sub>	34.65 ksi	allowable tension on bolt
T bolt	65.82 k	

d inches	# bolts	ratio	T kips	M k-in
53.75	1	1.000	65.82	3538
45.84	2	0.853	112.27	5147
26.75	2	0.498	65.51	1752
7.66	2	0.142	18.76	144
			sum M	10580
			sum T	262.35

C	263.6 k	compression/bearing block 100.5% convergence
---	---------	---

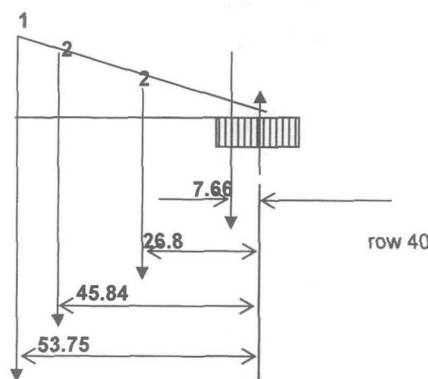


Figure 24-2 View of bolt strain diagram.

M <sub>ot</sub>	488.0 k-ft	overturning moment
W	6.944 k	weight to resist overturning
M <sub>rt</sub>	15.5 k-ft	righting moment

row 50

M bolts	881.7 k-ft	provided
M_net	472.5 k-ft	488.0 k-ft - 15.5 k-ft

T bolt req'd	35.3 K	$472.5 / 881.7 * 65.82$ k bolt tension
--------------	--------	--

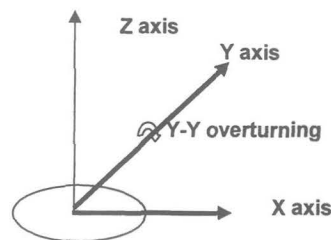
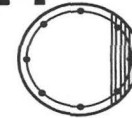


Figure 24-3 AXIS DIAGRAM

row 70



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24 Bolt Patterns.xls

**FOUR LEGS -- CIRCULAR BASE PLATES w/ FOUR BOLTS**

This calculation is for a 4-legged tank and is not a part of the stack calculation set.

d_bolt	1.50 inch	gross diameter of bolt
n_bolt	5 unit	threads per inch
A_threaded	1.3378 in <sup>2</sup>	threaded portion of bolt in tension and shear $0.7854 * (1.50 - 0.9743 / 5)^2$

**Bolt Locations**

A	36.5 in	far bolt(s)
B	27.5 in	CL of circular base plate
C	18.5 in	
Base PL	24.00 inch	diameter of base plate
F_bearing	0.750 ksi	bearing working stress max
d_bearing	7.500 in	estimated depth of compression area in the direction of the FORCE -- iterate manually

101.2% convergence

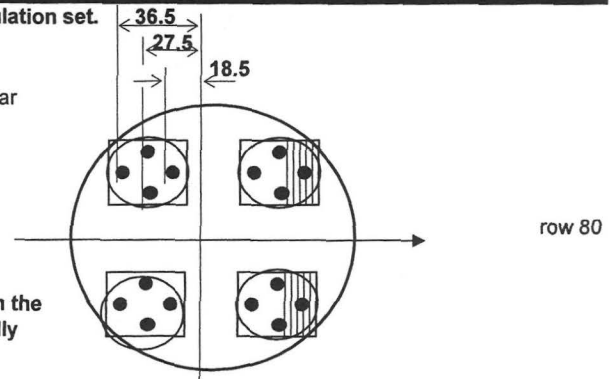


Figure 24-4 PLAN VIEW OF BASPLATES

**Circular Base Plates**

For a bearing area as a partially loaded semicircle to full semicircle

leg b	11.12 in	$((24.00 / 2)^2 - (24.00 / 2 - 7.500)^2)^{0.5}$
chord	22.25 in	
leg c	12.00 in	radius
angle a	1.1864 radians	$\text{atan}(11.12 / (24.00 / 2 - 7.50))$
A_segment	120.8 in <sup>2</sup>	$(24.00 / 2)^2 * (1.1864 - \text{SIN}(1.1864) * \text{COS}(1.1864))$
A_semi c	226.2 in <sup>2</sup>	area of semicircle
A_bearing 1	120.8 in <sup>2</sup>	

xc	7.60 in	cg of bearing area 1
xc_semi c	5.09 in	
xc_bearing 1	7.60	

For a bearing area as a loaded semicircle to fully loaded circle

angle a	4.3280 radians	
A_segment	120.8 in <sup>2</sup>	
A_bearing 2	347.0 in <sup>2</sup>	A semi c - A segment
xc_seg	-7.60 in	
xc_bearing 2	5.97 in	
A_sum	120.8 in <sup>2</sup>	
xc_sum	-9.54 in	

**xc sum 7.60 in for base plate bearing area**

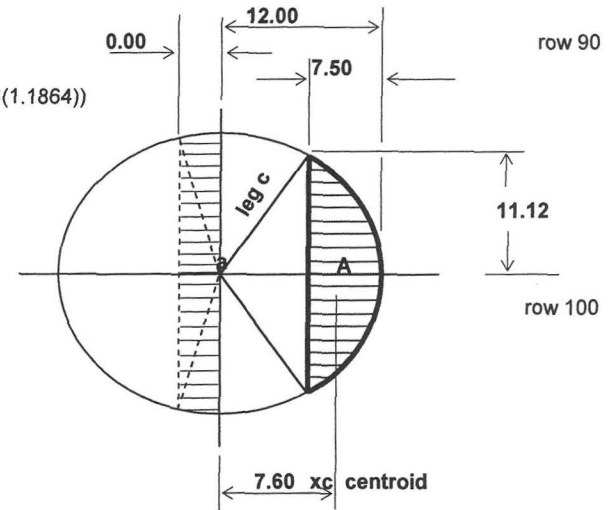


Figure 24-5 Circular segment calculation.

F <sub>u</sub> bolt	58 ksi	ultimate tension value of bolt material
E bolt	29000 ksi	young's modulus of elasticity
F <sub>t</sub>	19.14 ksi	allowable tension on bolt
T bolt	25.61 k	

A	B	C	ratio	T kips	M k-in
71.60	2	71.60	1.000	51.21	3667
62.60	4	71.60	0.874	89.55	5606
53.60	2	71.60	0.749	38.34	2055
				sum M	11327

C 181.2 k 120.8 \* 0.750 \* 2 base plates compression/bearing block  
101.2% convergence

M <sub>ot</sub>	1045.0 k-ft	overturning moment
W	148.05 k	weight to resist overturning
M <sub>rt</sub>	450.3 k-ft	righting moment
M <sub>net</sub>	594.7 k-ft	required 1,045.0 k-ft - 450.3 k-ft
M_bolts	943.9 k-ft	provided

**T bolt reqd 16.1 K 594.7 / 943.9 \* 25.61 k**

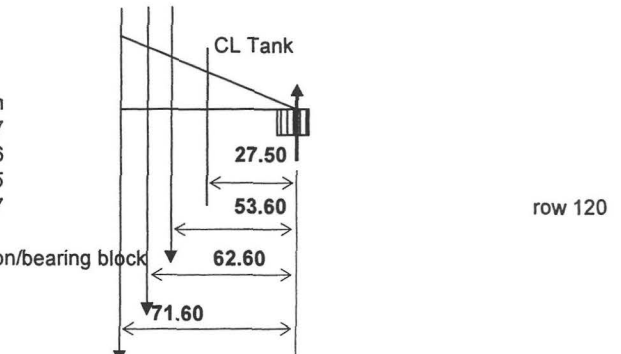
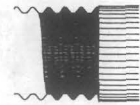


Figure 24-6 Diagram of bolt strain.



A B C D E F G H I J K L M N  
BOLT THREADS

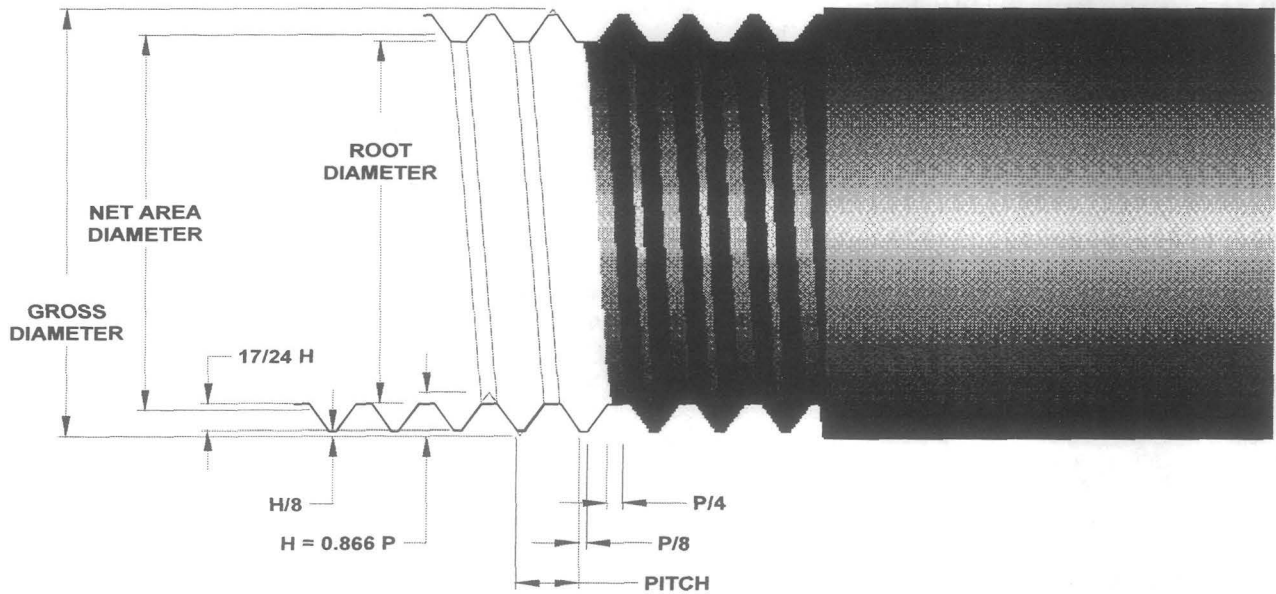


Figure 25-1 Bolt threads and bolt body.

row 40

Reference: AISC 9th Edition Part 4 - 3 tension on gross area  
Section J - 3, page 5 - 72 and some common sense  
American Institute of Steel Construction (AISC)

D	1.2500 in	
D threads	1.2191 in	
n	7 threads/inch	
pitch	0.1429 in	distance between threads
H	0.1237 in	0.866 P
H/6	0.0206 in	
H/8	0.0155 in	
K root	1.0747 in	diameter to thread roots
A tensile	0.9691 in <sup>2</sup>	
D tensile	1.1108 in	
pitch_angle	2.2785 degrees	

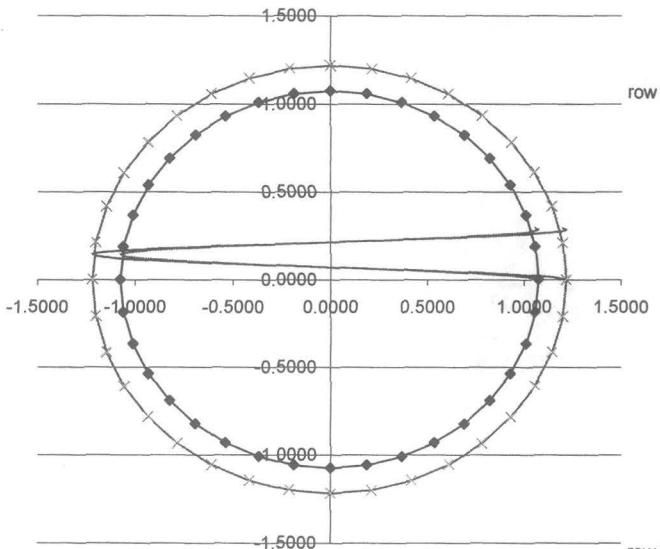


Figure 25-3 The thread cross-section.

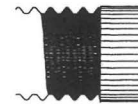
You will note that this manual contains only examples and templates.

There are no problems or example problems, just opportunities to do engineering and make a living.

row 80



Figure 25-2 The bolt thread spiral from an AutoCAD DRAWING.



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**BOLT STRENGTH**

**Shear Across Bolt**

D	1.25 in	gross diameter
n	7 count	number of threads per inch
Grade	A364 Gr. BD type	AISC Values
F <sub>t</sub>	54 ksi	F <sub>u</sub> * 0.33
A gross	1.227 in <sup>2</sup>	$\pi * (D / 2)^2$ 3.14 * (1.250 / 2) <sup>2</sup>

V gross	66.3 k	on gross section of bolt 54 * 1.227
---------	--------	--

A threads	0.969 in <sup>2</sup>	=0.7854*(D - 0.9743 / n) <sup>2</sup> 0.7854 * (1.250 - 0.9743 / 7) <sup>2</sup>
-----------	-----------------------	---

V threaded	52.3 k	at threaded portion of bolt 54 * 0.969
------------	--------	---

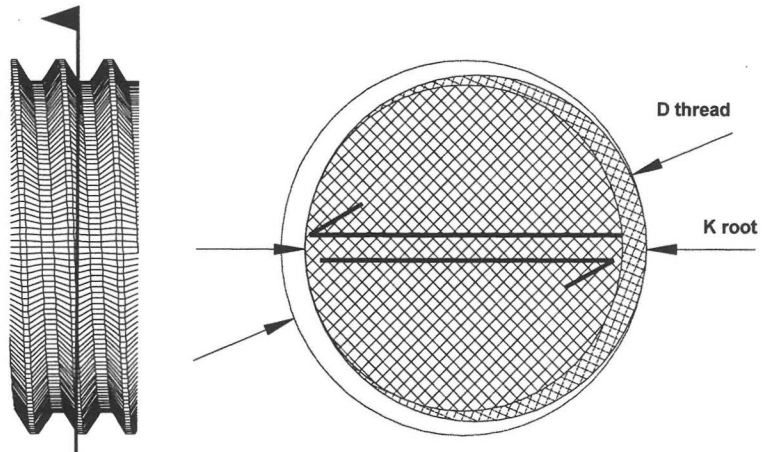


Figure 25-4 This is a cut through an elevation and the resulting section showing the area of the thread(s).

**BOLT GRADE VALUES**

Grade	Calculated Values					AISC Values			row 110
	F <sub>v</sub> yield	F <sub>u</sub> ultimate	F <sub>t</sub>	F <sub>v</sub> =0.17F <sub>u</sub>	F <sub>v</sub> =0.22F <sub>u</sub>	F <sub>t</sub>	F <sub>y</sub>	threads in plane gross	
A36	36	58	19.14	9.86	12.76	19.1	9.9	12.8 carbon steel with/without head	
A307		60	19.8	10.2	13.2	20	10	13.2 carbon steel with head	
A325 to 1" Grade 5, B7	92	120	39.6	20.4	26.4	44	21	30 carbon,	
A325-1 1 1/8" to 1 1/2"	81	105	34.65	17.85	23.1	44	17.9	23.1 carbon,	
A490 Grade 8, 1/2" to 1 1/2"	120	150	49.5	25.5	33	54	28	40 alloy,	
A354 Gr. BD 1/2" to 2 1/2"	120	150	49.5	25.5	33	54	28	40 alloy, quenched & tempered steel with/without head stainless steel	
AISI 304 SS	65	100	33	17	22				

A36 can be purchased at the hardware store as allthread rod.  
A354 Grade BD is usually specified as interchangeable with A490 bolts. A354 Gr. BD is often furnished as a high-strength anchor bolt and is also used in high temperature conditions, like your car engine's head bolts.

head n bolt head number of threads

**Values Calculated per the AISC Ninth Edition -- Thread Stripping Shear**

Grade	A325 type	AISC Values
F <sub>t</sub>	44 ksi	tension
F <sub>v</sub>	21 ksi	shear through threads in plane

D gross	1.25 in	gross diameter of bolt
n	7 threads/inch	
H	0.124 in	
K root	1.075 in	least diameter
w thread	0.1071 in	actual width of thread pitch - pitch/4
F/thread	5.698 k/thread	F <sub>v</sub> * area of thread in shear 21 ksi * 0.75 * 0.1071 inch * 1.075 in * π

Threads 7 n threads provided

T threads	39.88 k	7 threads * 5.698 k
-----------	---------	---------------------

T gross	54.00 k	A gross * F <sub>t</sub> 1.227 * 44
---------	---------	--

T threads	42.64 k	A threads * F <sub>t</sub> 0.969 * 44
-----------	---------	--

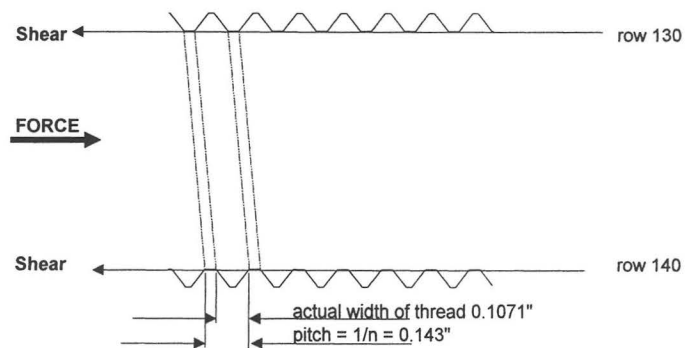
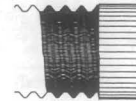


Figure 25-5 Stripping shear through the bolt threads.



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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>SUMMARY</b>														
Diameter		1.2500 in		gross diameter										
n		7 count		number of threads per inch										
Grade		A325												
F <sub>t</sub>		44 ksi		tension										
F <sub>v</sub>		21 ksi		shear										
<b>Thread Stripping Shear</b>														
Threads		7 n		threads provided										row 160
T stripping		39.88 k		stripping capacity										
<b>Bolt Tension</b>														
T gross		54.00 k		on gross section of bolt										
T threads		42.64 k		at threaded portion of bolt										
<b>Shear Across Bolt</b>														
V gross		66.3 k		on gross section of bolt										row 170
V threaded		52.3 k		at threaded portion of bolt										
<b>Loads</b>														
T required		<b>35.60 k</b>												
V required		<b>1.38 k</b>		sum of wind pressure at 35.6 mph during vortex shedding										

**COMBINED LOADS FOR THE UNITY EQUATION**

**For Shear and Tension on Threaded Portion of the Bolt**

T governs		39.88 k		min(39.88, 42.64)										
<b>Parabolic Curve</b>														
Tension				Shear										Sum
$(35.60 / 39.88)^2$	+			$(1.4 / 52.3)^2$	=									0.797 + 0.001
0.797	+			0.001	=									<u>0.797</u>
<b>Straight Line</b>														
$(35.60 / 39.88)$	+			$(1.4 / 52.3)$	=									0.893 + 0.026
0.893	+			0.026	=									<u>0.919</u>

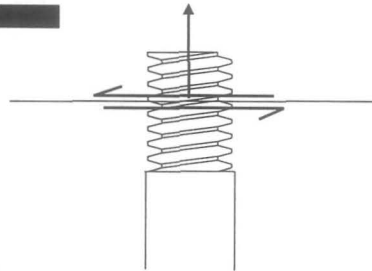


Figure 25-6 Tension and shear through the bolt threads.

**For Shear Through the Unthreaded Portion of the Bolt and Tension on Threaded Portion of the Bolt**

<b>Parabolic Curve</b>														
Tension				Shear										Sum
$(35.60 / 39.88)^2$	+			$(1.4 / 66.3)^2$	=									0.797 + 0.000
0.797	+			0.000	=									0.797
<b>Straight Line</b>														
$(35.60 / 39.88)$	+			$(1.4 / 66.3)$	=									0.797 + 0.021
0.797	+			0.021	=									0.818

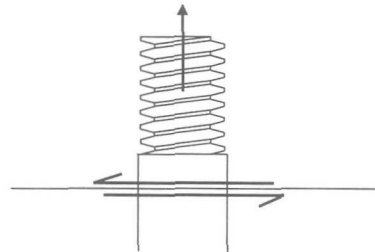


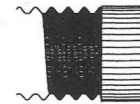
Figure 25-7 Tension and shear through the bolt body.



# BOLT THREADS Threads versus Strength of Bolt EXHAUST STACK

25

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12/20/05  
18:02



25 Bolt Threads.xls

A B C D E F G H I J K L M N  
BOLT THREADS AISC Ninth Edition First Printing (7/89)

Diameter bar stock inch	Area		Root A <sub>K</sub> in <sup>2</sup>	Tensile Stress in <sup>2</sup>	Threads per inch n	Pitch in	F <sub>t</sub>	F <sub>t</sub>	Thread Shear Plane length in	F <sub>v</sub> * area	F <sub>t</sub> / thread	length required inch	H in
	Root K inch	Gross A <sub>D</sub> in <sup>2</sup>					tension on gross (nominal) k	tension on threaded (net area) k		of thread in shear plane k	per thread Threads Required n		
1/4	0.189	0.0491	0.027	0.032	20	0.050	2.16	1.18	0.0375	0.351	6.16	0.308	0.043
3/8	0.298	0.1104	0.068	0.077	16	0.063	4.86	2.98	0.0469	0.691	7.03	0.439	0.054
1/2	0.406	0.1963	0.126	0.142	13	0.077	8.64	5.53	0.0577	1.159	7.45	0.573	0.067
5/8	0.514	0.3068	0.202	0.226	11	0.091	13.5	8.88	0.0682	1.734	7.78	0.708	0.079
3/4	0.627	0.4418	0.302	0.334	10	0.100	19.4	13.3	0.0750	2.327	8.35	0.835	0.087
7/8	0.739	0.6013	0.419	0.462	9	0.111	26.5	18.4	0.0833	3.047	8.68	0.965	0.096
1	0.847	0.7854	0.551	0.606	8	0.125	34.6	24.2	0.0938	3.929	8.80	1.099	0.108
1 1/8	0.950	0.994	0.693	0.763	7	0.143	43.7	30.5	0.1071	5.036	8.68	1.241	0.124
1 1/4	1.075	1.227	0.890	0.969	7	0.143	54.0	39.1	0.1071	5.699	9.47	1.354	0.124
1 3/8	1.171	1.485	1.054	1.155	6	0.167	65.3	46.4	0.1250	7.243	9.02	1.503	0.144
1 1/2	1.296	1.767	1.294	1.405	6	0.167	77.8	56.9	0.1250	8.016	9.70	1.617	0.144
1 3/4	1.505	2.405	1.744	1.899	5	0.200	105.8	76.7	0.1500	11.170	9.47	1.895	0.173
2	1.727	3.142	2.300	2.498	4.5	0.222	138.2	101.2	0.1667	14.242	9.71	2.157	0.192

**Comparison of Published and Calculated Threaded Areas**

Values in the AISC Ninth Edition, First Printing (7/89) vary from the formula  $0.7854 \cdot (D - 1.3/n)^2$  for the root area A<sub>K</sub>. The difference between the first and second AISC printings is shown below and in the graph. ICE calculations equal the revised AISC values.

Diameter bar stock inch	Threads per inch n	AISC	AISC 1st ed	% difference
		ICE A <sub>K</sub> in <sup>2</sup>	(7/89) A <sub>K</sub> in <sup>2</sup>	
0.25	20	0.027	0.032	16.0
0.375	16	0.068	0.078	13.1
0.5	13	0.126	0.142	11.5
0.625	11	0.202	0.226	10.7
0.75	10	0.302	0.334	9.6
0.875	9	0.419	0.462	9.3
1	8	0.551	0.606	9.1
1.125	7	0.693	0.763	9.2
1.25	7	0.890	0.969	8.2
1.375	6	1.054	1.16	9.2
1.5	6	1.294	1.41	8.3
1.75	5	1.744	1.90	8.2
2	4.5	2.300	2.50	8.0

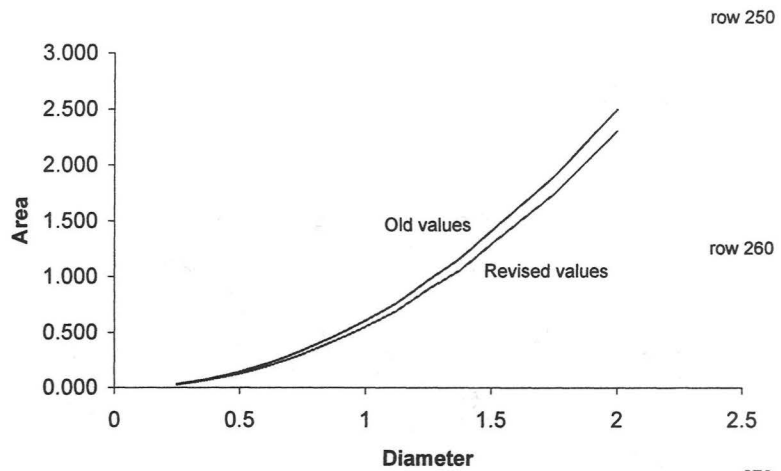
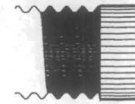


Figure 25-8 VERIFICATION GRAPH

The diagram shown in the AISC Ninth Edition and previous editions is inaccurate. The gross diameter of the bolt threads is never as great as the bolt stock from which they were cut or rolled.



25 Bolt Threads.xls

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**BOLT GRADES**

A354 Grade BD bolt stock is the same as  
A490 headed bolts and  
SAE Grade 8 bolts

Threaded bolt stock may be marked **BD** or with the  
six spoke symbol.

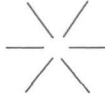
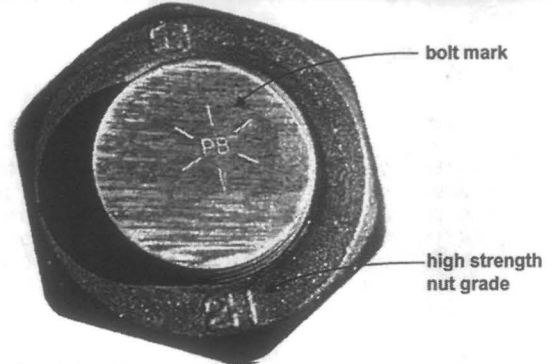


Figure 25-9 The old bolt mark for Grade BD bolts.



row 300

Figure 25-10 An older bolt with the spokes and initials representing Portland Bolt Company.

row 310

**STEEL GRADES**

Steels	Grade	Yield	Tensile Range
A36		36	58 - 80 carbon steel
A53		35	60 min
A500	A	33	45 min
A500	B	42	58 min
A501		36	58 min
A529	50, 55	42	60 - 85 carbon steel
A572	42	42	60 min high strength, low alloy
A572	50	50	65 min
A588	< 4"	50	70 min high strength, low alloy
A709	36	36	58 - 80
A709	50	50	65 min
A709	50W	50	70 min
A913	50	50	65 min
A992		50	65

row 320

ASTM established A992 in 1998 to replace/upgrade A36 and A572 grade 42 and is commonly provided in lieu of A36.

A992 is produced in the US from recycled steel and scrap in arc furnaces.

**Bolt to be Installed**

row 330



Figure 25-11 The 1 1/2" Ø bolt in an epifoam insulation sleeve is shown here with a 10 Lb. hammer and hit wrench. The surveyor's rod is used for reference.

row 350

Epifoam sleeves, pipes, and plastic pipes are used to prevent concrete bond with the bolt. This allows bolt stretch during impact events. The bolt can be pretensioned with the hit wrench or a large impact hammer. Calculate the turn of the nut versus the length of the bolt between the nuts.

row 360



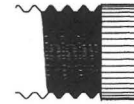
# BOLT THREADS

## Threads versus Strength of Bolt

### EXHAUST STACK

# 25

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25 Bolt Threads.xls

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A B C D E F G H I J K L M N  
GRAPHING RANGES

		K root diameter			D threads			
Sine	Cosine	x	y	z	x	y	z	
0	1	0	1.0747	0.0000	0.0000	1.2191	0.0000	0.0000
0.1736482	0.9848078	1	1.0584	0.1866	0.0079	1.2006	0.2117	0.0079
0.3420201	0.9396926	2	1.0099	0.3676	0.0159	1.1456	0.4169	0.0159
0.5	0.8660254	3	0.9308	0.5374	0.0238	1.0557	0.6095	0.0238
0.6427876	0.7660444	4	0.8233	0.6908	0.0317	0.9339	0.7836	0.0317
0.7660444	0.6427876	5	0.6908	0.8233	0.0397	0.7836	0.9339	0.0397
0.8660254	0.5	6	0.5374	0.9308	0.0476	0.6095	1.0557	0.0476
0.9396926	0.3420201	7	0.3676	1.0099	0.0556	0.4169	1.1456	0.0556
0.9848078	0.1736482	8	0.1866	1.0584	0.0635	0.2117	1.2006	0.0635
1	6.126E-17	9	0.0000	1.0747	0.0714	0.0000	1.2191	0.0714
0.9848078	-0.173648	10	-0.1866	1.0584	0.0794	-0.2117	1.2006	0.0794
0.9396926	-0.34202	11	-0.3676	1.0099	0.0873	-0.4169	1.1456	0.0873
0.8660254	-0.5	12	-0.5374	0.9308	0.0952	-0.6095	1.0557	0.0952
0.7660444	-0.642788	13	-0.6908	0.8233	0.1032	-0.7836	0.9339	0.1032
0.6427876	-0.766044	14	-0.8233	0.6908	0.1111	-0.9339	0.7836	0.1111
0.5	-0.866025	15	-0.9308	0.5374	0.1190	-1.0557	0.6095	0.1190
0.3420201	-0.939693	16	-1.0099	0.3676	0.1270	-1.1456	0.4169	0.1270
0.1736482	-0.984808	17	-1.0584	0.1866	0.1349	-1.2006	0.2117	0.1349
1.225E-16	-1	18	-1.0747	0.0000	0.1429	-1.2191	0.0000	0.1429
-0.173648	-0.984808	19	-1.0584	-0.1866	0.1508	-1.2006	-0.2117	0.1508
-0.34202	-0.939693	20	-1.0099	-0.3676	0.1587	-1.1456	-0.4169	0.1587
-0.5	-0.866025	21	-0.9308	-0.5374	0.1667	-1.0557	-0.6095	0.1667
-0.642788	-0.766044	22	-0.8233	-0.6908	0.1746	-0.9339	-0.7836	0.1746
-0.766044	-0.642788	23	-0.6908	-0.8233	0.1825	-0.7836	-0.9339	0.1825
-0.866025	-0.5	24	-0.5374	-0.9308	0.1905	-0.6095	-1.0557	0.1905
-0.939693	-0.34202	25	-0.3676	-1.0099	0.1984	-0.4169	-1.1456	0.1984
-0.984808	-0.173648	26	-0.1866	-1.0584	0.2063	-0.2117	-1.2006	0.2063
-1	-1.84E-16	27	0.0000	-1.0747	0.2143	0.0000	-1.2191	0.2143
-0.984808	0.1736482	28	0.1866	-1.0584	0.2222	0.2117	-1.2006	0.2222
-0.939693	0.3420201	29	0.3676	-1.0099	0.2302	0.4169	-1.1456	0.2302
-0.866025	0.5	30	0.5374	-0.9308	0.2381	0.6095	-1.0557	0.2381
-0.766044	0.6427876	31	0.6908	-0.8233	0.2460	0.7836	-0.9339	0.2460
-0.642788	0.7660444	32	0.8233	-0.6908	0.2540	0.9339	-0.7836	0.2540
-0.5	0.8660254	33	0.9308	-0.5374	0.2619	1.0557	-0.6095	0.2619
-0.34202	0.9396926	34	1.0099	-0.3676	0.2698	1.1456	-0.4169	0.2698
-0.173648	0.9848078	35	1.0584	-0.1866	0.2778	1.2006	-0.2117	0.2778
-2.45E-16	1	36	1.0747	0.0000	0.2857	1.2191	0.0000	0.2857
0.1736482	0.9848078	37	1.0584	0.1866	0.2937	1.2006	0.2117	0.2937

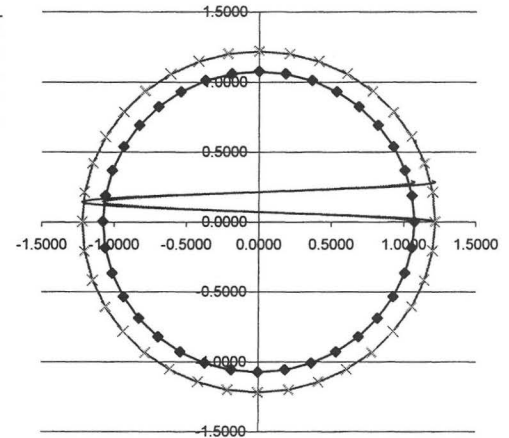


Figure 25-12 This is a graph of bolt threads relative to the gross round-bar stock diameter and thread pitch.

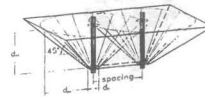
row 390

row 400

row 410

row 420

row 430



**ANCHORING IN CONCRETE**

This chapter presents two approaches to bolting in concrete.

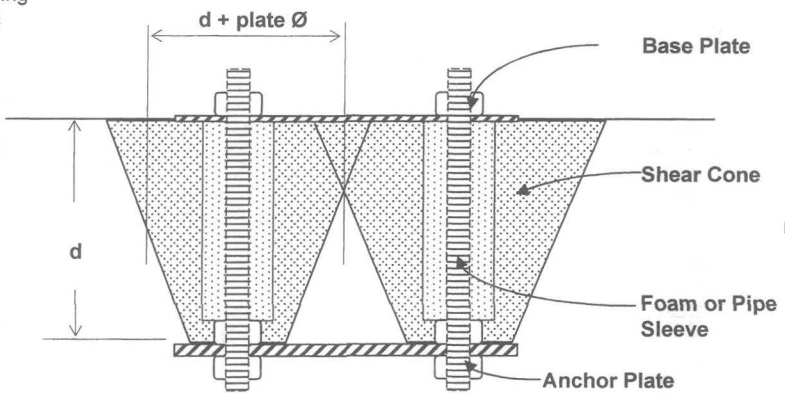
The first method uses the shear-friction method where the bolt clamps the steel base plate against the supporting concrete surface. This is useful in tank and equipment bolting though steel or plywood positioning templates are used to locate the bolt projection through the concrete.

Isolate the bolt from the concrete with a pipe insulation sleeve or length of pipe. This allows the bolts to be pushed sideways to get them up through the bolt holes.

row 20

This method has the additional advantage of allowing the bolt to stretch along its length during a seismic event or mishap with a truck or a forklift.

After the concrete cures, say seven days, the nut should be brought to hand tight and then turned about 1/4 thread of a turn to prestress the bolt and add in clamping. The amount of turn should be calculated. The turn will have to be done with a hit-wrench or impact hammer.



row 30

The plate serves as the anchor -- not the shank of the bolt. Calculate the plate in punching shear. Reduce the shear cone for anchor bolts placed closely together.

Figure 26-1 Elevation of punching shear cones.

row 40

The second method is the '97 UBC bolt group calculation.

This is intended more for a group of headed weld studs in an anchor plate. This method uses the projected area on the surface of the concrete to calculate the effect of the group.

This method has been revised in the 02 ACI 318 appendix D.

row 50

Where anchor spacing is greater than  $2 * d_m$  calculate the anchorage with the value of a single anchor \* number of anchors.

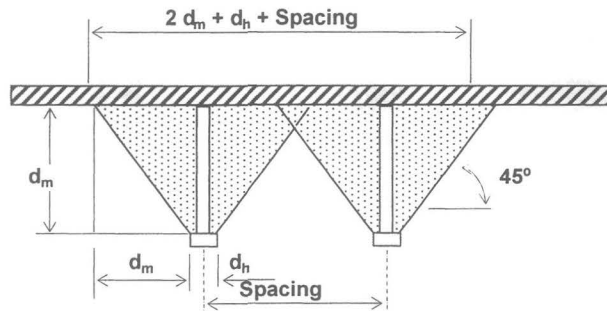


Figure 26-2 Elevation of anchor group shear cones.

row 60

At the end of this chapter is a parsing of Code language. This amounts to an argument against text only explanations of engineering concepts.

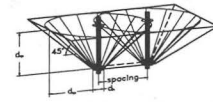
The 02 ACI presents code language, a running commentary, and diagrams. This is preferable to the text only presentation which can be interpreted a number of ways. Comprehensive presentations expose themselves to an uncovering, so-to-speak, of errors in reasoning. However, I feel that the ACI presentation is preferable.

row 70



# BOLT GROUP PULLOUT EXHAUST STACK

Vortex moment and shear govern



27 Bolt Group Pullout.xls

## ENGINEERING with the SPREADSHEET

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### SHEAR FRICTION CONNECTION -- PUNCHING SHEAR UBC 1911.7

This design uses the anchor bolt to clamp the steel baseplate down onto the concrete slab/foundation. After grouting beneath the base plate, the bolt is tensioned by tightening the nut -- usually about 1/4 turn of the nut.

Lateral loads are converted to bolt tension loads via the concept of shear friction. Bolt lateral capability is factored down with the factors  $\lambda$  and  $\mu$  which account for a steel plate trying to slide on concrete.

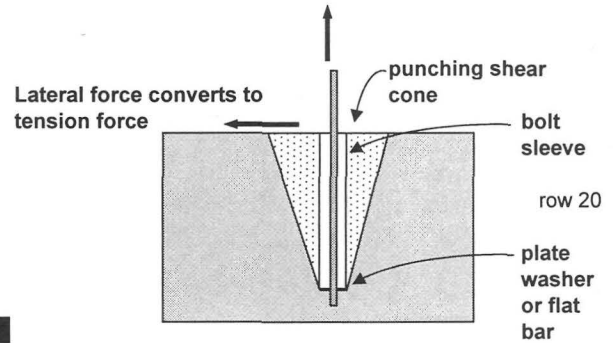


Figure 27-1 Converting lateral force to tension force.

### Force per Turn-of-the-Nut

d	21.0 in	
threads	5 threads/inch	
Dia	1.75 in	
turn	0.125 turn of nut	45degrees
stretch	0.025000 inch	0.125 turn /5 threads/inch
strain	1.001190 inches/inch	$(d + stretch) / d$ $(21.0" + 0.025000") / 21.0"$

$E_s$	29000 k/in <sup>2</sup>	Young's modulus for steel
$A_{bolt}$	2.41 in <sup>2</sup>	$(1.75" / 2)^2 * \pi$ gross area of the bolt

force	83.04 k	$E_s * A_{bolt} * (strain - 1)$ $29,000 \text{ ksi} * 2.41 \text{ in}^2 * (1.001190 - 1)$
-------	---------	--

### Force per Lateral Movement

displace	0.125 inch	
lengthen	21.000372 inch	$\sqrt{21.0^2 + 0.125^2}$

force	25.95 k	$(lengthen - d) * E_s * A_{bolt}$ $(21.000372 - 21.0) * 29,000 \text{ ksi} * 2.41 \text{ in}^2$
-------	---------	--

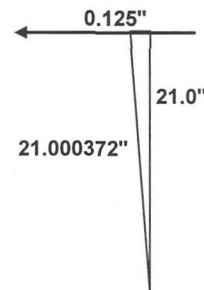
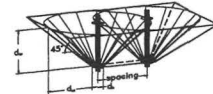


Figure 27-2 Bolt stretched by lateral displacement.



Vortex moment and shear govern



27 Bolt Group Pullout.xls

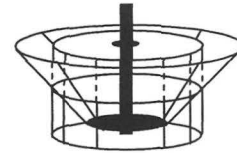
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A	B	C	D	E	F	G	H	I	J	K	L	M	N
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**SHEAR FRICTION CONNECTION -- Base Plate Sliding / Shear Plane**

T_tens	35.60 k	required tension
V_shear	1.38 k	required shear
f <sub>c</sub>	3 k/in <sup>2</sup>	
A <sub>c</sub>	100 in <sup>2</sup>	shear area A <sub>c</sub> (base plate or shear plane)
f <sub>v</sub>	132 k/in <sup>2</sup>	specified yeild strength = F <sub>u</sub> tensile for bolt material
A <sub>st</sub>	2.405 in <sup>2</sup>	bolt area A <sub>vf</sub>
μ	0.7 unitless	UBC 1911.7.4.3
V <sub>n</sub>	222.2 k ult	A <sub>vf</sub> * f <sub>v</sub> * μ UBC (11-25)
Limited by		
V <sub>n</sub>	60.0 k ult	0.2 * f <sub>c</sub> * A <sub>c</sub> UBC 1911.7.5
V <sub>n</sub>	80.0 k ult	800 * A <sub>c</sub>
V <sub>n</sub>	60.0 k ult	



row 140

Figure 27-3 Single anchor punching shear cone.

**Punching Shear**

d	21.0 in	embed depth to top of anchor plate
PL_dia	3.0 in	plate diameter
b <sub>o</sub>	75.4 in	at d/2 from edge if anchor plate [(d/2) * 2 + PL_diameter] * π (21.0 + 3.0) * π
V <sub>c</sub>	347 k ult	4√f <sub>c</sub> * b <sub>o</sub> * d UBC (11-37) where b <sub>o</sub> * d = A <sub>o</sub> 4 * (3 * 1000) <sup>0.5</sup> * 75.4 * 21.0 / 1000
Φ	0.85 unitless	strength reduction factor
V <sub>u</sub>	294.9 k_ult	
P allowed	60.0 k ult	minimum of 294.9, 80.0, 60.0, 222.2
P allowed	42.9 k working	60 k_ult / 1.4 UBC (12 - 11) basic load combinations
λ	1 unit	UBC 1911.7.4.3
Tu_sum	37.6 k_ult	factor * (t_tens + V_shear / (μ * λ)) UBC 1911.7.4.3 1.0 * (35.60 + 1.38 / (0.70 * 1.00))
T_sum	37.6 k	Tu_sum / (factor = 1.00) for working strength

42.9 > 37.6 required OK

row 150

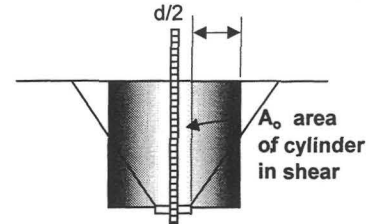


Figure 27-4 Punching shear cylinder.

**SHEAR FRICTION CONNECTION -- Bearing Against Anchor Plate**

Diameter	1.75 in	Area of bearing must be at least 1.5 x anchor shank area 1923.3.4
A shank	2.41 in <sup>2</sup>	
factor	1.0	seismic factor UBC1612.2.1 (12-5) / UBC 1909.2.3
μ	0.7 unit	UBC 1911.7.4.3
λ	1 unit	UBC 1911.7.4.3
A <sub>1</sub>	18.10 in <sup>2</sup>	gross area of plate (square or round)
A <sub>1</sub> net	16 in <sup>2</sup>	A <sub>1</sub> net - A shank
A <sub>2</sub>	600 in <sup>2</sup>	area of supporting surface which is wider on all sides than the bearing area
area_mult	2.0	√(A <sub>2</sub> /A <sub>1</sub> ) not to exceed 2.0 MIN(2, (600 / 16) <sup>0.5</sup> )
Φ_bearing	0.9 factor	UBC 1909.3.2.4 Φ = 0.70 or UBC 1918.13.4 for post tensioned concrete = 0.90
f <sub>c</sub>	3 k/in <sup>2</sup>	
T_allow	138.43 k	Φ_bearing * (0.85 * f <sub>c</sub> * A <sub>1</sub> net) * area_mult 0.90 * (0.85 * 3 * 18) * 2.0

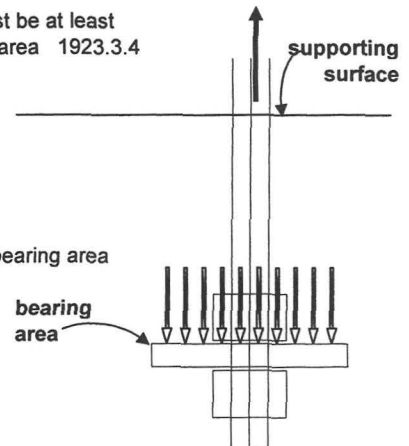
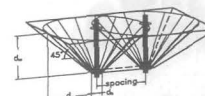


Figure 27-5 Concrete bearing against the anchor plate.

q <sub>plate</sub>	2.395 k/in <sup>2</sup>	Tu_sum / A <sub>1</sub> net for plate design OK q <sub>concrete</sub> bearing allowed = 2.700 ksi
--------------------	-------------------------	--

row 190

Vortex moment and shear govern



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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>ANCHORAGE TO CONCRETE, Tension -- Fully Encased Bolt UBC 1923.2</b>														
Inspect		1.3	unitless		inspection factor									
T_tens		0.00	k_ult		required tension /bolt - ultimate									
V_shear		11.40	k_ult		required shear /bolt - ultimate									
P_u		0.0	k_ult		tension									
V_u		14.8	k_ult		shear									
d_bolt		0.75	in		anchor shank diameter									
A_b		0.44	in <sup>2</sup>		net cross-section area of bolt									
d_e		10	in		edge distance toward loaded edge									
Edge 2		3	in		edge distance away from loaded edge									
			1 logic											
			0 logic											
Edge			0 logic											
f_ut		58	k/in <sup>2</sup>		bolt ultimate tensile strength									
P_ss		23.1	k_ult		0.9 * A_b * f_ut 0.9 * 0.44 in <sup>2</sup> * 58 ksi									
V_ss		19.2	k_ult		0.75 * A_b * f_ut 0.75 * 0.44 in <sup>2</sup> * 58 ksi									
λ		1.00	unitless		concrete factor									
d_h		1.25	in		Tributary area of plate 1.2 in <sup>2</sup> or head Actual plate may be rectangular									
d_m		5.0	in		depth of embedded plate for pullout									
f_c		3	k/in <sup>2</sup>		compressive strength of concrete									
A_p		99	in <sup>2</sup>		effective area of projected cone onto the surface of the slab ((1.3 + 2 * 5.0) / 2) <sup>2</sup> * π									
P_c		5.4	k_ult		λ * A_p * √f_c UBC 1923.3.2 1.00 * 99 in <sup>2</sup> * √3,000 /1000									
V_c		19.4	k_ult		800 * A_b * √f_c UBC 1923.3.3 800 * 0.44 * √3 * 1000 /1000 for bolts more than 10 diameters towards the loaded edge V_c not governed by A_b									
V_c		34.4	k_ult		2 π d_e <sup>2</sup> λ f_c 2 * π * 10.0 <sup>2</sup> * 1.00 * √3 * 1000 /1000									
V_c		34.4	k_ult											
Φ		0.85	unitless		0.85 for confined anchor embedment 0.65 for unconfined anchor embedment UBC 1923.3.2 exception									

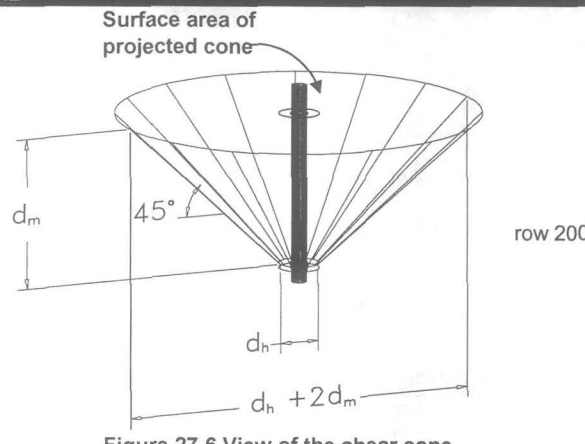


Figure 27-6 View of the shear cone.

**INSPECTION -- UBC 1923.2** row 210

- 1.3 Special inspection provided for bolts anchored in compression zone
- 2 No special inspection
- 2 Special inspection provided for bolts anchored in tension zone
- 3 No special inspection for bolts anchored in the tension zone

**λ UBC 1923.3.2** row 220

- 1.00 normal weight concrete
- 0.85 sand light weight concrete
- 0.75 all-light weight concrete

**Edge distance**

Shear loading more than 10 diameters from the loaded edge. row 230

Tension or shear away from an edge more than 5 diameters away and with reinforcing to prevent concrete in tension failure.

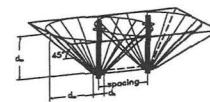
Edge distance not less than 4 diameters in any case.

$$\frac{1}{\Phi} \left[ \left( \frac{P_u}{P_c} \right)^{5/3} + \left( \frac{V_u}{V_c} \right)^{5/3} \right] = \frac{1}{0.85} \left[ \left( \frac{0.0}{5.4} \right)^{5/3} + \left( \frac{14.8}{34.4} \right)^{5/3} \right] = 0.289 < 1.000 \text{ OK}$$

$$\left[ \frac{P_u}{P_{SS}} \right]^2 + \left[ \frac{V_u}{V_{SS}} \right]^2 = \left[ \frac{0.0}{23.1} \right]^2 + \left[ \frac{14.8}{19.2} \right]^2 = 0.595 < 1 \text{ OK}$$

row 250

Vortex moment and shear govern



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**ANCHORAGE TO CONCRETE, Tension -- Fully Encased Bolts in a Row UBC 1923.2**

For a group of connectors, use the area of a truncated pyramid projected onto the surface of the slab

Rectangular area of projected pyramid

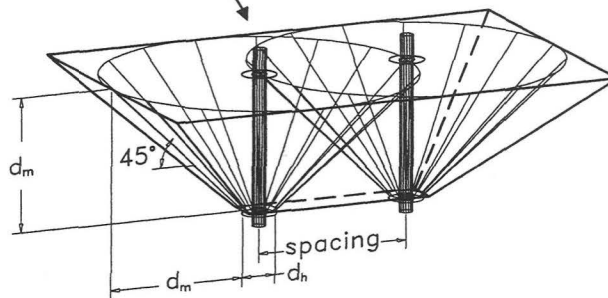


Figure 27-7 View of shear cones in a row.

$P_u$	0.0 k_ult	tension
$V_u$	14.8 k_ult	shear
spacing	4.0 in	anchor spacing
number	5 unit	number of anchors
	1 logic	OK $4.0 \leq 2 * 5.0$ Use Bolt Group
$P_{ss}$	115.3 k_ult	$0.9 * A_b * f_{ut} * \text{number}$ $0.9 * 0.44 \text{ in}^2 * 58 \text{ ksi} * 5$
$V_{ss}$	96.1 k_ult	$0.75 * A_b * f_{ut} * \text{number}$ $0.75 * 0.44 \text{ in}^2 * 58 \text{ ksi} * 5$
Length	27.25 in	$2 * 5.0 \text{ dm} + (4.0 \text{ spacing}) * (5 \text{ number} - 1) + 1.25 \text{ dh}$
Width	11.25 in	$2 * 5.0 \text{ dm} + 1.25 \text{ dh}$
$A_p$	306.6 in <sup>2</sup>	Length * Width
$P_c$	16.8 k_ult	$\lambda * A_p * \sqrt{f'_c}$ UBC 1923.3.2 $1.00 * 307 \text{ in}^2 * 3,000 / 1000$
$V_c$	172.1 k_ult	$V_c * \text{number}$ $34.4 * 5$

row 270

row 280

$$\frac{1}{\Phi} \left[ \left[ \frac{P_u}{P_c} \right]^{5/3} + \left[ \frac{V_u}{V_c} \right]^{5/3} \right] = \frac{1}{0.85} \left[ \frac{0.0}{16.8}^{5/3} + \frac{14.8}{172.1}^{5/3} \right] = 0.020 < 1.000 \text{ OK}$$

$$\left[ \frac{P_u}{P_{ss}} \right]^2 + \left[ \frac{V_u}{V_{ss}} \right]^2 = \left[ \frac{0.0}{115.3} \right]^2 + \left[ \frac{14.8}{96.1} \right]^2 = 0.024 < 1.000 \text{ OK}$$

row 290

HILTI	$F_y$	$F_u$	
HAS Std / A36	36	58	row 300
HAS Super /B7	105	125	
HAS SS /A 304 SS	65	100	

A307		60
A108 studs		60
A325 to 1" Grade 5, B7	92	120
A325-1 1 1/8" to 1 1/2"	81	105
A490 Gr 8, 1/2" - 1 1/2"	120	150
A354 Gr. BD 1/2" to 2 1/2"	120	150

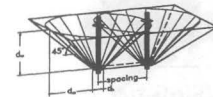
row 310



# BOLT GROUP PULLOUT EXHAUST STACK

**27**

Christy  
18:03  
12/20/05



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Vortex moment and shear govern

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### ANCHORAGE TO CONCRETE, Tension -- Fully Encased Group of Bolts UBC 1923.2

For a group of connectors, use the area of a truncated pyramid projected onto the surface of the slab

This calculation was not a part of the stack calculation set.

$P_u$	0.0 k_ult	tension
$V_u$	14.8 k_ult	shear
spacing_	4.0 in	symetrical in both directions 4, 9, 16, 25, etcetera
number_	4 unit	
	1 logic	OK $4.0 \leq 2 * 5.0$ Use Bolt Group
$P_{ss}$	92.2 k_ult	$0.9 * A_b * f_{ut} * \text{number}_$ $0.9 * 0.44 \text{ in}^2 * 58 \text{ ksi} * 4$
$V_{ss}$	76.9 k_ult	$0.75 * A_b * f_{ut} * \text{number}_$ $0.75 * 0.44 \text{ in}^2 * 58 \text{ ksi} * 4$
Length	15.25 in	$2 * 5.0 \text{ dm} + (4.0 \text{ spacing}) * (\sqrt{4 \text{ number}} - 1) + 1.25 \text{ dh}$
Width	15.25 in	$2 * 5.0 \text{ dm} + (4.0 \text{ spacing}) * (\sqrt{4 \text{ number}} - 1) + 1.25 \text{ dh}$
$A_b$	232.6 in <sup>2</sup>	Length * Width
$P_c$	12.7 k_ult.	$l * A_p * \sqrt{f_c}$ UBC 1923.3.2 $1.00 * 233 \text{ in}^2 * (3,000 \text{ ksi})^{0.5}$
$V_c$	137.7 #REF!	$V_c * \text{number}$ $34.4 * 4$

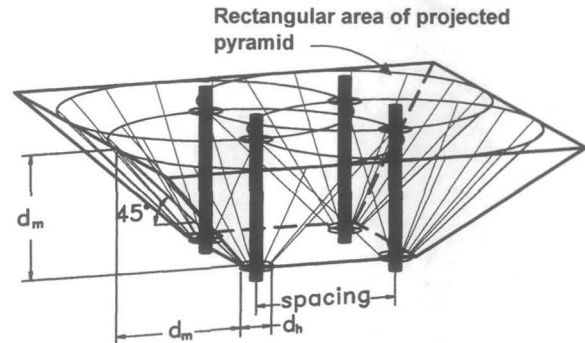


Figure 27-8 View of grouped shear cones.

row 330

row 340

$$\frac{1}{\Phi} \left[ \left( \frac{P_u}{P_c} \right)^{5/3} + \left( \frac{V_u}{V_c} \right)^{5/3} \right] = \frac{1}{0.85} \left[ \left( \frac{0.0}{12.7} \right)^{5/3} + \left( \frac{14.8}{137.7} \right)^{5/3} \right] = 0.029 < 1.000 \text{ OK}$$

$$\left[ \frac{P_u}{P_{ss}} \right]^2 + \left[ \frac{V_u}{V_{ss}} \right]^2 = \left[ \frac{0.0}{92.2} \right]^2 + \left[ \frac{14.8}{76.9} \right]^2 = 0.037 < 1.000 \text{ OK}$$

row 350

row 360

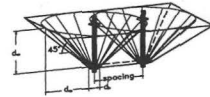
row 370



# BOLT GROUP PULLOUT EXHAUST STACK

**27** Christy  
18:03  
12/20/05

Vortex moment and shear govern



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A B C D E F G H I J K L M N  
ANCHORAGE TO CONCRETE, Shear -- Fully Encased Bolt UBC 1923.3.3

### PARSING UBC 1923.3.2 WHERE:

$A_p$  = the effective area of the projection of an assumed concrete failure surface upon the surface from which the anchor protrudes.

For a single anchor or for an anchor group where the distance between anchors is equal to or greater than twice their embedment length, the surface is assumed to be that of a truncated cone radiating at a 45 degree slope from the bearing edge of the anchor toward the surface from which the anchor protrudes.

row 380

The effective area is the projection of the cone on this surface.

For an anchor which is perpendicular to the surface from which it protrudes, the effective area is a circle.

For an anchor group where the distance between anchors is less than twice their embedment lengths, the failure surface is assumed to be that of a truncated pyramid radiating at a 45 degree slope from the bearing edge of the anchor group toward the surface from which the anchors protrude.

row 390

The effective area is the projection of this truncated pyramid on this surface.

In addition, for thin sections with anchor groups, the failure surface shall be assumed to follow the extension of this slope through to the far side rather than be truncated, and the failure mode resulting in the lower value of  $FP_c$  shall control.

row 400

Do you really think that you can understand this without diagrams?

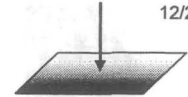
row 410

row 420

row 430



**ROARK FLAT PLATES  
EXHAUST STACK**



28 Roark Flat Plates.xls

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**FLAT CIRCULAR PLATES / CONSTANT THICKNESS** Roark, 5th Edition Table 24 pg 334

a 2.400 in radius to outer edge  
b 0.880 in radius to inner edge  
r<sub>o</sub> 1.600 in radius to location of w

**Check plate bending with several models from Roark and Young page 334**

P 42.90 k  
trib length 10.05 in

**APPROXIMATE RADIUS OF BOLT HEAD**  
For allowable P allowed working calculated in the Bolt Group Pullout template  
**ALONG EDGE OF WASHER**

w 4267 lb/in point load / circumference line load  
q\_uniform 2371 lb/in<sup>2</sup> uniformly distributed load

r\_ 1.00 in radial location of evaluated quantity

t 1.000 in thickness of plate  
v 0.285 unit poisson ratio  
E 29000 ksi Young's modulus of elasticity

r<sub>o</sub> / r 1.600

**CONSTANTS.....**

C\_1' 0.24  
0.42

C\_1 0.658320 unit

C\_2' 0.40

C\_2 0.148945

C\_3' 1.14

C\_3'' -0.87

C\_3 0.024992

C\_4 1.210583

C\_5 0.432778

C\_6' 1.14

C\_6 0.104596

C\_7 1.084433 unit

C\_8' 0.10

C\_8 0.690564

C\_9' 0.64

C\_9'' 0.15

C\_9 0.293091

D 2630314 lb-in

plate constant  
 $29,000 * 1.00^3 / (12 * (1 - 0.285^2)) * 1000$  lb/k

F\_1' 0.08

F\_1 0.13

F\_2' 0.97

F\_2 0.01

F\_4' 0.63

F\_4 0.72

F\_5 0.11

F\_6 0.01

F\_7 0.12

F\_9' 0.08

F\_9 0.00

F\_9 0.07

r r\_ 0 logic 1.000 > 1.600 singularity factor

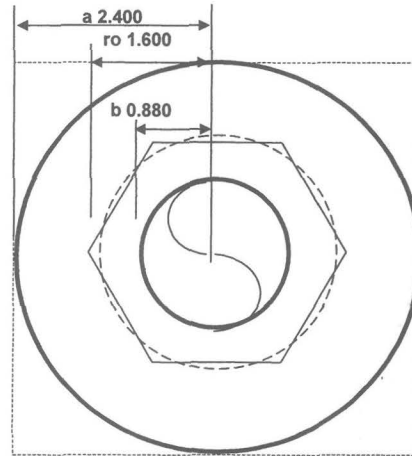
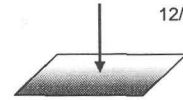


Figure 28-1 PLAN VIEW OF PLATE/WASHER

lb/in<sup>2</sup> = psi  
k = 1000 Lbs.



**FLAT CIRCULAR PLATES / CONSTANT THICKNESS -- Continued**

Roark Table 24, Case 2k: Outer edge free, inner edge simply supported... page 342

**INPUTS FROM ABOVE**

a	2.400 in	radius to outer edge
b	0.880 in	radius to inner edge
r <sub>o</sub>	1.600 in	radius to location of w
q <sub>uniform</sub>	2371 lb/in <sup>2</sup>	uniformly distributed load
t	1.00 in	thickness of plate
v	0.29 unit	Poisson ratio
E	29000 ksi	Young's modulus of elasticity

y <sub>b</sub>	0	] per Roark
M <sub>ra</sub>	0	
M <sub>rb</sub>	0	
Q <sub>a</sub>	0	
Q <sub>b</sub>	0	

q <sub>b</sub> '	-0.01149	=-q*(a <sup>3</sup> )/(D*C7)
q <sub>b</sub> ''	0.22204	=(C <sub>9</sub> /((2*A*B)))*(A <sup>2</sup> -R0 <sup>2</sup> )
q <sub>b</sub>	-0.00255 radian	

Q <sub>b</sub>	4310 lb/in	shear
----------------	------------	-------

$(Q_{uniform} / (2 * b)) * (a^2 - r_o^2)$   
 $(2,371 / (2 * 0.880)) * (2.400^2 - 1.600^2)$

y <sub>a</sub> '	-0.0040
y <sub>a</sub> ''	0.0006
y <sub>a</sub> '''	0.0000

y <sub>a</sub>	-0.0035 in	deflection
----------------	------------	------------

q <sub>a</sub> '	-0.00309
q <sub>a</sub> ''	0.00099
q <sub>a</sub> '''	0.00006
q <sub>a</sub>	-0.00216 radian

r	1.00 in	radial location of quantity being evaluated -- input from above
M <sub>t</sub>	-5231 lb-in/in	theta * D * (1 - v <sup>2</sup> ) / r + v * Mr -0.00216 * 2,630,314 * (1 - 0.285 <sup>2</sup> ) / 1.600 + 0.285 * 0

t	1.0000 in	from input above
S	0.16667 in <sup>3</sup>	1 * t <sup>2</sup> / 6
f <sub>b</sub>	-31 k/in <sup>2</sup>	M <sub>t</sub> / S

**CANTILEVER PLATE COMPARISON**

q	2371 psi
L	1.96 in
M <sub>pl</sub>	4554 lb-in
t <sub>pl</sub>	1.00 in
S <sub>pl</sub>	0.16667 in <sup>3</sup>
f <sub>b</sub>	27.32 ksi

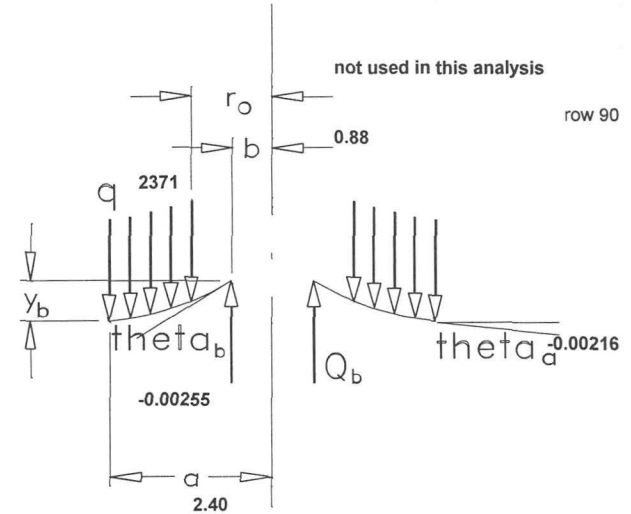


Figure 28-2 PLATE LOADING AND DEFLECTION

Q	unit shear	lb / inch of circumference
M <sub>o</sub>	unit applied line moment	in-lb / inch of circumference
M <sub>r</sub>	unit radial bending	in-lb / inch of circumference
M <sub>t</sub>	unit tangential bending	in-lb / inch of radius

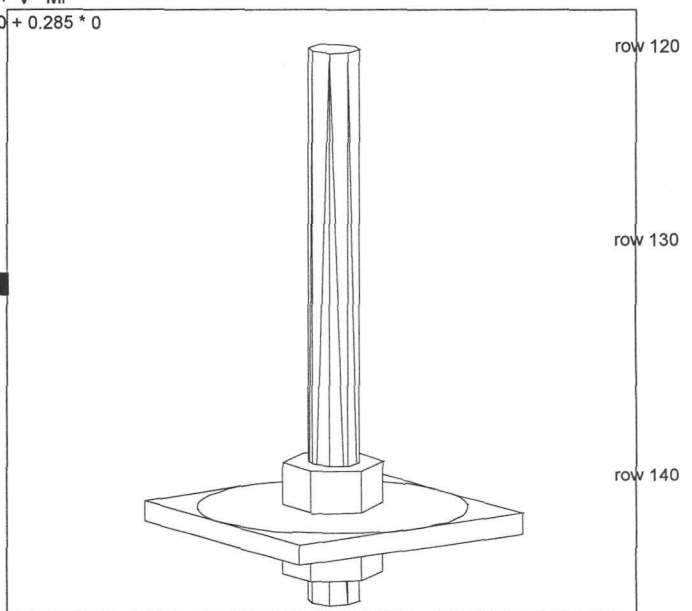
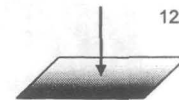


Figure 28-3 CANTILEVERED ANCHOR PLATE

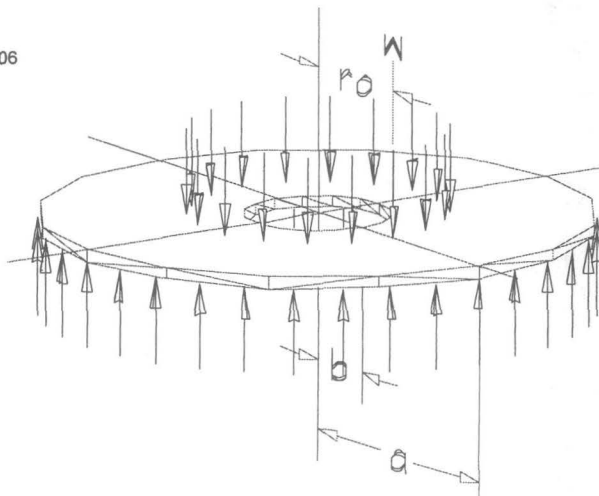


28 Roark Flat Plates.xls

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FLAT CIRCULAR PLATES / CONSTANT THICKNESS -- Continued  
Roark Table 24, Case 1a: Outer edge simply supported, inner edge free ... page 335

$y_b'$	0.1406	
$y_b$	0.00 in	$-4,267 * 2.40^3 / 2,630,314 * 0.1406$ lb/in in <sup>3</sup> / lb-in
$\theta_{b'}$	0.22	
$\theta_{b''}$	-0.001	
$M_{rb'}$	0.00	
$M_{rb''}$	0.00	
$Q_{b'}$	0.00	
$Q_b$	0.00 lb/in	
$y'$	0.00	
$y''$	0.00	
$y'''$	0.00	
$y''''$	0.00	
$y$	0.00	
$\theta_{a'}$	0.00	
$\theta_{a''}$	0.00	
$\theta_{a'''}$	0.00	
$\theta_{a''''}$	0.00	
$\theta_{a}$	-0.001	
$M_r'$	-266.80	
$M_r''$	0.00	
$M_r'''$	0.00	
$M_r''''$	0.00	
$M_r$	-266.80 lb-in	



row 160

row 170

Figure 28-4 PLATE LOADING

row 180

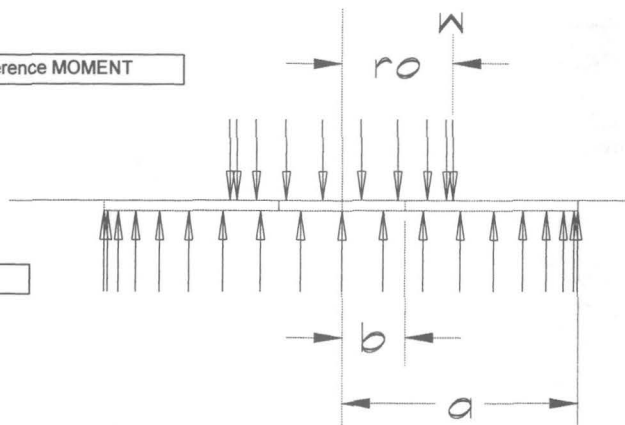
$M_t$  -1576.45 lb-in tangential moment / inch of circumference MOMENT

S provided 0.1666667 in<sup>3</sup>/in 1.0000<sup>3</sup>/6

$f_b$  -9459 lb/in<sup>2</sup> /in stress in plate  
-9.5 ksi

$Q$  =  $B164 * b / r - W * r_0 / r - \dots * R_{RO}$   
 $\theta_{a'}$

$Q_a$  -2844.89 lb / inch of circumference SHEAR



row 190

row 200

Figure 28-5 PLATE LOADING

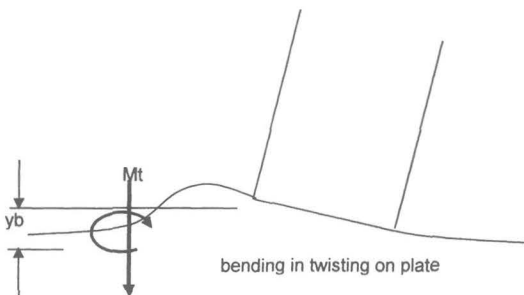


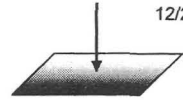
Figure 28-6 PLATE TWISTING



Figure 28-7 PLATE BENDING

row 210

row 220



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**FLAT CIRCULAR PLATES / CONSTANT THICKNESS -- Continued**

Values from above for Roark Table 24, Case 1a page .... 362

a	2.4 in	radius to outer edge
ro	1.6 in	radius to location of w
q	2371 lb/in <sup>2</sup>	
t	1 in	thickness of plate
v	0.285 unit	poisson ratio
E	29000000 psi	Young's modulus of elasticity

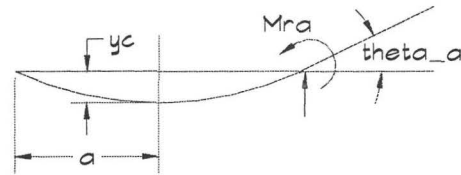


Figure 28-8 PLATE BENDING DIAGRAM

supported edge  
simply supported edge

Roark, Table 24 Case 10a: Outer edge simply supported ... page 363

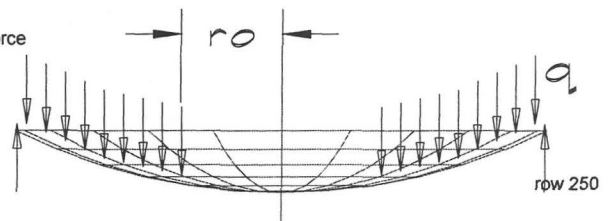
ya	0	per Roark
Ma	0	
L_11	0.000	from above
L_17	0.045	from above
yc	-0.0005 in	$-q * a^4 / (2 * D) * (L_17 / (1 + v) - 2 * L_11)$ $-2,371 * 2.400^4 / (2 * 2,630,314) * (0.04514 / (1 + 0.285) - 2 * 0.00044)$

deflection at center of plate

row 240

Mc	616 lb-in	$q * a^2 * L_17$ M at center of plate
S	0.1666667 in <sup>3</sup>	
fb	3698 psi	
qa	0.0007 radians	$q / (8 * D * a * (1 - v)) * (a^2 - ro^2)^2$
Qa	-1580.50	$-q / (2 * a) * (a^2 - ro^2)$

shear force



row 250

Figure 28-9 PLATE SUPPORT

supported edge  
fixed edge

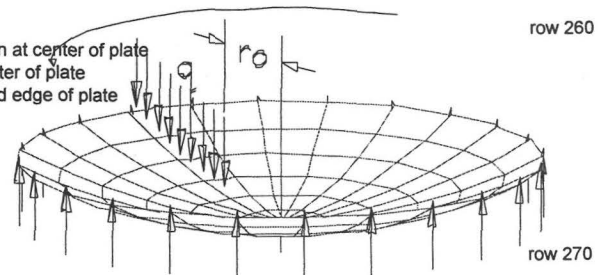
Roark Table 24, Case 10b: Outer edge fixed supported ... page 363

ya	0	per Roark
theta_a	0	
L_11	0.000	from above
L_14	0.005	from above
L_17	0.045	from above
yc	0.000 in	$-q * a^4 / (2 * D) * (L_14 - 2 * L_11)$
Mc	616.37 lb-in	$q * a^2 * L_17$
Mra	-526.832 lb-in	$-q / (8 * a^2) * (a^2 - ro^2)^2$

deflection at center of plate  
M at center of plate  
M at fixed edge of plate

row 260

S_plate	0.167 in <sup>3</sup>	$b * t^3 / 6$
M	616 lb-in	
fb	4 k/in <sup>2</sup>	

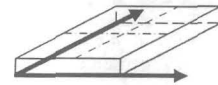


row 270

Figure 28-10 VIEW OF PLATE DEFLECTION

row 280

row 290



### FOOTING CONFIGURATIONS

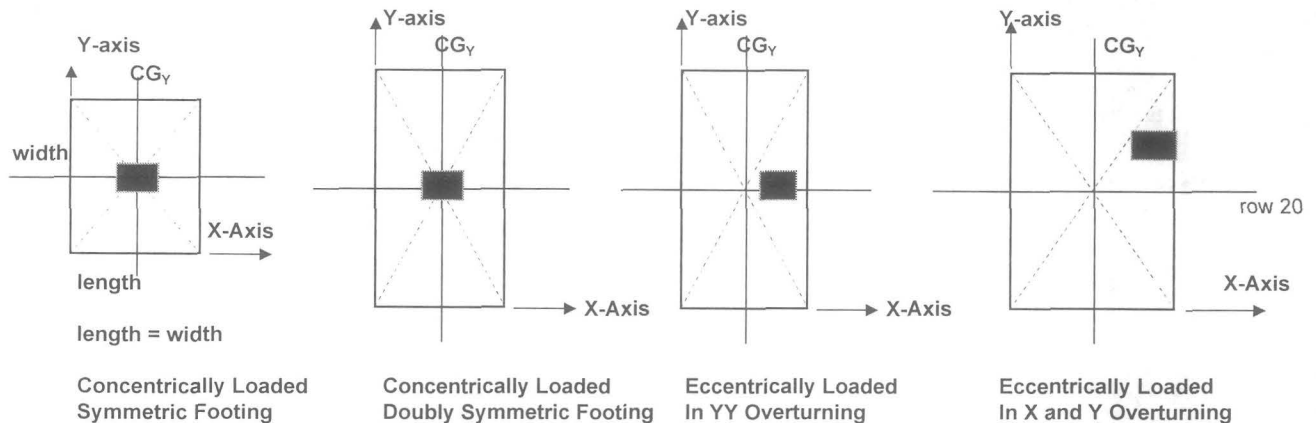


Figure 29-1 Loading configurations of eccentrically loaded rectangular footings.

row 30

So long as all edges are positively loaded, any of these configurations can be calculated with the trapezoidal soil loading profile.

When an edge is unloaded X or Y overturning (but not both together) can be calculated with the triangular soil loading profile. Where a footing is eccentrically loaded in both X and Y overturning, loading can be determined using iterative calculations or the *Rotating Footing* template.

### Theory Versus Reality

Concrete footings are designed as rigid elements which is conservative. Concrete is flexible and deflects into the soil. The interior of the footing loads the soil more than the edges do.

row 40

A key element in soil loading is the soil modulus which is measured in  $\text{lb}/\text{in}^2/\text{in}$ .

This value is usually given as  $\text{lb}/\text{in}^3$ .

Good soil usually has a modulus of  $200 \text{ lb}/\text{in}^3$  or better.

I've built floating foundations on soil having a modulus of  $20 \text{ lb}/\text{in}^3$ .

Good fill will have a modulus of  $400$  to  $500 \text{ lb}/\text{in}^3$  but in conditions where soil modulus is poor, good fill results are not possible. Either a floating foundation or some type of piling is required.

row 50



Figure 29-2 Deflections as governed by soil modulus.

row 60

Eccentrically loaded footings and floating foundations on poor soil risk significant differential deflections. Concrete flexibility and soil modulus should be considered together when differential deflections are calculated.

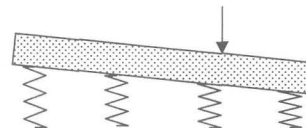
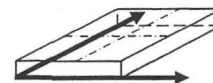


Figure 29-3 Differential deflections due to an eccentric loads.

row 70

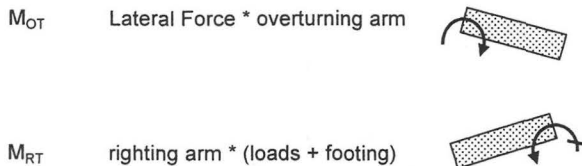


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**FOOTING CONFIGURATIONS -- Continued**

All forces are calculated at the concrete/soil interface -- not the top of the footing.



No matter where a moment is placed along a line, the effect is the same. All of the moment symbols could be shown in the middle of the concrete/soil interface but then, you wouldn't be able to read the diagram.

Generally, we try to design footings as concentrically loaded. Some footings must be eccentrically loaded when there is not enough room to locate the footing directly under the load.

Eccentrically loaded footings under expected dead and live loads should have all edges positively loaded. Eccentricity should conform to:

$$e < \text{length}/6$$

Footings subjected to lateral, overturning loads due to seismic, wind, or other impact loading may unload one edge. Soil does not work in tension. This results in a triangular soil loading profile.

If the footing demonstrates triangular loading in both directions, calculate the soil pressure with the *Rotating Footing* template.

The footing calculated here is a simple, doubly symmetric shape. Length and width can be different with the center of gravity of the footing in the exact, geographic middle.

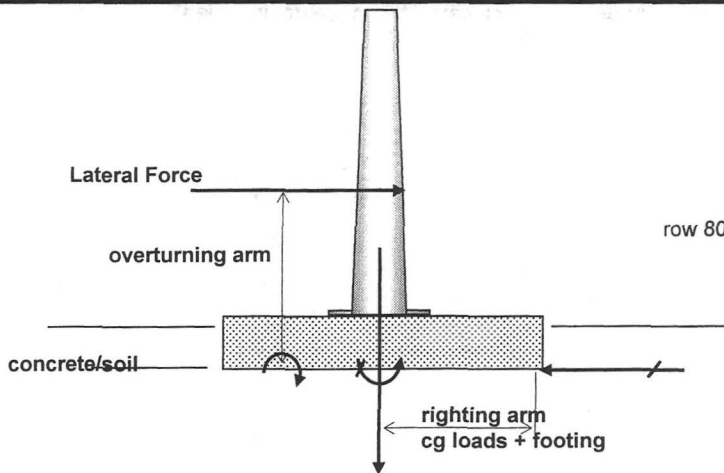


Figure 29-4 Applied forces and reactions. row 90

→ acting force  
← reaction

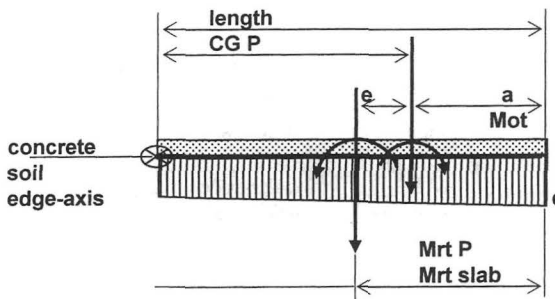


Figure 29-5 TRAPAZOIDAL FOOTING PROFILE

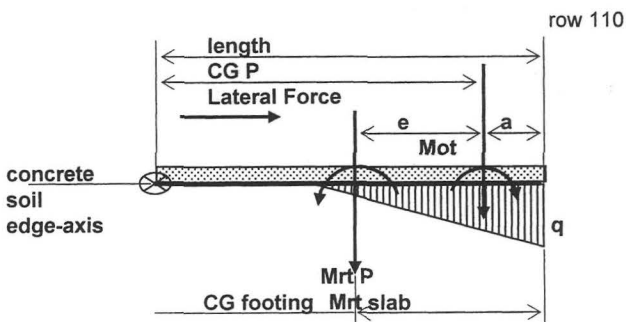
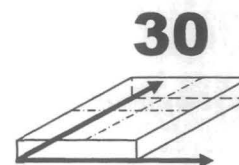


Figure 29-6 TRIANGULAR FOOTING PROFILE

⊗ X or Y axis normal to the page (in and out of the page)



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A	B	C	D	E	F	G	H	I	J	K	L	M	N
TRAPEZOIDAL SOIL LOADING, ALL EDGES LOADED												16.00' x 16.00' x 2.00'	

The trapezoidal loading calculations are not included in the stack calculation set.

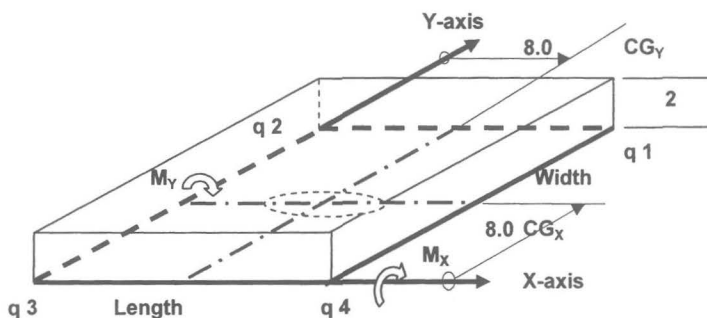


Figure 30-1 FOOTING VIEW

- $M_x$  moment about the x-axis or an axis parallel to the x-axis, k-ft
- $Mot_x$  overturning moment about the x-axis, k-ft
- $Mrt_x$  righting moment about the x-axis from loads working in the opposite direction of  $Mot_x$ , k-ft
- $CG_x$  center of gravity from the x-axis, ft  
This is a distance from the x-axis, not a vector.
- $e_x$  eccentricity of all loads including dead and live loads, the slab, and moment due to seismic or wind forces geographical center of gravity  $CG_x$ , ft
- $I_{xx}$  moment of inertia about the x-axis or an axis parallel to the x-axis,  $ft^4$
- $q_x$  soil pressure along the loaded, top, edge, ksf

row 30

from x ↑ **16.00** ft width of slab  
 $I_{xx}$  ↑ 5461  $ft^4$  rotate about axis parallel to XX  
 $CG_x$  ftg ↑ 8.0 ft from the bottom edge

from y → **16.00** ft length of slab  
 $I_{yy}$  → 5461  $ft^4$   
 $CG_y$  ftg → 8.0 ft from the left edge

Locate the Structure CG on the Slab  
 $CG P_x$  ↑ **8.0** ft from the bottom edge

$CG P_y$  → **8.0** ft from the left edge

$h_{slab}$  **2.00** ft slab depth  
 Area 256  $ft^2$   
 weight c 76.8 k weight of concrete  
 19.0  $yard^3$  volume of concrete

$P_{DL}$  **6.944** k dead loads  
 $P_{LL}$  **0.000** k live loads  
 $P_{DL+LL}$  **6.944** k sum of structure DL + LL  
 $P_{sum}$  **83.744** k sum of structure DL + LL + concrete footing

$q$  at rest 1.309 ksf

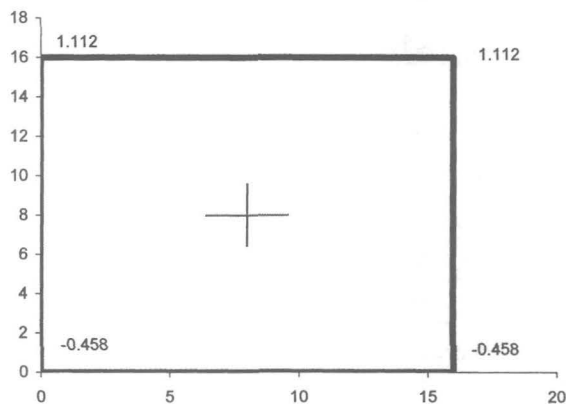


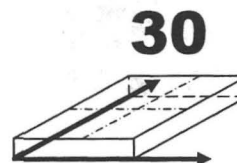
Figure 30-2 Footing loaded under entire footing bearing area in trapezoidal loading.

ASD values  
 $Mot_x$  ↑ **536.1** k-ft  
 $Mrt_{DL_x}$  55.6 k-ft  
 $Mrt_{LL_x}$  0.0  
 $Mrt_{slab_x}$  614.4  
 sum  $Mrt_x$  **670.0**

ASD values  
 $Mot_y$  → **0.0** k-ft  
 $Mrt_{DL_y}$  55.6 k-ft  
 $Mrt_{LL_y}$  0.0  
 $Mrt_{slab_y}$  614.4  
 sum  $Mrt_y$  **670.0**

row 60

row 70



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>TRAPEZOIDAL SOIL LOADING, ALL EDGES LOADED -- Continued</b>														16.00' x 16.00' x 2.00'
$a_x$		1.60 ft		$(Mrt_x - Mot_x) / p\_sum$ (670.0 - 536.1) / 83.744				$a_y$	8.00 ft		$(Mrt_y - Mot_y) / p\_sum$ (670.0 - 0.0) / 83.744			
$cg_x \uparrow$		8.00 ft		from loaded top edge				$cg_y \rightarrow$	8.00 ft		from loaded right edge			
$e_x$		6.40 ft		$cg_x - a_x$				$e_y$	0.00 ft		$cg_y - a_y$			

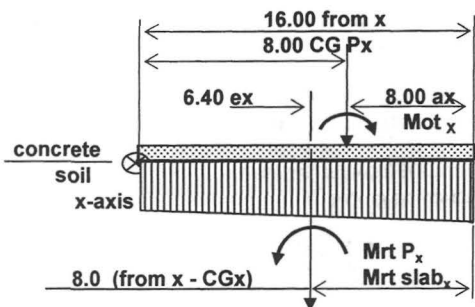


Figure 30-3 Trapezoidal footing profile rotating about the x-axis for  $Mot_x$ .

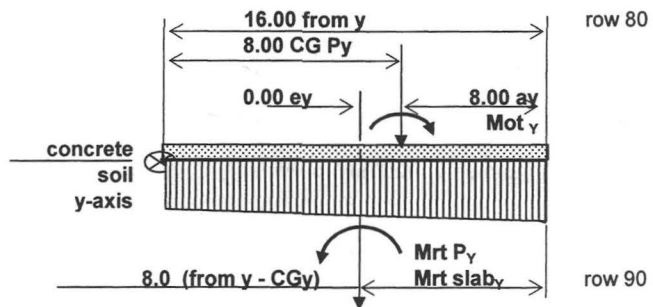


Figure 30-4 Trapezoidal footing profile rotating about the y-axis for  $Mot_y$ .

**Trapezoidal q in X and Y Directions**

	P/A	$\pm Pe_x c_x / I_{xx} \uparrow$	sum q	P/A	$\pm Pe_y c_y / I_{yy} \rightarrow$	sum q
q 1 & 2	0.327	0.785	1.112 ksf	0.327	0.000	0.327 ksf
q 3 & 4	0.327	-0.785	-0.458 ksf !!!	0.327	0.000	0.327 ksf

**Trapezoidal q at Each Corner**

	P/A	$\pm Pe_x c_x / I_{xx} \uparrow$	$\pm Pe_y c_y / I_{yy} \rightarrow$	sum q
q 1	0.327	0.785	0.000	1.112 ksf
q 2	0.327	0.785	0.000	1.112 ksf
q 3	0.327	-0.785	0.000	-0.458 ksf
q 4	0.327	-0.785	0.000	-0.458 ksf

← These flagged loadings indicate that triangular loading calculations apply

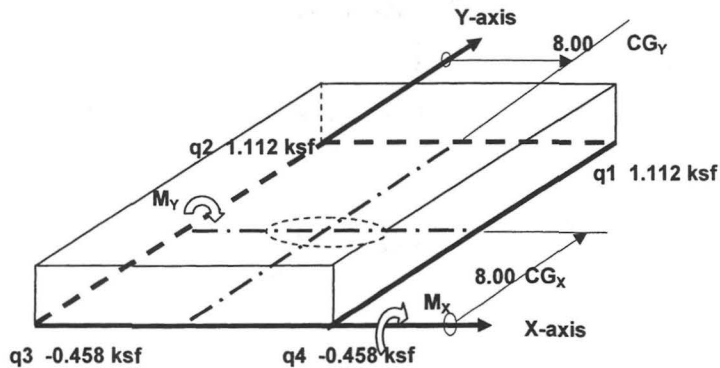


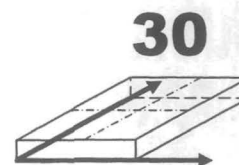
Figure 30-5 Trapezoidal bearing values.

All values to calculate soil pressure are taken from the concrete/soil interface, not the top of the slab.

Anchor bolt values are calculated at the top of the slab.

row 120

row 130



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Soil cannot work in tension under a footing. However, the footing can exert force on just part of its available bearing area.

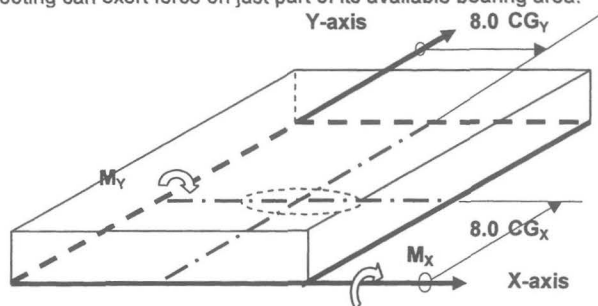


Figure 30-6 FOOTING VIEW

$M_x$  moment about the x-axis or an axis parallel to the x-axis, k-ft  
 $Mot_x$  overturning moment about the x-axis, k-ft  
 $Mrt_x$  righting moment about the x-axis from loads working in the opposite direction of  $Mot_x$ , k-ft  
 $CG_x$  center of gravity from the x-axis, ft  
 $e_x$  eccentricity of all loads including dead and live loads, the slab, and moment due to seismic or wind forces geographical center of gravity  $CG_x$ , ft  
 $I_{xx}$  moment of inertia about the x-axis or an axis parallel to the x-axis, ft<sup>4</sup>  
 $q_x$  soil pressure along the loaded, top, edge, ksf  
 $a_x$  the 1/3 point of the triangular soil loading profile, ft

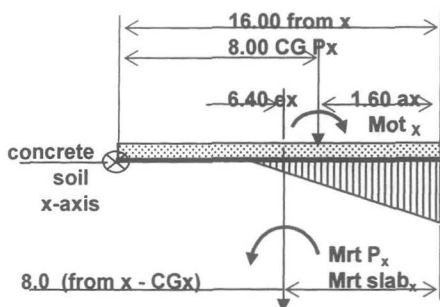


Figure 30-7 Triangular footing profile rotating about the x-axis.

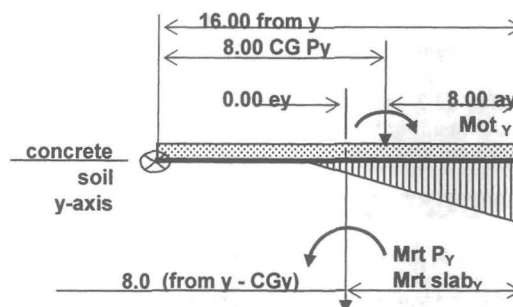


Figure 30-8 Triangular footing profile rotating about the y-axis.

from x ↑	16.00 ft	width along Y-axis	from y →	16.00 ft	length along X-axis
$CG_x$ ↑	8.0 ft	geographical location	$CG_y$ →	8.0 ft	
$CG_{P_x}$ ↑	8.0 ft	geographical location	$CG_{P_y}$ →	8.0 ft	
P sum	83.7 k	sum of structure DL + LL + slab			
$Mot_x$ ↑	536.1 k-ft	working wind or seismic structure from the top edge	$Mot_y$ →	0 k-ft	toward the right edge
$Mrt_{struct_x}$	55.6 k-ft	structure from the top edge	$Mrt_{struct_y}$	55.6 k-ft	structure from the right edge
$Mrt_{slab_x}$	614.4 k-ft	slab from the top edge	$Mrt_{slab_y}$	614.4 k-ft	slab from the right edge
$cg_x$	8.0 ft	from loaded top edge	$cg_y$	8.0 ft	from loaded right edge
$e_x$	6.40 ft.		$e_y$	0.00 ft.	
e's	1 logic	OK only one eccentricity			
$a_x$	1.60 ft		$a_y$	8.00 ft	

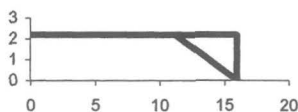


Figure 30-9 Triangular bearing profiles.

$q_x$ 1 & 2	2.183 ksf.	$\frac{2*P \text{ sum}}{(3*edge_x*(edge_y/2-e_x))}$	$q_y$ 1 & 3	0.436 ksf.	$\frac{2*P \text{ sum}}{(3*edge_y*(edge_x/2-e_y))}$
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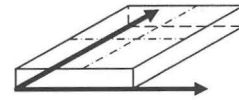
row 190



# FOUNDATION DESIGN EXHAUST STACK

# 31

Christy  
18:09  
12/20/05



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## CONCRETE DESIGN IN UPLIFT

For Bolt Circle		
cg	8.00 ft	longest cg to be considered
radius	2.00 ft	radius of tank pads or bolts from CL tank
box	3.54 ft	$(\pi) * \text{radius}^2 * 0.5$
		equivalent side of square
arm	4.46 ft	
slab_h	2.00 ft	depth of slab
q_ult	0.42 ksf_ult	$1.4 * \text{slab}_h * 0.15 \text{ k/ft}^3$
Pu	1.9 k_ult	
Mu	4.2 k-ft_ult	top reinforcing in tension

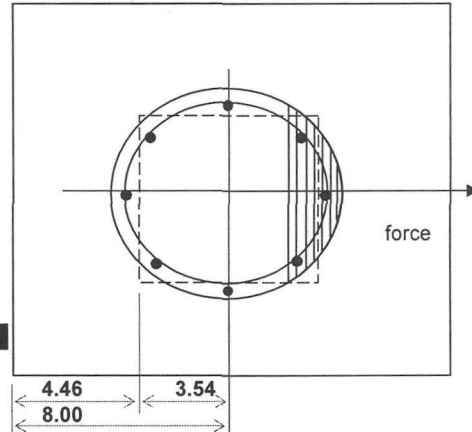


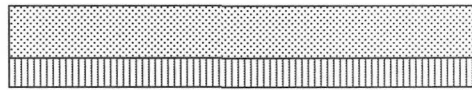
Figure 31-1 CIRCULAR LOADING PLAN

## LRFD FACTORING '97 UBC

DL	1.309 ksf
wind+DL	2.183 ksf
wind	0.874 ksf

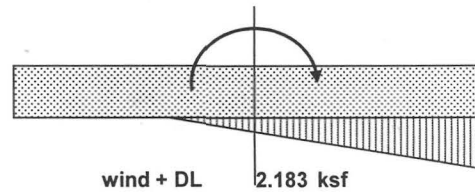
1612.2.1 Basic load combinations with exception 2 -- multiply loads with 1.1 for loads including seismic forces

D	1.309	dead load -- max DL righting moment
L	0	live load or earth pressure
L <sub>r</sub>	0	roof live load
S	0	snow
W	0.874	wind
E	0	seismic -- when derived from the UBC, use E/1.4
T	0	differential settlement
H	0	earth pressure
F	0	fluid pressure, load factor = 1.4
f <sub>1</sub>	1.0	1.0 floors in public assembly, LL > 100 psf, garage 0.5 of other live loads
f <sub>2</sub>	0.2	0.7 roofs that can't shed snow, 0.2 other
E <sub>-</sub>	1.1 multiplier	use 1.1 for concrete and masonry subjected to seismic forces



DL 1.309 ksf  
LL 0.000 ksf  
Figure 31-2 At-rest DL and LL loads.

12-1	2.016	1.1 * 1.4 D
12-2	1.728	1.1 * (1.2D + 1.6*L + 0.5* (L or S))
12-3	2.497	1.1 * (1.2D + 1.6(L <sub>r</sub> or S) + (f <sub>1</sub> L or 0.8W))
12-4	2.978	1.1 * (1.2D + 1.3W + f <sub>1</sub> L + 0.5(L <sub>r</sub> or S))
12-5a	1.728	1.1 * (1.2D + 1.0E + (f <sub>1</sub> LL + f <sub>2</sub> S))
12-6a	2.546	1.1 * (0.9D + 1.0E or 1.3W)
12-6b	2.546	1.1 * (0.9D - 1.0E or 1.3W)
max	2.978 ksf ult	



wind + DL 2.183 ksf  
Figure 31-3 Overturning soil loading profile.

1909.2		
9-1	1.833	1.4D + 1.7L
9-2a	2.489	0.75 (1.4D + 1.7L + 1.7W)
9-2b	1.512	1.1 * 0.75 (1.4D + 1.7L + 1.7E)
9-3a	2.314	0.9D + 1.3W
9-3b	1.440	1.1 * (0.9D + 1.3 E)
9-4a	1.833	1.4D + 1.7L + 1.7H
9-4b	1.178	0.9D + 0L + 1.7H
9-5	1.374	0.75 (1.4D + 1.4T + 1.7L)
9-6	1.833	1.4 (D + T)
max	2.489 ksf ult	
ratio	1.364	wind + DL ultimate / wind + LL

row 20

row 30

row 40

row 50

row 60

row 70

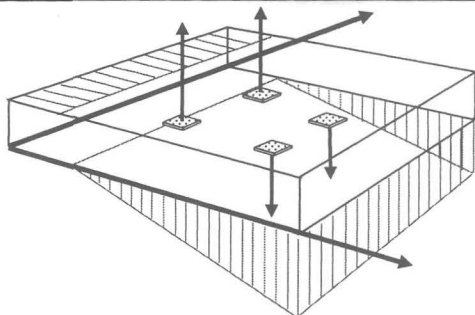
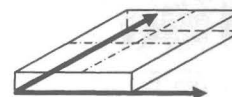


Figure 31-4 SOIL PRESSURE VIEW

q loaded	1.661 ksf	soil pressure loading slab + DL + LL
q unload	0.000 ksf	
3a	19.98 ft	3 * a <sub>x</sub> or a <sub>y</sub> or length/width of footing
L	21 ft	length of footing in direction of 3a
W	17 ft	width of footing perpendicular to direction of vessel movement

h	2.5 ft	depth of footing
d	2.17 ft	

ratio	0.893 unitless	ratio of LRFD to ASD loads
ratio use	1 unitless	use this ratio of LRFD to ASD loads

### Moment One

Determine cantilever moment from face of equivalent square. Use an averaged soil pressure against an approximated beam of width = d.

Cant 1	6.50 ft	cantilevered slab approximated to face of equivalent square $(1 - 2.50 / \text{MIN}(21.00, 19.98)) * (1.661 - 0.000)$
q triangle	1.453 ksf	
q rect	0.000 ksf	
q avg	1.453 ksf	
M	30.7 k-ft	
<b>Mu</b>	<b>30.7 k-ft ult</b>	

### Moment 2

CG down	6.5 ft	baseplate(s) bearing down to loaded edge
	0	
M	-2.7	full triangle
q triangle	1.121 ksf	$(1 - 6.50 / \text{MIN}(21.00, 19.98)) * (1.661 - 0.000)$
q rect	0.00 ksf	
q	1.121 ksf	for reference
M 2	15.8 k-ft	$6.50 * 2/3 * 1.121 * 6.50 / 2$
M 3	0 k-ft	$0.000 * 6.50^2 / 2$
M sum	15.8 k-ft	
<b>Mu</b>	<b>15.8 k-ft ult</b>	

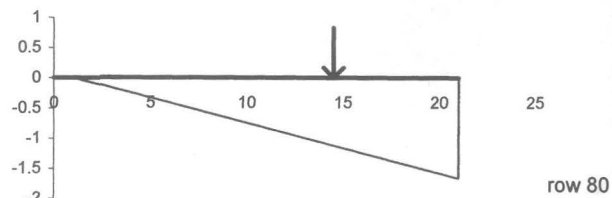


Figure 31-5 SOIL PRESSURE PROFILE

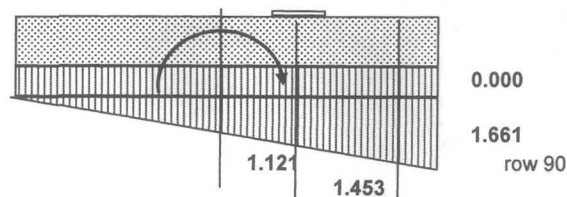


Figure 31-6 SOIL PRESSURE DIAGRAM

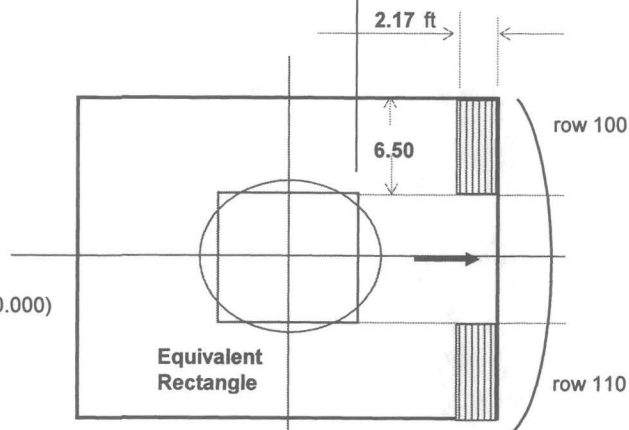


Figure 31-7 LOADING PLAN

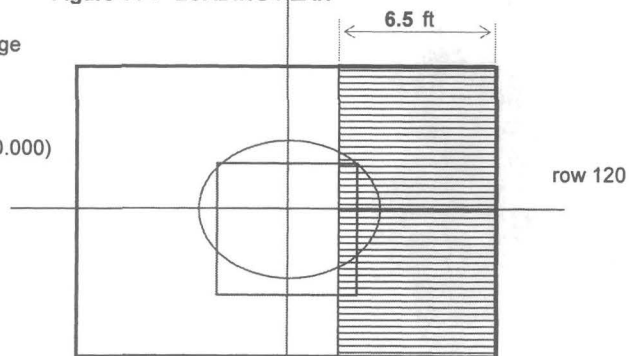


Figure 31-8 LOADING PLAN

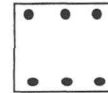


# REINFORCED CONCRETE BEAM INTRODUCTION EXHAUST STACK

Not included on the CD-ROM

# 32

Christy  
15:32  
12/20/05



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32 Concrete Beam Introduction.xls

A B C D E F G H I J K L M N  
The Concrete Beam Template

The concrete beam template can be used for singly and doubly reinforced rectangular, spandrel, and T beams. It is a documented and range named template suitable for study or explaining your design to the Building Official.

American Concrete Institute  
<http://www.aci-int.org/general/home.asp>

**Inputs**  
Dimensions and reinforcing

**Summary Output**  
Mu provided  
Moments of inertia

**Gross Moment of Inertia**  
Including  $+A'_s$  and  $-A'_s$   
 $w x x/2 = n A'_s (x - d') + n A_s (d' - x)$

row 20

**$\rho$  minimum**  
Minimum density of reinforcing  
 $3 \sqrt{f'_c} / f_y b_w d$  02 ACI 10.5.1 (10-3)  
 $200 b_w d / f_y$  ACI 21.3.2 seismic

**Effective Moment of Inertia**  
Using the cracked section

row 30

**Rectangular/ T-beam Logic**

**Creep versus Time**  
**Temperature Reinforcing**

**$\beta_1$  Reduction Factor**  
reduce the .85 factor by .05 for each 1000 psi over 4000 psi

**Balanced Strain**  
 $\epsilon'_c / (\epsilon'_c + \epsilon_t / E_s) d$

**Whitney's Stress Block**  
 $\beta_1 * x_{balance} = a$  max stress block

**Tension Reinforcing Strain**  
 $\epsilon_t = f_y / E_s$

row 40

**Solution for  $x_{balance}$  Strain**  
Using the quadratic equation

row 50

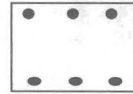
**Calculation of  $M_n$  and  $M_u$**   
 $M_n = a b_w \text{ arm} = T_s \text{ arm}$   
 $M_u = 0.9 M_n$

row 60

**Verifying Graphs**

Figure 32-1 TEMPLATE LAYOUT

row 70



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**CONCRETE BEAM DESIGN** | gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

$f_y$	60 ksi	yield strength of reinforcing
$f_c$	3 ksi	compressive strength of concrete
$d'$	2.5 in	depth of compression reinforcing
$b_w$	13 in	width
$d$	20.5 in	depth of tension reinforcing
depth_OA	27 in	overall depth

	Bar Qty	Bar Size#	$A_s$
$A'_s$	0.00	6	0.00 in <sup>2</sup>
$A_s$	1.00	6	0.44 in <sup>2</sup>

$M$ working	21.9 k-ft	required service level moment
$M_u$ req'd	30.7 k-ft ult	required ultimate/factored moment

$M_u$  prov 39.80 k-ft ultimate provided

OK Beam stressed to 77 % **NOTE: 77% ≈ 75%**

**!!! As min 0.89 > As provided 0.44** see  $\rho_{min}$  below

OK x balance 7.62 ≥ 0.937 required

Length	39 ft	length of joist
t	4.5 in	thickness of slab
c	78 in	spacing of joists
flange	0 logic	0 = no flanges, 1 = spandrel, 2 = T beam

$I_a$	21500 in <sup>4</sup>	
$I_{cracked}$	1365 in <sup>4</sup>	
$I_e$	21500 in <sup>4</sup>	
$\epsilon_t$	0.00507 unitless	allowable tension reinforcing strain 0.00400 minimum strain allowed

#### $\rho_{min}$ -- Minimum Reinforcement in Flexural Members

$A_s \min_1 = 0.73 \text{ in}^2$   $3 \sqrt{f_c} / f_y b_w d$  02 ACI 10.5.1 (10-3)  
 $3 * \sqrt{3 * 1000} * 13.0 * 20.5 / 60 / 1000$

$A_s \min_2 = 0.89 \text{ in}^2$   $200 * w * d / f_y / 1000$  02 ACI 10.5.1  
 $200 * 13.0 * 20.5 / 60 / 1000$

$A_s \text{ logic} = 0 \text{ logic}$   $MAX(0.89, 0.73) \leq 0.44$

When the area of tension reinforcing steel is less than  $+A_s$  minimum, the amount of reinforcing provided must be increased by 1/3 beyond that needed for tensile reinforcement. 02 ACI 10.5.3

When the beam is stressed to 75% and  $+A_s = 1.33 * A_s$  provided, the minimum requirements of reinforcement have been met.

#### For Seismic Resistance

$A_s \min = 0.89 \text{ in}^2$   $200 * b_w * d / f_y$  ACI 21.3.2  
 $200 * 13 * 20.5 / 60 / 1000$

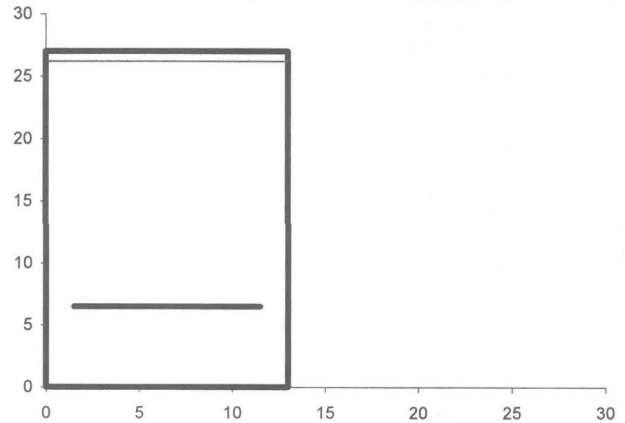


Figure 33-1 Beam cross-section with Whitney's stress block and reinforcing.

row 30

Bar Size # in American nomenclature, bar size is given as a number which equates to 8 th's of an inch hence, a #6 bar is 6/8 inch = 3/4"

$f_y$  ultimate tensile strength of reinforcing, k/in<sup>2</sup>  
 $f_c$  ultimate compression strength of concrete, k/in<sup>2</sup>

American Concrete Institute  
<http://www.aci-int.org/general/home.asp>

row 40

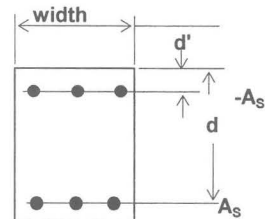


Figure 33-2 Beam cross-section.

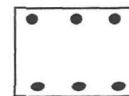
row 50

$-A_s, A'_s$  negative reinforcing - usually the top steel, in<sup>2</sup>

$+A_s$  positive reinforcing - usually the bottom steel, in<sup>2</sup>

row 60

row 70



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CONCRETE BEAM DESIGN -- Continued I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

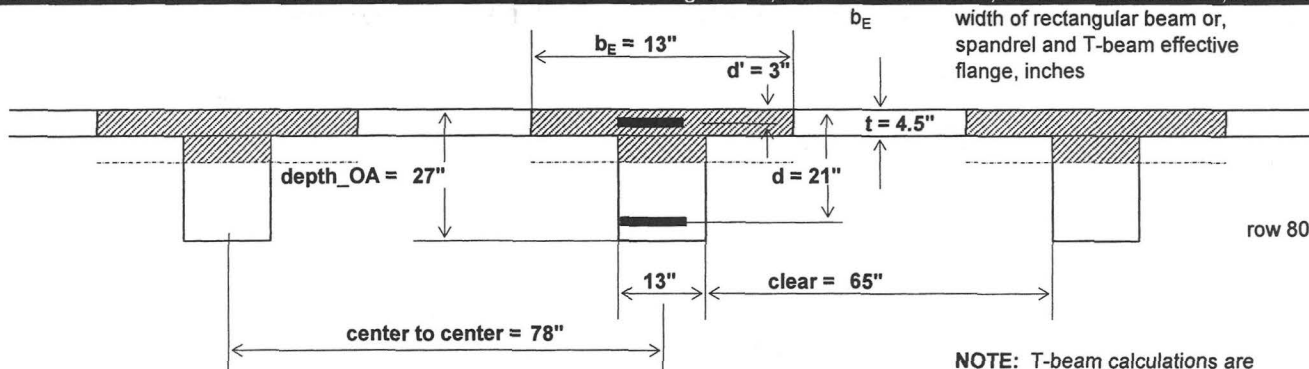
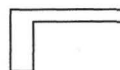


Figure 33-3 T-beam framing cross section.

NOTE: T-beam calculations are required before the doubly reinforced calculations can be done.

**Spandrel beam ACI 8.10.3**

$b_E$	39 in	39' * 12 in/ft /12
$b_E$	40 in	4.5" * 6 + 13" beam width
$b_E$	45.5 in	(78" - 13" beam width) /2 + 13" spandrel
$b_E$	39 in	



**T-beam 02 ACI 8.10.2**

$b_E$	117 in	39' * 12 in/ft /4
$b_E$	85 in	4.5" * 16 + 13" beam width
$b_E$	78 in	78" c-c beam spacing
$b_E$	78 in	maximum width of flange
$b_E$	78 in	



**Type of beam and overhang**

slab trib	$b_E$	logic	$b_E$	overhang OH
beam	13	1	13	0
spandrel	39	0	0	0
T-beam	78	0	0	0
			13	0

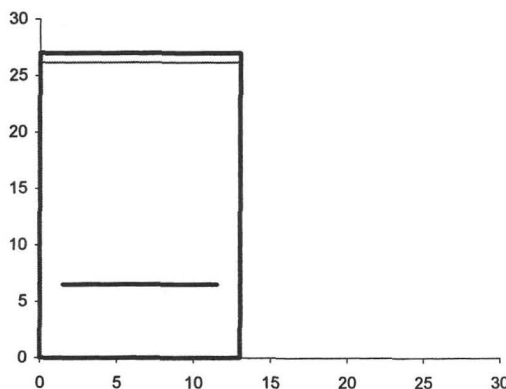
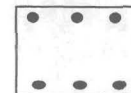


Figure 33-4 Beam cross-section.

**vLookUp Table**

Bar	Area
10M	0.12
15M	0.27
20M	0.49
25M	0.76
30M	1.1
35M	1.49
45M	2.47
55M	3.68
0	0
3	0.11
4	0.2
5	0.31
6	0.44
7	0.6
8	0.79
9	1
10	1.27
11	1.56
14	2.25
18	4
Bar	Area
top	6 0.00
Bar	Area
bottom	6 0.44

row 130



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A B C D E F G H I J K L M N  
STRESS-STRAIN RELATIONSHIPS I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

$\beta_1$	0.85 unitless	reduce the .85 factor by .05 for each 1000 psi over 4000 psi IF( 3 ksi > 4, 0.85 - (3 ksi - 4) * 0.05, 0.85)
$\beta_1$	0.85	but not less than 0.65 IF( 0.85 < 0.65, 0.65, B210)
$\epsilon'_s$ limit	0.00207 unitless	$f_y / E_s$ 60 / 29000 compression strain for reinforcing full engagement
$\epsilon_t$	0.00507 unitless	allowable tension reinforcing strain 0.00400 minimum strain allowed
$\epsilon_t$	0.00207 unitless	$60 f_y / 29,000 E_s$ calculated for reference only

B 1,  $\beta_1$  reduction factor for higher strengths of concrete, unitless. ACI 10.2.7  
a space is included between the B and the 1 so that the spreadsheet does not read this range name as a cell address.

$E_s$  steel modulus of elasticity, 29000 ksi

**Note:** that  $\epsilon_t$  is the lower limit for tension reinforcing strain where the minimum = 0.0040. This is conservative and may be increased to 0.005 where greater ductility is required as for tension controlled members. See 02 ACI 10.3.3, 10.3.4 and 10.3.5. commentary for a comprehensive explanation of this new approach in the code. Older codes used 0.75  $\rho_b$ .

To follow some textbook examples, you will have to set  $\epsilon_t$  to 0.00207 or greater.

$x_{balance}$	7.62 in	$0.003 / (0.003 + 0.00507) * 20.50"$
$a_{max}$	6.48 in	$0.85 * 7.62$ in
$\epsilon'_s$	0.00807 unitless	$20.50" / 7.62" * 0.003$
$\epsilon'_s$ min	0.00207 unitless	MIN(0.00807, 0.00207)

Stated another, traditional way;  
the basic relationship to determine  $x_{balance} * d$  is:

$$\epsilon'_c \quad 87 \text{ unitless} \quad 0.003 * 29,000 \text{ ksi}$$

$$\epsilon_y E_s \quad 147.03 \text{ ksi} \quad 29000 / 0.00507$$

$$x_{bal} * d \quad \frac{\epsilon'_c}{\epsilon'_c + \epsilon_y E_s} = \frac{0.003}{0.003 + f_y / 29,000} = \frac{87}{87 + 147} = 0.372 * d \text{ inches} = \underline{7.62 \text{ in}}$$

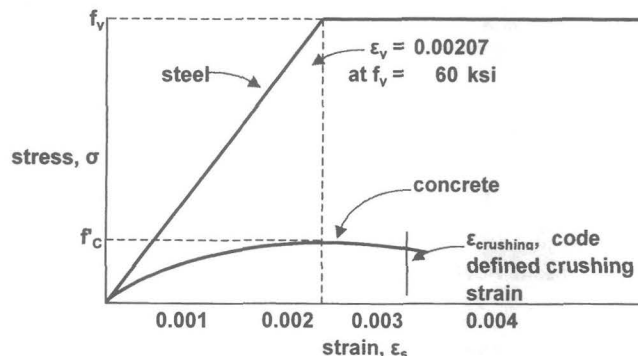


Figure 33-5 Stress and strain relationships for concrete and steel.

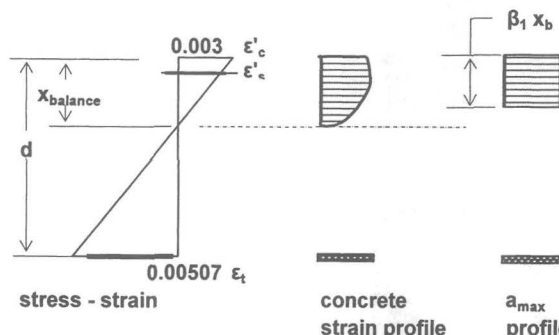


Figure 33-6 The balanced strain condition.

row 170

### The Limit for Tension Reinforcing

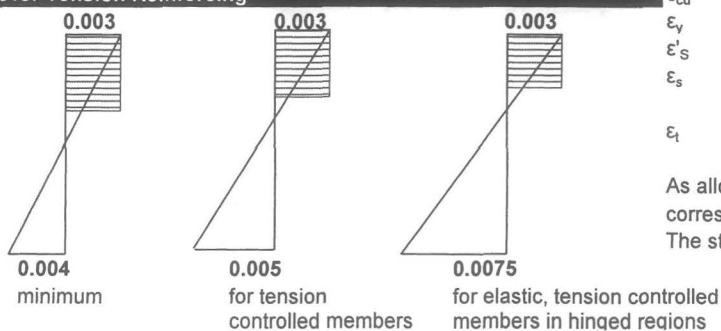
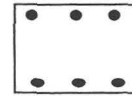


Figure 33-7 Tensile strain versus depth of compression block.

- $\epsilon_{cu}$  concrete crushing strain, 0.003, unitless
- $\epsilon_y$  strain at first yield, unitless
- $\epsilon'_s$  strain in compression reinforcing, unitless
- $\epsilon_s$  strain in tension reinforcing, unitless
- $\epsilon_t$  allowable tension reinforcing strain, unitless

As allowable tension reinforcing strain  $\epsilon_t$  increases, the corresponding Whitney's stress block decreases. The stress block is a function of  $\beta_1 * x_{balance} = a$ .

row 190



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DEPTH of COMPRESSION BLOCK I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

For tension and compression forces -- solve for x.

Setup relationships to be solved with the quadratic equation:

$$[-b \pm (b^2 - 4ac)^{1/2}] / [2a] = 0$$

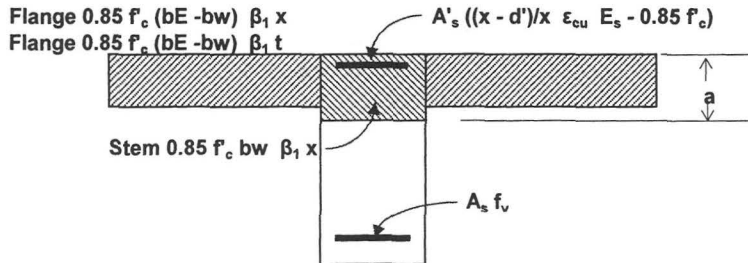


Figure 33-8 The balance of compression forces against the tension force  $A_s f_v$ .

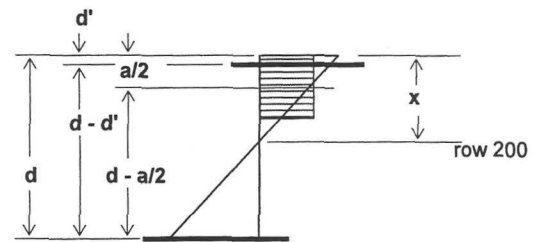


Figure 33-9 Calculating Whitney's stress block.

Calculate  $x_{balance}$  strain

Tension	Stem	Flange	Compression Reinforcing	
$A_s f_v =$	$0.85 f_c bw \beta_1 x$	$0.85 f_c (bE - bw) \beta_1 (x \text{ or } t)$	$+A'_s ((x - d')/x) \epsilon_{cu} E_s - 0.85 f_c$	row 210
$A_s f_v =$	$0.85 f_c bw \beta_1 x$	$0.85 f_c (bE - bw) \beta_1 (x \text{ or } t)$	$+A'_s (x - d')/x \epsilon_{cu} E_s$	$-A'_s 0.85 f_c$
$A_s f_v$	$-0.85 f_c bw \beta_1 x$	$-0.85 f_c (bE - bw) \beta_1 (x \text{ or } t)$	$-A'_s 0.85 f_c$	$= A'_s (x - d')/x \epsilon_{cu} E_s$
$A_s f_v$	$-0.85 f_c bw \beta_1 x$	$-0.85 f_c (bE - bw) \beta_1 (x \text{ or } t)$	$-A'_s 0.85 f_c$	$= A'_s \epsilon_{cu} E_s - A'_s d'/x \epsilon_{cu} E_s$
$A_s f_v$	$-0.85 f_c bw \beta_1 x$	$-0.85 f_c (bE - bw) \beta_1 (x \text{ or } t)$	$-A'_s 0.85 f_c$	$= -A'_s d'/x \epsilon_{cu} E_s$
$A_s f_v x^2$	$-0.85 f_c bw \beta_1 x^2$	$-0.85 f_c (bE - bw) \beta_1 (x \text{ or } t) x$	$-A'_s 0.85 f_c x$	$= -A'_s d' \epsilon_{cu} E_s$ row 220

Where the compression block  $a$  is less than flange depth  $t$

a	b	c
$-0.85 f_c bw \beta_1 x^2$	$A_s f_v x$	$+A'_s d' \epsilon_{cu} E_s$
$-0.85 f_c (bE - bw) \beta_1 x^2$	$-A'_s 0.85 f_c x$	$-A'_s \epsilon_{cu} E_s x$
$-28.178$	$0.0$	$0$
$0$	$0.0$	$0$
$-28.178 \text{ k/in}$	$26.4$	$26.4 \text{ k}$
$x$	$0.94 \text{ in}$	
	1 logic	
$a$	$0.796 \text{ in}$	
	0 logic	

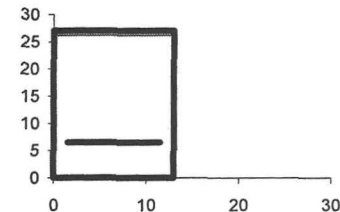
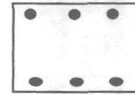


Figure 33-10 Beam cross-section.

Where the compression block  $a$  is greater than flange depth  $t$

a	b	c
$-0.85 f_c bw \beta_1 x^2$	$A_s f_v x$	$+A'_s d' \epsilon_{cu} E_s$
$-0.85 f_c (bE - bw) \beta_1 (x - t)^2$	$-A'_s 0.85 f_c x - A'_s \epsilon_{cu} E_s x - 0.85 f_c (bE - bw) t x$	$-A'_s \epsilon_{cu} E_s (x - t)$
$-28.178$	$0.0$	$0$
$0$	$0.0$	$0$
$-28.178$	$26.4$	$26.4$
$x$	$0.94 \text{ in}$	
	1 logic	
$a$	$0.796$	
	$0.796$	

row 250



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DEPTH of COMPRESSION BLOCK -- Continued I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

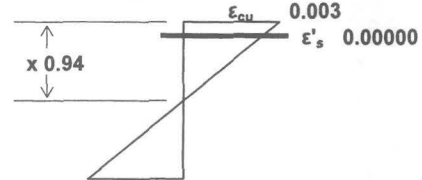
x	0.94 in	IF(0, 0.94, 0.94)
a	0.796 in	0.94 * 0.85

x distance of the neutral axis from extreme compression fiber, in  
a Whitney's compression block

**Direct calculation of compression reinforcing stress**

$\epsilon'_s$	0.00000 unitless	MAX((0.94 - 2.5) / 0.94 * 0.003, 0)
$\epsilon_v$	0.00207 unitless	60 / 29000
$f'_v$	0 ksi	MIN(0.00000 / 0.00207 * 60, 60)

$\epsilon'_s$  compression strain  
 $\epsilon_v$  compression strain limit



row 200

**Calculate compression forces and moments**

$C_s$	0.0 k	(0 - 0.85 * 3) * 0.00
$C_c$ stem	26.4 k	0.85 * 3 * 13 * 0.796
$C_c$ flange	0.0 k	0.85 * 3 * MIN(0.796, 4.5) * (13 - 13)

Figure 33-11 Compression reinforcing strain.

$M_n C_s$	0 k-in	(20.5 - 2.5) * 0.0
$M_n$ stem	531 k-in	26.4 * (20.5 - 0.796 / 2)
$M_n$ flange	0 k-in	0.0 * (20.5 - MIN(4.5, 0.796) / 2)

$C_s$  force in compression reinforcing, k  
 $C_c$  force in compressed concrete, k

$M_n$	531 k-in	0 + 531 + 0
$M_n$	44 k-ft	531 / 12 in/ft
$M_u$	40 k-ft ult	0.9 * 531

$M_n$  ultimate moment, k-ft  
 $M_u$   $M_n$  a reduced by 0.9, k-ft ultimate

77 %	$M_u$ required / $M_u$
1 logic	40 provided > 31 required
1	OK x balance 7.62 ≥ 0.937 required

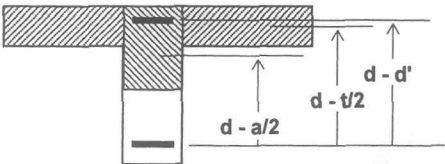
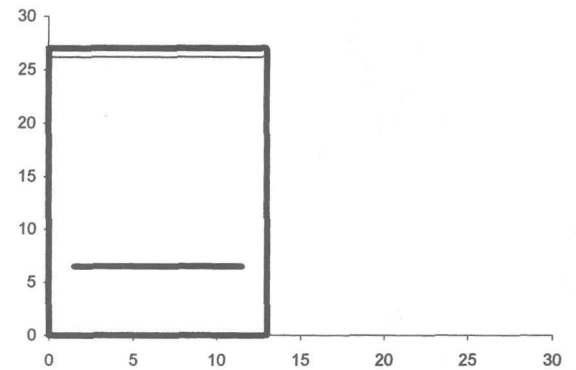


Figure 33-12 Distances to compression forces.

**Check compression reinforcing against tension reinforcing**

arm	20.10 in	531 / (0 + 26 + 0)
$M_{n, comp}$	531 k-in	Compression block and reinforcing
T	26.4 k	0.44 * 60
$M_{n, tens}$	531 k-in	20.10 * 26.40 Tension reinforcing

T force in tension reinforcing, k



row 300

Figure 33-13 Beam cross-section used in appropriate pages to help in understanding and verifying math.

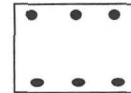
row 310



# REINFORCED CONCRETE BEAM EXHAUST STACK

## 33

Christy  
18:10  
12/20/05



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**MOMENT of INERTIA** I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

$E_c$  3122 ksi  $57000 * (3 * 1000)^2 / 1000$   
 $n$  9.29 unitless  $29000 / 3,122$

To find the neutral axis  $NA_x$  for + and - reinforcing and the stress block:

#### For the Gross (Overall) Section

$$w * x / 2 = n A'_s (x - d') + n A_s (d' - x)$$

$A_{arm}$  0 in<sup>3</sup>  $d' * n * -A_s$   
 $2.5 * 9.29 * 0.00$

This is solved with the quadratic equation.

84  $d * n * +A_s$   
 $20.5 * 9.29 * 0.44$



Area deduct 0  $2.5 * 0.00$

**Figure 33-14 Beam / T-beam cross section for  $Ad^2 / A$  = center of gravity from the top extreme fiber.**

9  $20.5 * 0.44$

0  $OH * t^2 / 2$   
 $13.0 * 4.5^2 / 2$

$n$  ratio of modulus of elasticity  $E_s / E_c$ , unitless

4739  $width * d_{OA}^2 / 2$   
 $13.0 * 27.0^2 / 2$

row 330

sum 4813 in<sup>3</sup>

$E_c$  modulus of elasticity of concrete, ksi  
 $d_{OA}$  beam overall depth, inches

Area 0 in<sup>2</sup>  $-A_s * n$   
 $9.29 * 0.00$

**NOTE: use  $Ad^2$  only. Do not rotate component areas around their own axes as in  $bd^3/12$ . Most moment of inertia calculations use  $Ad^2 + bd^3/12$ .**

4  $+A_s * n$   
 $9.29 * 0.4$

0  $OH * t$   
 $13.0 * 4.5$

row 340

351  $width * d_{OA} - s_{area} - s_{area}$   
 $13.0 * 27.0 - 0.00 - 0.44$

sum 355 in<sup>2</sup>

CG 13.57 in  $4,813 / 354.65$  from the top fiber

#### For Gross Section About the CG

$Ad^2$  conc 2 in<sup>4</sup>  $(d_{OA} * width) * (d_{OA} / 2 - Cg)^2$   
 $(27.0 * 13.0) * (27.0 / 2 - 13.57)^2$

row 350

0  $(OH * t) * (t/2 - Cg)^2$   
 $(0.0 * 4.5) * (78.0 / 2 - 13.57)^2$

$Ad^2$  steel 0 in<sup>4</sup>  $n * -A_s * (Cg - d')^2$   
 $9.29 * 6.00 * (13.6 - 2.5)^2$

196  $n * A_s * (d - Cg)^2$   
 $9.29 * 0.00 * (20.5 - 13.6)^2$

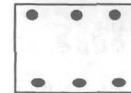
row 360

Area deduct 0  $-A_s * (Cg - d')^2$   
 21  $A_s * (d - Cg)^2$

I concrete 21323 in<sup>4</sup>  $width * d_{OA}^3 / 12 + OH * t^3 / 12$   
 $13 * 27^3 / 12 + 0 * 4.5^3 / 12$

Ig 21500 in<sup>4</sup>  $2 + 0 + 0 + 196 - 0 - 21 + 21,323$

row 370



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EFFECTIVE MOMENT of INERTIA

I gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

For the Cracked Section

Where the equilibrium equation is:

$$C_c + C_s = T$$

Where n - 1 deducts the area of compression concrete

For a rectangular beam:

$$b_w x x/2 + (n - 1) A'_s (x - d') = n A_s (d - x)$$

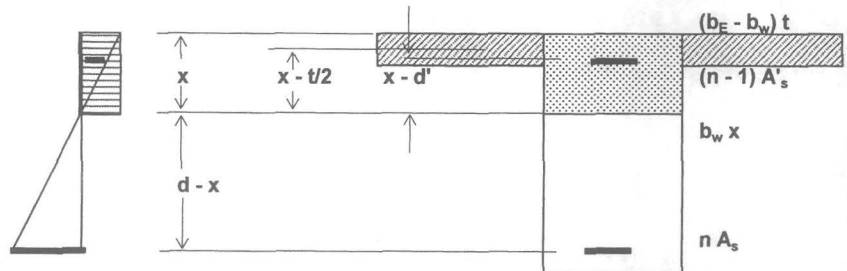


Figure 33-15 The component areas of the cracked section.

For a rectangular, spandrel, or T beam

flg logic      0 logic      1 if beam has a flange

stem      flange      compression reinforcing      tension reinforcing  
 $b_w x^2/2 +$        $(b_E - b_w) t (x - t/2) * \text{flg logic} +$        $(n - 1) A'_s (x - d') =$        $n A_s (d - x)$        $-n A_s (d - x) = 0$

$b_w x^2/2 +$        $(b_E - b_w) t x * \text{flg logic} +$        $(b_E - b_w) t (-t/2) * \text{flg logic} +$        $(n - 1) A'_s (x - d')$

$a x^2$       6.5 in       $b_w x^2/2 +$   
6.5

$b x$       4.1       $(b_E - b_w) t x * \text{flg logic} +$        $(n - 1) A'_s x$        $-n A_s (-x)$   
0      0.0      4.1

$c$       -83.8       $(b_E - b_w) t (-t/2) * \text{flg logic} +$        $(n - 1) A'_s (-d')$        $-n A_s d$   
0      0.0      -84

row 400

$NA_x$	3.290 in	$\frac{[-b \pm \sqrt{b^2 - 4ac}]/2a}{[-4 + \sqrt{4^2 - 4 * 6.5 * -84}]/(2 * 6.5)}$
--------	----------	--

row 410

row 420

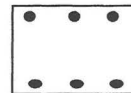
row 430



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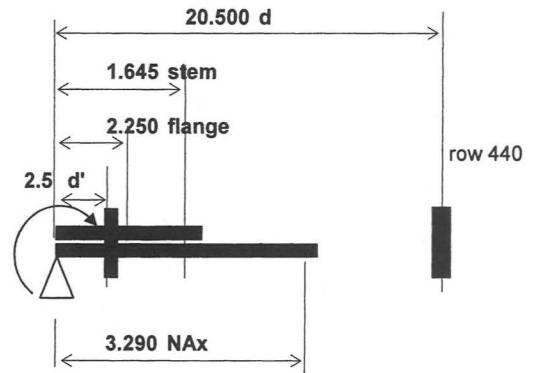
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**EFFECTIVE MOMENT of INERTIA -- Continued** | gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

### Two Methods of Checking NA<sub>x</sub>

Take the moments of each component area about the extreme fiber in compression. Divide the sum of the moments by the area of the components. Compare this calculated NA<sub>x</sub> to the NA<sub>x</sub> calculated above.

	area	arm	area*arm
A's	0.00	2.500	0.000
stem	42.77	1.645	70.341
flange	0.00	2.250	0.000
As	4.09	20.500	83.786
sum	46.85		154.126
M/area			3.290



Take the sum of the area moments about the calculated NA<sub>x</sub> to see if they are balanced.

	area	arm	area*arm
A's	0.00	0.790	0.000
stem	42.77	1.645	70.341
flange	0.00	1.040	0.000
As	-4.09	17.210	-70.341
			0.000

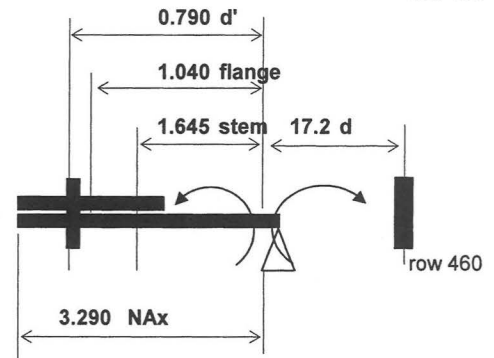


Figure 33-16 Moment of inertia is calculated as a balance of forces.

### For the Cracked Section About NA<sub>x</sub>

I conc.	154 in <sup>4</sup>	$w * NA_x^3 / 3 + (b_E - w) * MIN(NA_x, t)^3 / 12$ $13 * 3.29^3 / 3 + (13 - 13) * MIN(3.29, 4.5)^3 / 12$
Ad <sup>2</sup>	1211 in <sup>4</sup>	$n * A_s * (NA_x)^2 + n * A'_s * (NA_x - d)^2$ $9.29 * 0.44 * (20.5 - 3.29)^2 + 9.29 * 0.00 * (3.29 - 2.50)^2$
I <sub>cracked</sub>	1365 in <sup>4</sup>	cracked section for ± reinforcing

I<sub>cracked</sub> I<sub>cr</sub>, cracked moment of inertia

row 470

Where M wk'g is the unfactored M at the section for which the deflection is computed

### For the Effective Moment of Inertia

fr	411 lb/in <sup>2</sup>	7.5 f <sub>c</sub> <sup>2</sup>
M <sub>cr</sub>	55 k-ft	fr * I <sub>g</sub> / γ <sub>t</sub> for rectangular section only
+M wk'g	22 k-ft	
	335752 in <sup>4</sup>	$(M_{cr}/M_a)^3 * I_g$
	-19949 in <sup>4</sup>	$[1 - (M_{cr}/M_a)^3] * I_{cr}$
I <sub>e</sub> comp	315803 in <sup>4</sup>	$(M_{cr}/M_a)^3 * I_g + [1 - (M_{cr}/M_a)^3] * I_{cr}$
I <sub>g</sub>	21500 in <sup>4</sup>	
I <sub>e</sub>	21500 in <sup>4</sup>	GOVERNS

row 480

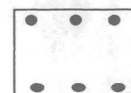
row 490



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**CREEP vs. TIME in MONTHS** | gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

$\rho'$	0.00000	unitless	density of compression reinforcing	$\rho'$	density of compression reinforcing at midspan, unitless
L_60	$\xi$	$\lambda$	← multiply computed deflection by $\lambda$	$\xi$	time dependent factor for sustained load, 02 ACI 9.5.2.5
L_12	2.0	2.000		$\lambda$	multiplier for additional longterm deflection
L_6	1.4	1.400			
L_3	1.2	1.200			
	1.0	1.000			

row 500

### Temperature Reinforcing Minimum

depth	16 in	depth not to exceed 16" for temperature reinforcing calculation
$A_s$ req'd	0.346 in <sup>2</sup> @ 12"	
	0.432 in <sup>2</sup> @ 15"	
	0.518 in <sup>2</sup> @ 18"	

row 510

$\rho$ temp	0.65 in <sup>2</sup> /ft	entire slab 0.0020
$\rho$ temp/2	0.32 in <sup>2</sup> /ft	entire slab limit to 16" depth

row 520

row 530

row 540

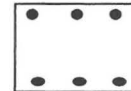
row 550



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VERIFIING GRAPHS | gross 21,500 in<sup>4</sup> / I cracked 1,365 in<sup>4</sup> / I effective 21,500 in<sup>4</sup>

This is the VBA code for the macro that Paste Value(s) the input/output values into the graphing range. Having the "New Macro" recorder input your keystrokes may not record your intentions.

```
Sub Macro2()  
'  
' Macro2 Macro  
' Macro recorded 9/11/2002 by Craig T. Christy  
'  
' Keyboard Shortcut: Ctrl+Shift+Z  
'  
Range("r13:r18").Select ← If you don't want to use this range, input your own selection.  
Selection.Copy  
Selection.End(xlToRight).Select  
ActiveCell.Offset(0, 1).Range("A1").Select  
ActiveSheet.Paste  
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _  
False, Transpose:=False  
Selection.End(xlToLeft).Select  
End Sub
```

Press [Ctrl] [Shift] z

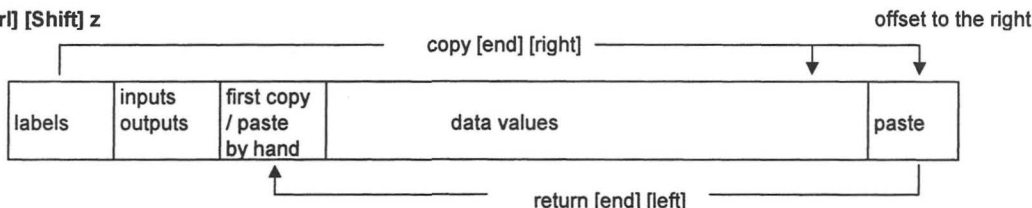


Figure 33-17 GRAPHING VALUES FLOW DIAGRAM

Rectangular beam with variable +As tension reinforcing

fy	60	+As	3.54	aa	0.43	0.45	0.5	0.6	0.7	0.8	0.9	1
fc	3	Mu prov	39.80		41.75	43.66	48.40	57.81	67.1	76.38	85.53	94.59
d'	2	M working	22		71	71	71	71	71	71	71	71
width	12	Mu req'd	31		100	100	100	100	100	100	100	100
d	36	Ig /100	215		142	142	142	143	144	145	146	146
depth_OA	38	I cr /100	14		21	21	22	25	28	31	34	36
A's	0	Ie /100	215		44	44	45	48	51	54	57	60
As	34	a * 50	39.819005		42.15686	44.11765	49.01961	58.8235	68.6	78.43	88.24	98.039

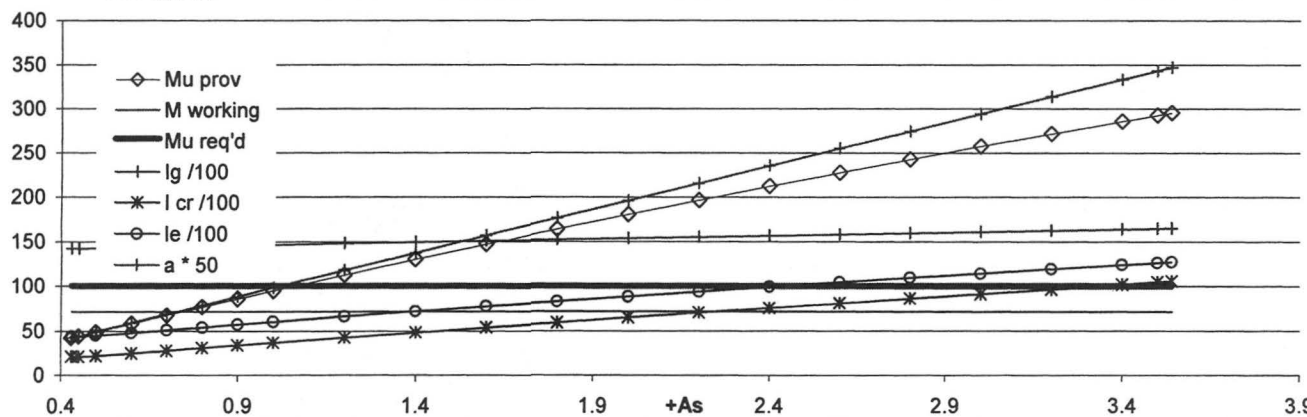


Figure 33-18 Rectangular beam +As compression reinforcing versus Mu Provided, Mu required, Ig, Icr, Ie.

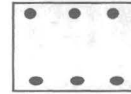
row 610



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VERIFIING GRAPHS -- Continued		I gross 21,500 in <sup>4</sup> / I cracked 1,365 in <sup>4</sup> / I effective 21,500 in <sup>4</sup>										
Rectangular beam variable -As' compression reinforcing												
fy	60	-As	6.00	aaa	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.80
f'c	3	MU prov	40		292	294	296	297	299	301	303	307
d'	2	a * 50	40		343	333	323	313	304	295	286	269
b <sub>w</sub>	12	MU req'd	31		250	250	250	250	250	250	250	250
d	22	lg /100	215		165	166	167	168	169	169	170	172
depth_OA	24	I cr /100	14		104	104	103	103	103	102	102	101
A's	varies	le /100	215		106	105	105	105	104	104	104	103
As	3.5											

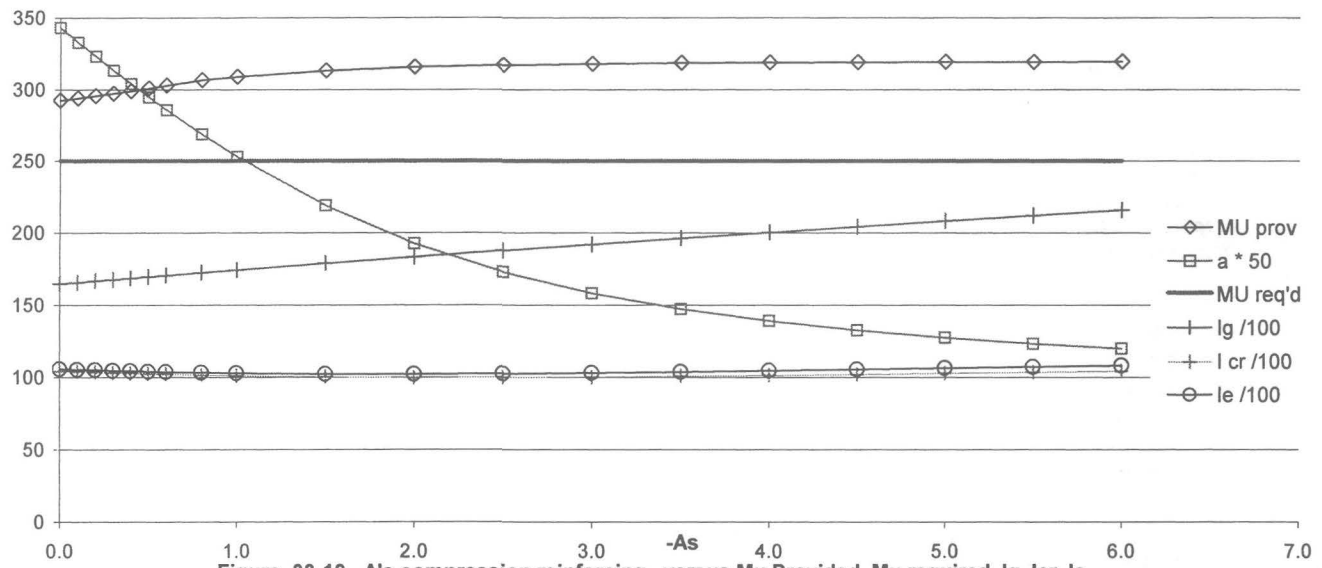


Figure 33-19 A's compression reinforcing versus Mu Provided, Mu required, lg, Icr, le.

### T-beam joist with variable spacing

T-beam joist with variable spacing		80	aa	12	13	14	15	20	25	30	35
fy	60	joist spacing									
f'c	3	MU prov	39.80	257.29	260.14	262.72	265.06	273	277.9	281.1	283.39
d'	2	MU req'd	250	250	250	250	250	250	250	250	250
width	12	lg /100	215.00	161.13	165.79	170.33	174.76	195	213.8	230.3	245.20
d	22	I cr /100	13.65	91.38	91.48	91.77	92.20	95.8	100.6	105.6	110.47
depth_OA	24	le /100	215.00	114.21	117.03	120.05	123.24	141	159.4	178.1	196.29
A's	0	a	7.964	58.824	55.490	52.157	48.824	35.3	28.24	23.53	20.168
As	3										
Length	40										
t	4										
c_	varies										
flange	2										

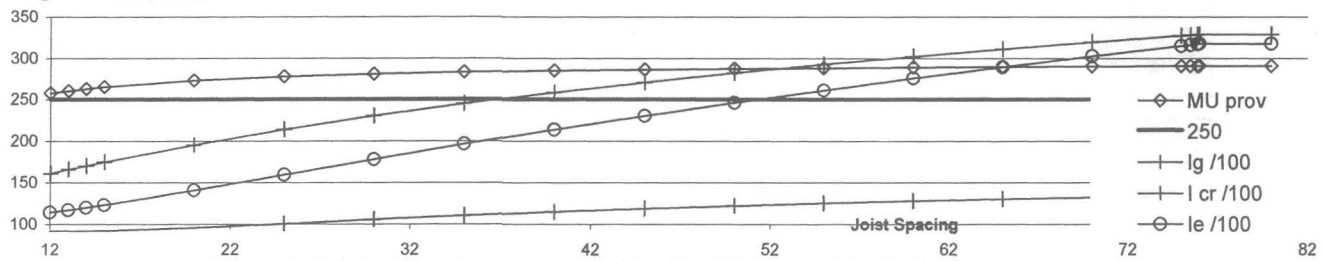


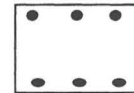
Figure 33-20 Joist spacing versus Mu Provided, Mu required, lg, Icr, le.



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### VERIFYING GRAPHS -- Continued

#### T-beam variable +As tension reinforcing

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
fy	60	+As		8.86 aa		0.4	0.5	0.6	0.7	0.8	0.9	1	1.2	
fc	3		Mu prov	39.80		42.24	49.06	58.76	68.44	###	87.67	97.24	116.26	
d'	2		Mu req'd	30.7		100	100	100	100	100	100	100	100	
width	12		lg /100	215.0012		201.8821	202.7001	203.864	205.023	206	207.3	208.5	210.74	
d	22		l cr /100	13.648494		23.09306	26.40514	30.86259	35.0689	39.1	42.92	46.62	53.68	
depth_OA	24		le /100	215.0012		83.62034	87.06423	91.77422	96.2889	101	104.9	109	116.92	
A's	0		a * 100	79.638009		33.72549	39.21569	47.05882	54.902	62.7	70.59	78.43	94.118	
As	varies													
Length	30													
t	4													
c_	30													
flange	2													

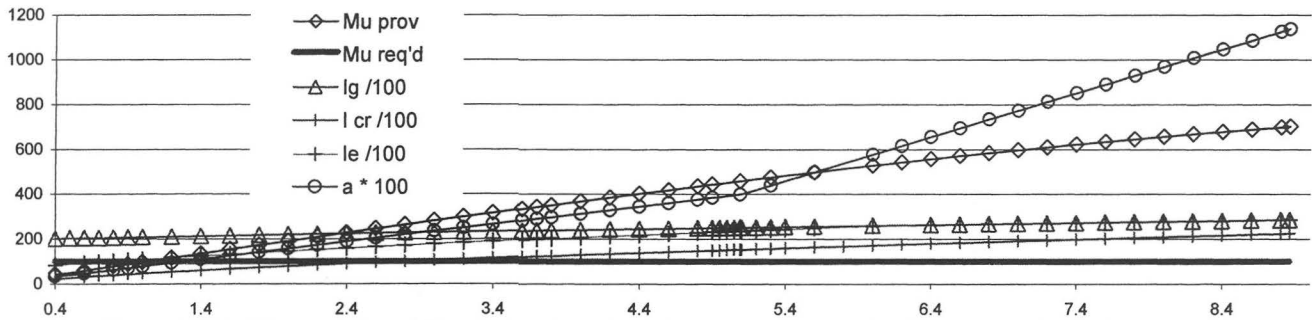


Figure 33-21 T-beam with variable +As tension reinforcing versus M\_provided, Mu required, lg, lcr, le.

#### T-beam variable -As' compression reinforcing

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
fy	60	+As		10.969 aa		0.1	0.2	0.3	0.5	1	1.5	2	2.11	
fc	3		Mu prov	39.80		143.93	146.41	148.96	154.25	###	###	###	207.37	
d'	2		Mu req'd	30.7		100	100	100	100	100	100	100	100	
width	12		lg /100	215.0012		208.2046	209.461	210.7118	213.197	219	225.3	231.2	232.44	
d	22		l cr /100	13.648494		7.919034	12.73429	17.35286	26.0852	45.6	62.83	78.33	81.556	
depth_OA	24		le /100	215.0012		75.61118	80.81894	85.86392	95.5338	118	138.1	156.9	160.86	
A's	2		a * 100	79.638009		117.1421	119.2233	121.359	125.799	138	151.7	167.3	170.93	
As	varies		f <sub>y</sub>	0		0	0	0	0	0	0	0	0	5
Length	30													
t	4													
c_	30													
flange	2													

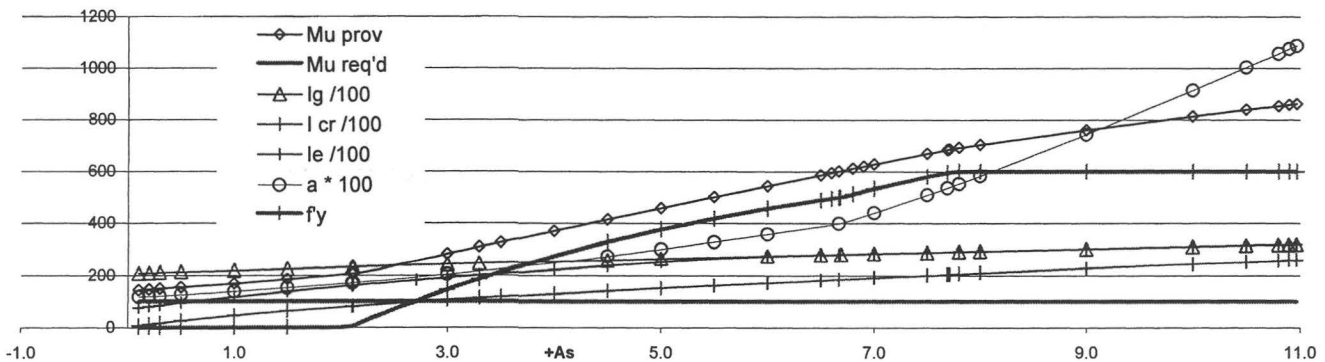


Figure 33-22 T-beam with variable -As' compression reinforcing versus M\_provided, Mu required, lg, lcr, le.

row 730

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### PUNCHING SHEAR

P base PL 263.6 k from bolt patterns template  
ratio 1.364 unitless from foundation design template  
P\_ult 359.6 k\_ult

### Bearing

F bearing 0.750 ksi working stress value  
A\_req'd 351.5 in<sup>2</sup> 263.6 k / 0.750 ksi

length 7.5 in b\_1  
width 46.9 in b\_2 approximated

### Punching Shear

f<sub>c</sub> 3 ksi  
d 20.5 in

b<sub>o</sub> 150 in  $(b_1 + d/2 + b_2 + d/2) * 2$   
 $(7.50 + 46.86 + 20.5) * 2$

A<sub>o</sub> 3069 in<sup>2</sup> b<sub>o</sub> \* d  
20.5 \* 150

b<sub>o</sub> 6.25 unitless ratio of long side to short side

V<sub>c</sub> 443.9 k\_ult  $(2 + 4/b_o) * (f_c * 1000)^{0.5} * b_o * d / 1000$  (11-35)  
 $(2 + 4 / 6.25) * (3 * 1000)^{0.5} * 150 * 20.5 / 1000$

a<sub>s</sub> 40 unitless

V<sub>c</sub> 1257.0 k\_ult  $(a_s * d / b_o + 2) * (f_c * 1000)^{0.5} * b_o * d / 1000$  (11-36)  
 $(6.25 * 20.5 / 150 + 2) * (3 * 1000)^{0.5} * 150 * 20.5 / 1000$

V<sub>c</sub> 672.5 k\_ult  $A_o * 4 * (f_c * 1000)^{0.5}$  (11-37)  
 $3,069 * 4 * (3 * 1000)^{0.5} / 1000$

V<sub>c</sub> allow 443.9 k\_ult MIN(443.9, 1,257.0, 672)

V <sub>u</sub> allow	377 k-ft_ult OK	V <sub>c</sub> * 0.85 359.6 < 377.3
----------------------	--------------------	--

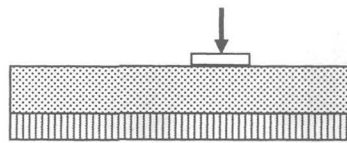
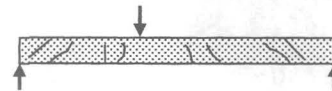


Figure 34-1 At-rest DL and LL values.

row 20

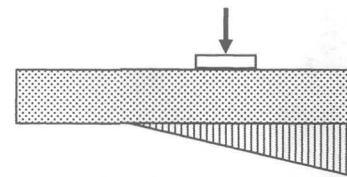


Figure 34-2 At-rest DL + LL + Wind values.

row 30

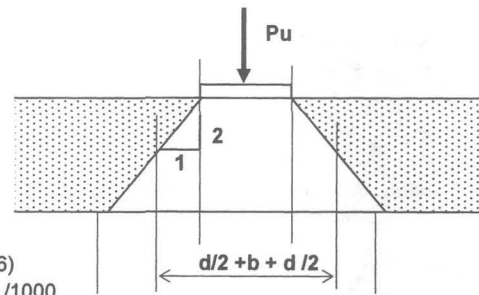


Figure 34-3 PUNCHING SHEAR PROFILE

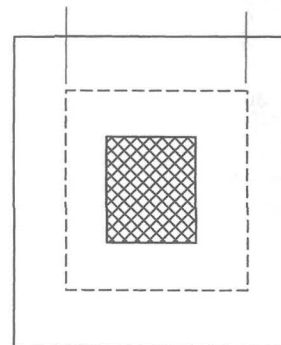


Figure 34-4 PUNCHING SHEAR PLAN VIEW

row 50

row 60

row 70

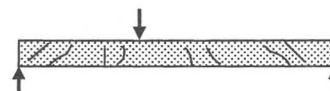


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BEAM SHEAR		
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tributary distance from center of bearing to edge of footing  
 $q$  loaded 1.661 ksf  
 $q$  1.121 ksf

See ACI 11.3

$V$  reqd 18.1 k\_ult  
ratio 1.364 unit  
 $V_u$  reqd 24.7 k\_ult

$d$  20.5 in extreme fiber in compression to centerline of reinforcing  
 $b_w$  12 in width transverse to direction of load  
 $f'_c$  3 ksi

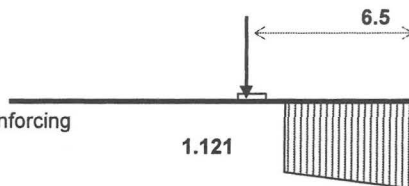


Figure 34-5 BEAM SHEAR PROFILE

**Concrete**  
 $V_c$  26.9 k  $2 * (f'_c * 1000)^{0.5} * width * d$  ACI (11-3)  
 $2 * (3 * 1000)^{0.5} * 12 * 20.5 / 1000$   
 $M_u$  30.7 k-ft\_ult  
 $F_v$  60 ksi flexural reinforcing strength  $V_c$  allowable shear carried by concrete  
 $A_s$  0.31 in<sup>2</sup> area of flexure reinforcing shear + flexure only row 90  
 $p_w$  0.0000 unitless density of flexure reinforcing  $V_s$  shear carried by stirrups  
 $V_u d / M_u$  1.01 unitless  $18.1 * 20.5 / 12 / 30.7$   
 $V_c$  25.6 k\_ult  $(1.9 * (f'_c * 1000)^{0.5} + 2500 * p_w * \min(1, V_u * d / M_u)) * b_w * d$   
 $(1.9 * (3 * 1000)^{0.5} + 2500 * 0.0000 * \min(1, 1.01)) * 12 * 20.5 / 1000$   
 $V_c$  47.2 k\_ult  $3.5 * (f'_c * 1000)^{0.05} * b_w * d$   
 $3.5 * (3 * 1000)^{0.05} * 12 * 20.5 / 1000$   
 $V_c$  min 25.6 k\_ult MIN(47.2, 25.6) row 100  
 $V_c$  26.9 k\_ult MAX(26.9, 25.6)

**Stirrup**  
 $s$  8.0 in. stirrup/tie spacing  $\leq d/2$ , 24" max spacing  
 $F_v$  40 ksi stirrup/tie yield strength  
 $A_v$  0.00 in<sup>2</sup> sum of area for all bars to resist shear row 110  
 $V_s$  0.0 k  $A_v * F_v * d / s$   
 $V_s$  max 107.8 k.  $8 * (f'_c * 1000)^{0.5} * width * d$   
 $8 * (3 * 1000)^{0.5} * 12 * 20.5 / 1000$   
 $V_s$  0.0 k MIN(0.0, 107.8)  
 $F$  0.85 unitless  
 $V_u$  allow 22.9 k\_ult  $F * (V_c + V_s)$   
 $0.85 * (26.9 + 0.0)$  row 120

row 130



# STACK DRAWINGS EXHAUST STACK



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35 Stack Drawings.xls

A B C D E F G H I J K L M

The following drawings are not on the CD Rom.

In terms of construction, this is a small project. The stack drawings are used both to fabricate the stack and install it.

**GENERAL NOTES**

THE CONTRACTOR SHALL VERIFY ALL DIMENSIONS AND CONDITIONS WITH THE STRUCTURAL/MECHANICAL DRAWINGS, AND EXISTING FIELD CONDITIONS.

THE CONTRACTOR SHALL BE RESPONSIBLE FOR ALL REQUIRED SAFETY PRECAUTIONS AND METHODS, TECHNIQUES, SEQUENCES, AND PROCEDURES REQUIRED TO PERFORM HIS WORK.

THE DRAWINGS INDICATE GENERAL AND TYPICAL DETAILS OF CONSTRUCTION. WHERE CONDITIONS ARE NOT SPECIFICALLY INDICATED BUT ARE SIMILAR IN NATURE TO THE DETAILS SHOWN, SIMILAR DETAILS OF CONSTRUCTION SHALL BE USED, SUBJECT TO REVIEW AND APPROVAL OF THE ENGINEER.

CHANGES IN CONSTRUCTION DETAILS, MEMBERS, AND ETC. MUST BE CONFIRMED BY WRITTEN MEMO AND/OR SKETCH FROM THE ENGINEER.

THIRD PARTY SPECIAL INSPECTION WILL BE PROVIDED FOR REINFORCING STEEL AND CONCRETE. SPECIAL INSPECTION OF ANCHOR BOLT ASSEMBLIES WILL BE PROVIDED BY THE ENGINEER.

**LOADS**

WIND ——— 150 MPH

SEISMIC ——— U.B.C. ZONE 3, I = 1.25, R = 2.2

CORROSION ALLOWANCE – 1/16"

8.35" EXPECTED DEFLECTION AT THE TOP OF THE STACK DUE TO VORTEX SHEDDING AT 36 MPH

**FOUNDATIONS**

REFER TO GEOTECHNICAL ENGINEER'S SPECIFICATIONS FOR SOIL PREPARATION AND FILL.

DESIGN SOIL ALLOWABLE BEARING IS 2000 PSF. STACK FOOTING TO BE FOUNDED FIRM ORIGINAL SOIL OR GRANULAR BACKFILL COMPACTED TO 95% MODIFIED PROCTOR DENSITY.

THE BOTTOM OF ALL FOOTINGS AND OTHER CONCRETE SHALL BE 18" MINIMUM BELOW FINISHED GRADE FOR FROST DEPTH PROTECTION.

**STRUCTURAL STEEL AND MISCELLANEOUS IRON**

ALL HOT ROLLED STRUCTURAL STEEL SHALL CONFORM TO ASTM A36 OR A992 AND TO U.B.C. STANDARDS.

ALL FABRICATION, ERECTION, AND IDENTIFICATION OF STRUCTURAL STEEL SHALL CONFORM TO AISC AND U.B.C. SPECIFICATIONS AND STANDARDS.

EMBEDS MUST BE ACCURATELY PLACED AND SECURED TO RESIST FOOT TRAFFIC AND CONCRETE PLACEMENT.

USE WELD METAL WITH A CHARPY V-NOTCH TOUGHNESS OF 20 OR GREATER AT 70° F.

THIS INCLUDES WELDING MATERIAL SUCH AS: E70TG-K2  
E71T-8  
E7018

THIS DOES NOT INCLUDE: E70T-4

PLACE 1"± STEEL SHIMS ON CONCRETE BEFORE SETTING THE STACK. JACKING / LEVELING NUTS ARE NOT ALLOWED.

**CONCRETE - CAST IN PLACE**

PROVIDED CONCRETE STRENGTH IS 3000 PSI WITH 3% TO 5% AIR ENTRAINMENT, 4 1/2" ± 1" SLUMP. PROVIDE LIGHT BROOM FINISH. CONCRETE MIXING, PLACING, AND CURING SHALL CONFORM TO THE ACI MANUAL OF CONCRETE PRACTICE AND ACI SPECIFICATIONS.

**CONCRETE REINFORCING STEEL**

ALL REINFORCING STEEL FOR CONCRETE SHALL BE ASTM GRADE 60. ALL REINFORCING STEEL SHALL BE ACCURATELY AND SECURELY PLACED PRIOR TO PLACING CONCRETE.

MINIMUM CONCRETE COVER FROM SURFACES SHALL BE:

- 3" +/- 1/4" TO THE BOTTOM OF FOOTINGS
- 2" +/- 1/4" TO EARTH OR WEATHER FACE



**4B** STACK VIEW  
**S1** 1/4" = 1'-0"



Not included on CD-ROM.

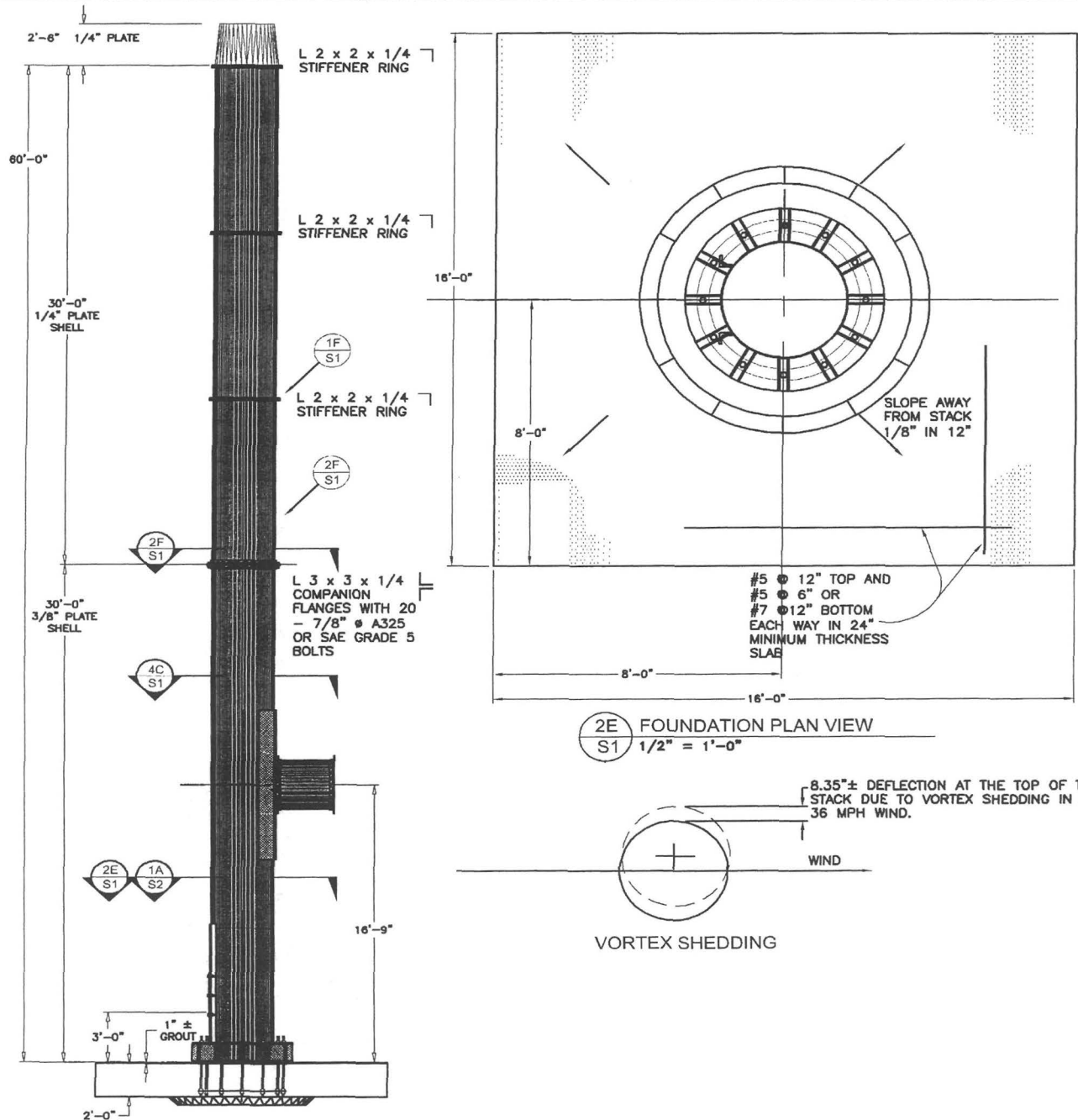


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A B C D E F G H I J K L M N



4C STACK ELEVATION  
S1 1/4" = 1'-0"



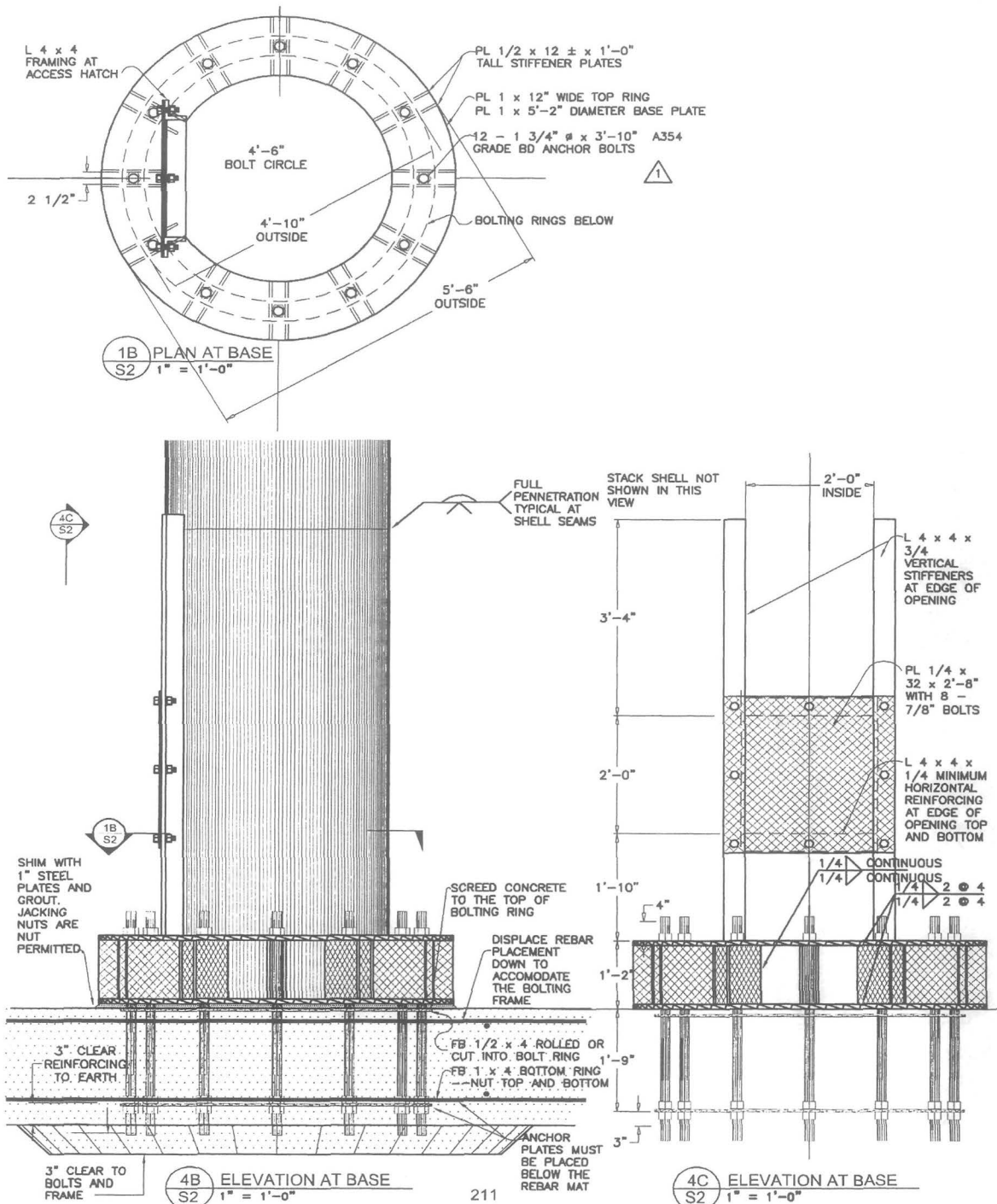
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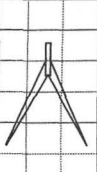


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A B C D E F G H I J K L M N





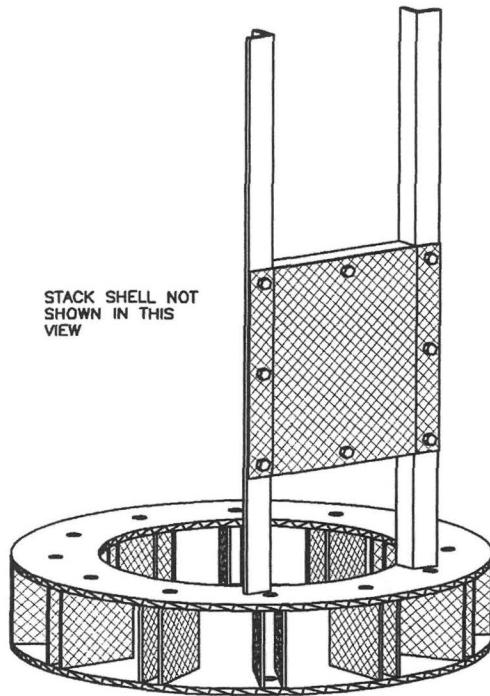
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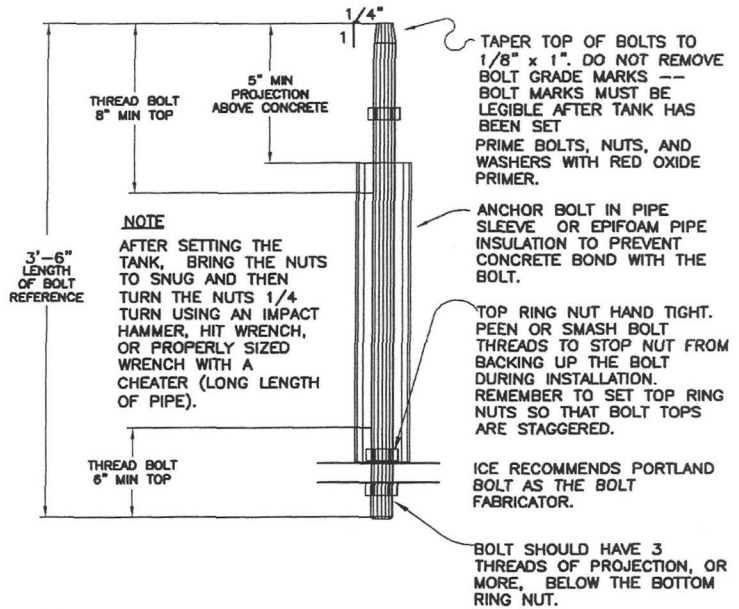
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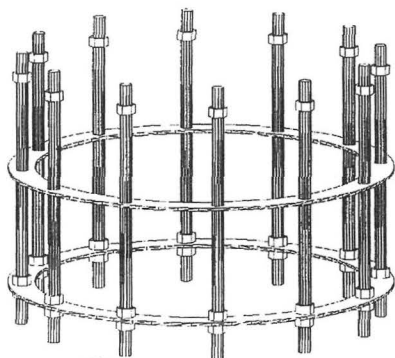
A B C D E F G H I J K L M N



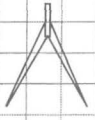
3D ACCESS HATCH VIEW  
S2 1" = 1'-0"



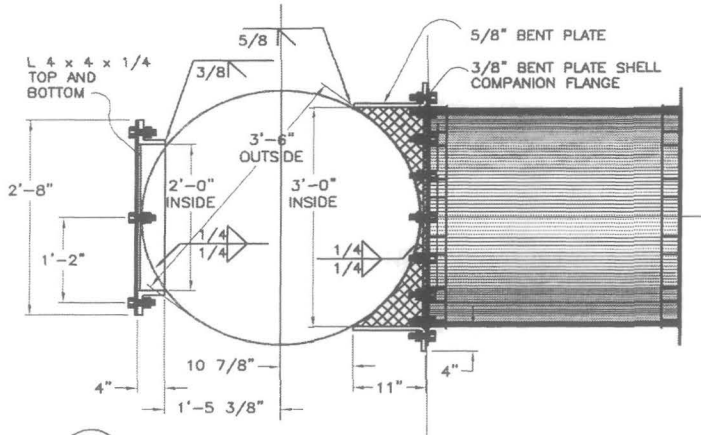
3E ANCHOR BOLT DETAIL  
S2 NO SCALE



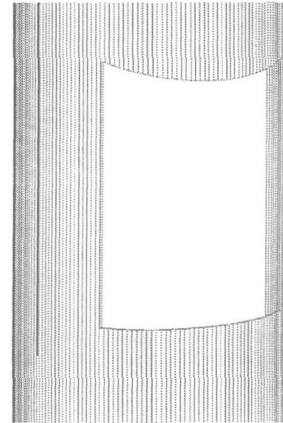
4D BOLT RING VIEW  
S2 1" = 1'-0"



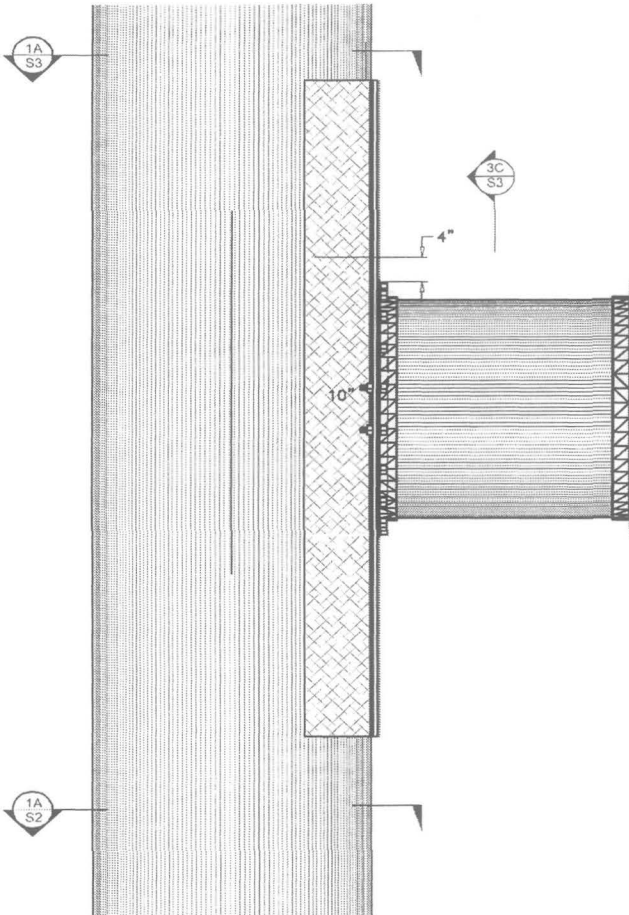
A B C D E F G H I J K L M N



1A PLAN AT INTAKE  
S3 1" = 1'-0"

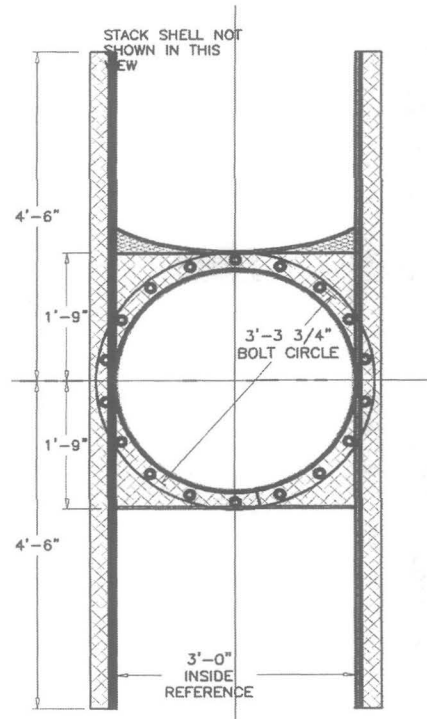


2C INTAKE VIEW  
S3 1" = 1'-0"



1A S3

4C ELEVATION AT INTAKE  
S3 1" = 1'-0"



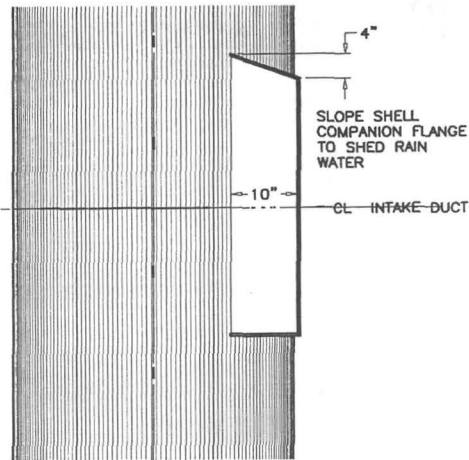
3C ELEVATION AT INTAKE  
S3 1" = 1'-0"

Not included on CD-ROM.

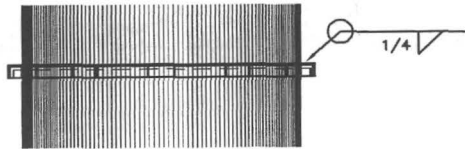
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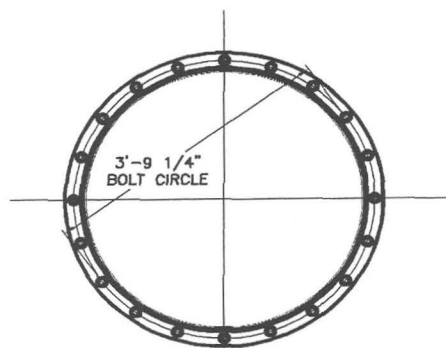
A B C D E F G H I J K L M N



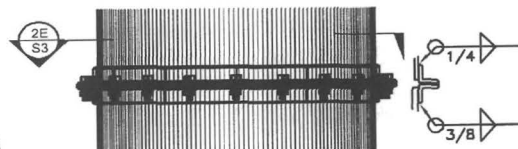
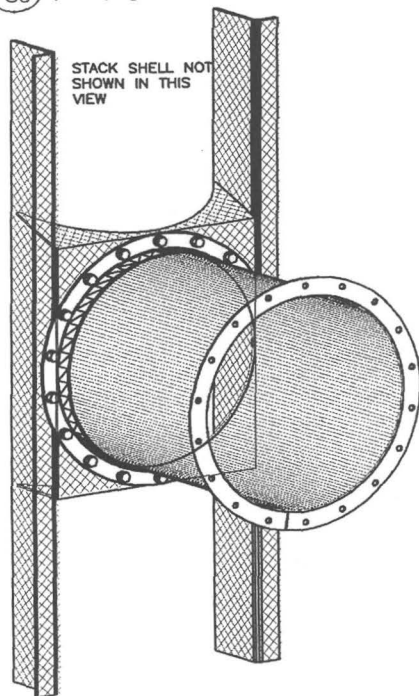
2D INTAKE FACE PLATE DETAIL  
S3 1" = 1'-0"



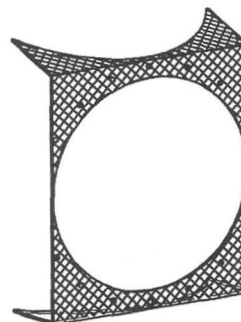
1E SHELL STIFFENER DETAIL  
S3 1" = 1'-0"



2E PLAN AT COMPANION FLANGES  
S3 1" = 1'-0"



3E COMPANION FLANGES DETAIL  
S3 1" = 1'-0"



ACCESS HATCH FRAMING  
ON FAR SIDE OF SHELL



4D INTAKE VIEW  
S3 1" = 1'-0"



**PART 4:**  
**ELEVATED**  
**STORAGE TANK**

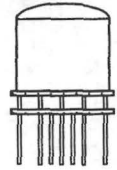




# ELEVATED STORAGE TANK INTRODUCTION

Not included on the CD-ROM

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A B C D E F G H I J

## ELEVATED STORAGE TANK

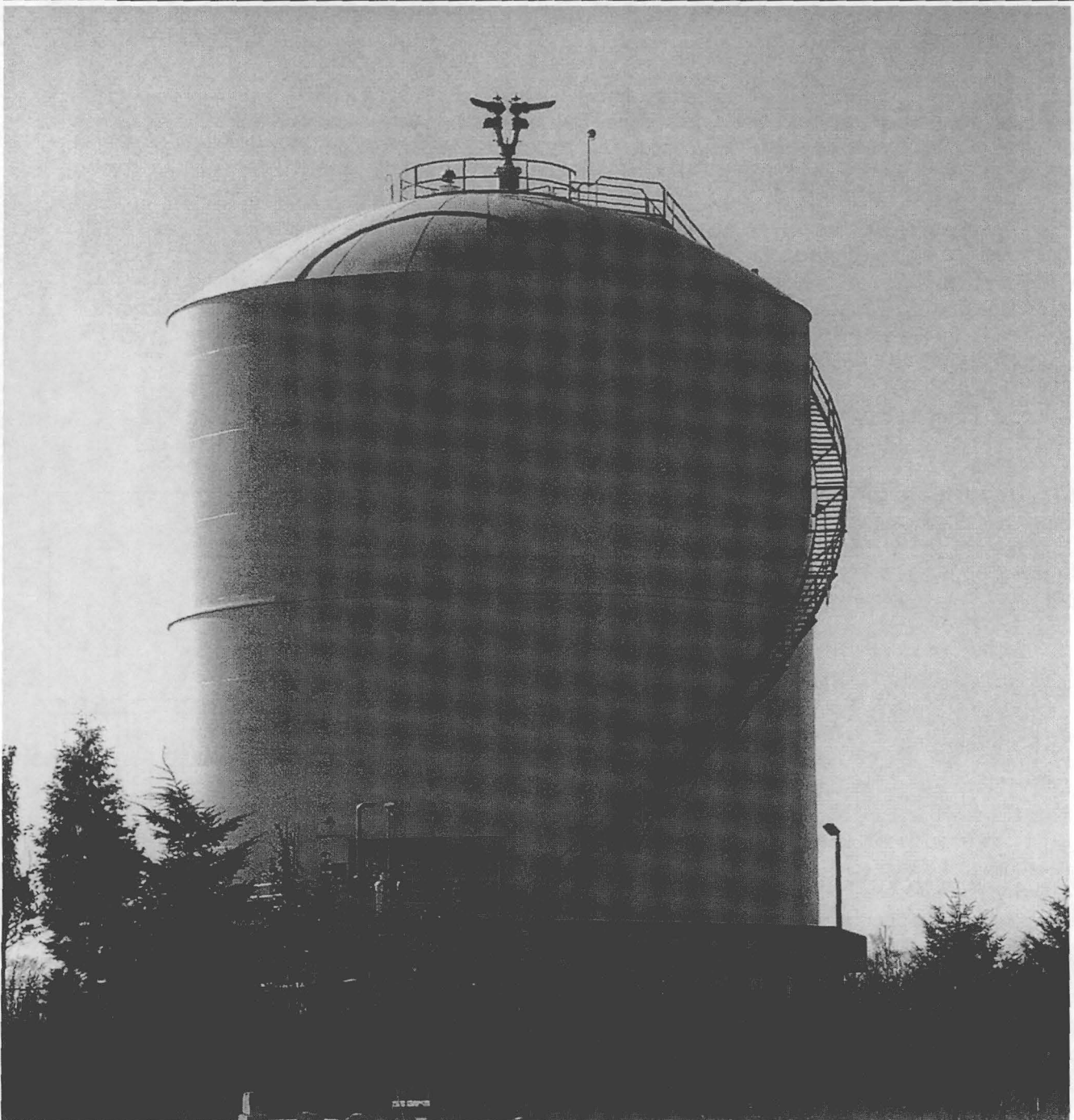


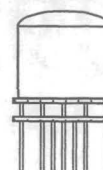
Figure 36-1 The tank.



# ELEVATED STORAGE TANK INTRODUCTION

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A	B	C	D	E	F	G	H	I	J
<b>ELEVATED STORAGE TANK</b>									

This is a bulk storage tank for high purity liquid nitrogen located in a seismic zone III somewhere in the western United States.

At water test weight, the tank and contents weigh about 6,000,000 Lbs. supported at 15 ft above grade. The actual product weighs 80% of what water weighs. Seismic design is based upon structure dead load and product live load. Wind design is for an empty tank but seismic governs. When the tank is in service, the upper deck is allowed to deflect and/or settle about 1/8" in 30 ft.

Settlement constraints are tight and fairly difficult to meet. In the past, these structures have been a 2 ft thick deck located on a maze of walls. This makes it easier to solve the settlement and seismic issues. But, the maze of walls creates unusable space below the deck. Also, liquid nitrogen is dangerous -- a release of liquid nitrogen in a confined area can easily kill someone. You need roughly 17.5% oxygen content in the air to be able to breathe and the vaporizing nitrogen can easily displace enough oxygen to suffocate you, and it's odorless.

An open frame below the tank leaves a well ventilated, usable space.

The design of this tank went through several iterations and input from the contractor and soils engineer. This project was not, however, value engineered. How the contractor's estimator can deliver a better design than the engineer is beyond me.

- Our goals were:
- Safety when in use
  - Structural settlements
  - Time for construction
  - Financial investment in the foundation
  - Utility of the space below the tank

The final three iterations eliminated walls which are expensive and time consuming and all battered piles which didn't work well in this situation. The final design uses the bending and compression of the soil at the piles to resist seismic lateral force. 21 of the 55 pilings run up through the pile cap to support the deck.

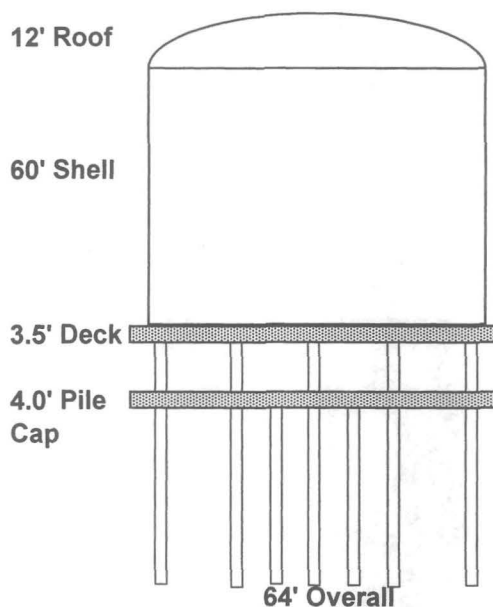
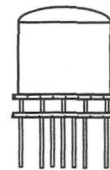


Figure 36-2 The design elevation diagram of the tank, deck, pile cap, and piling.

Pilings are filled with concrete and reinforcing cages to create composite columns. The deck and pile cap are reinforced with #7's at 4" each way. The last, important, design issue was how to create a moment joint between the piling and the pile cap and between the piling composite columns at the pile cap and deck.



A B C D E F G H I J

### ELEVATED STORAGE TANK -- Continued

**Iteration 1** is the most obvious. Run mat rebar through the columns as we normally do with beam reinforcing through a column cage. This entails torching holes in the steel pile and running #7's through the holes and the cage. This was going to be difficult and did not address the issue of punching shear.

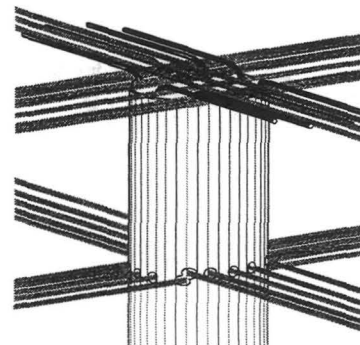


Figure 36-3 The torched piling concept.

**Iteration 2** is the second most obvious. Create collars to which A706 rebar can be welded and the punching shear can be resolved. Collars are cut from 3/4" plate and require a 1" x 1" backup bar below the collar for strength and welding.

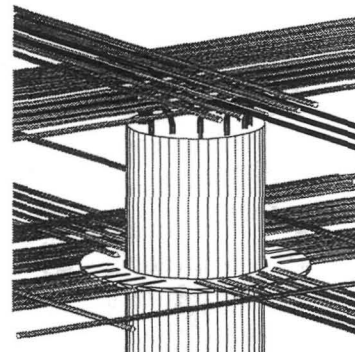


Figure 36-4 The pile collar concept.

The collar idea requires lots of fabrication and extensive field welding. To use collars would increase the construction time by weeks.

**Iteration 3** is obvious -- use 3/4" x 6" headed weld studs for shear and let the rebar mats confine the pile columns. Much of the moment is transferred between the slab and column through a lopsided shear mechanism.

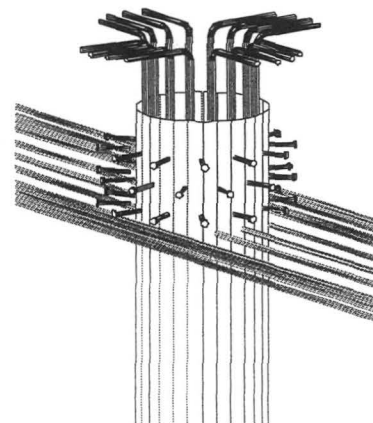
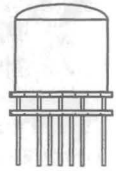


Figure 36-5 Weld studs to resist shear.

Installation of the weld studs at grade required about three hours.



A	B	C	D	E	F	G	H	I	J
ELEVATED STORAGE TANK -- Continued									

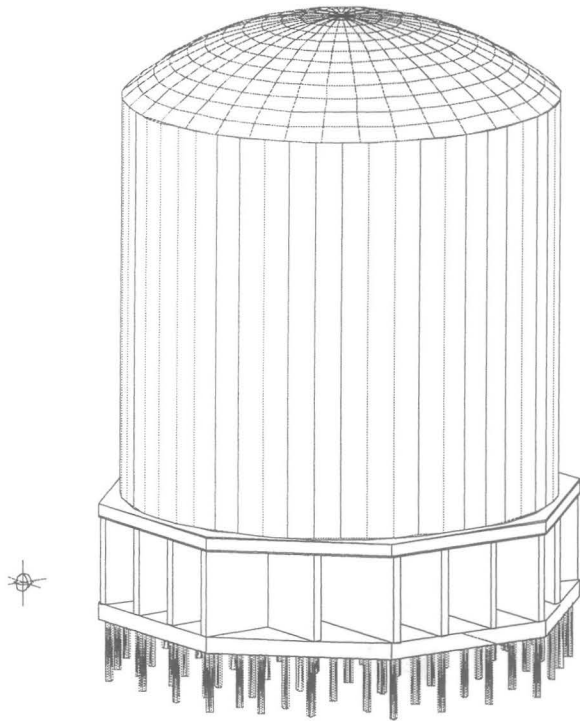


Figure 36-6 Tank structural support walls and slabs.

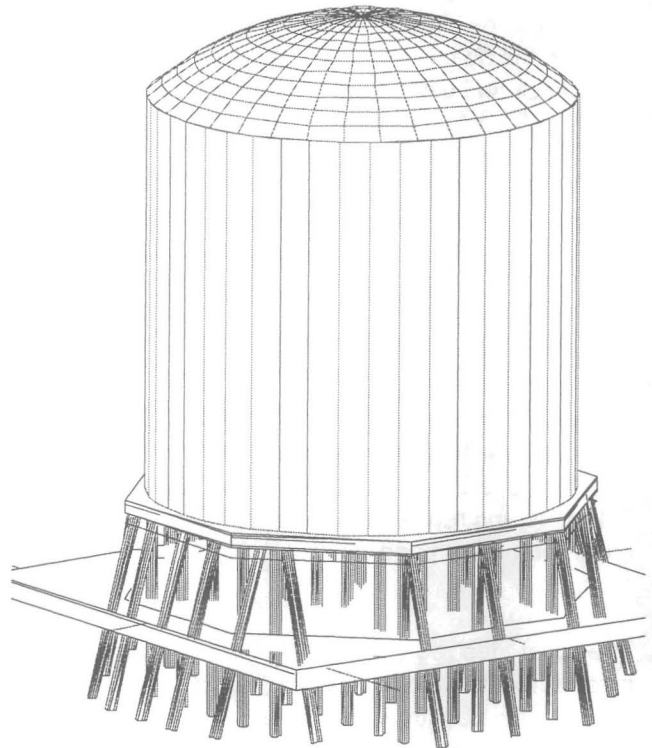


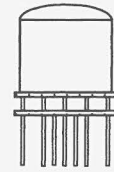
Figure 36-7 Tank on battered piling.



# ELEVATED STORAGE TANK INTRODUCTION

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A B C D E F G H I J

ELEVATED STORAGE TANK -- Pile Driving

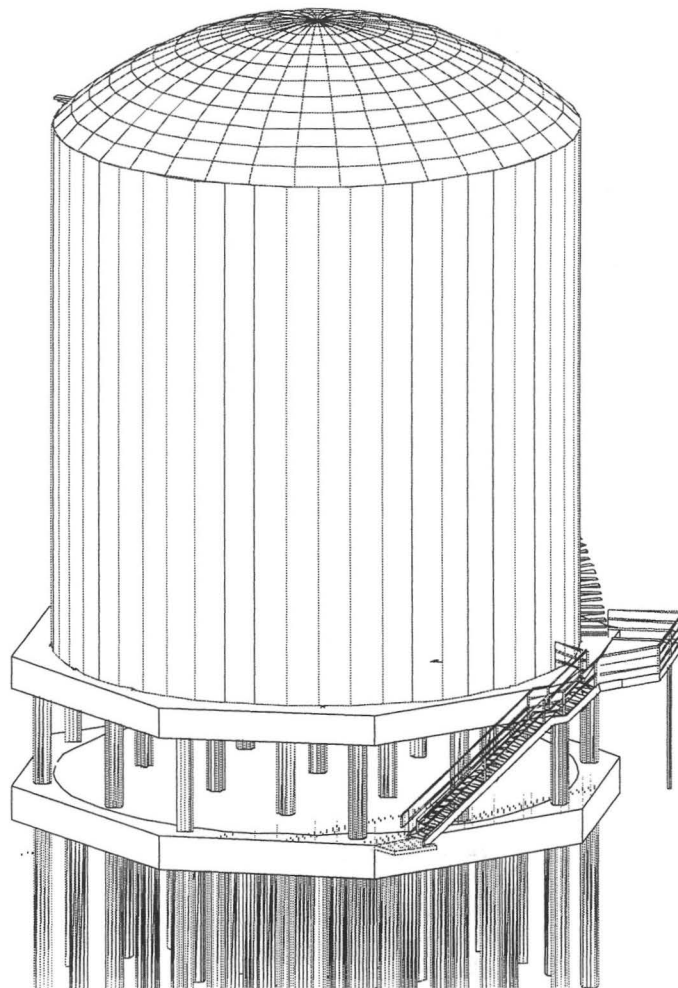


Figure 36-8 The pile driver setup.



# STRUCTURAL CALCULATIONS

for  
**TANK SUPPORT**



Prepared by:  
Craig T. Christy, P.E.  
December 3, 2002

**CONSULTING COMPANY**



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Christy

12/20/05

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Wind = 80 mph, exposure C tank empty  
Seismic zone 3, R = 2.9, T > 0.06 seconds tank full  
Seismic safety factor = 1.25  
Seismic governs

Minimum reinforcing for flexural members subject to seismic forces per ACI 21.3.2 also meets effective moment of inertia to limit deflections in at-rest water test.

Pile lateral deflection is permitted to be as great as 1" to develop lateral resistance to seismic event(s).



# SEISMIC CALCULATIONS TANK SUPPORT

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38 Seismic.xls

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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>SEISMIC CALCULATION WORKSHEET</b>													$V = 0.304 W_{Ultimate} = 0.217 W_{working stress}$
Z	0.3 unit	seismic zone factor		ZONE				1	2A	2B	3	4	
soil	$S_D$	soil profile type		Z				0.075	0.15	0.2	0.3	0.4	

Copy clip table values to reduce transcription errors.

SOIL PROFILE TYPE	blows/ft	logic
$S_A$ Hard rock		0
$S_B$ Rock	>50	0
$S_C$ Very dense soil & soft rock	15 to	0 row 20
$S_D$ Stiff soil	<15	5
$S_E$ Soft soil		0
$S_F$ Soil requiring evaluation		0
		5

**SEISMIC COEFFICIENT  $C_a$  UBC TABLE 16 Q**

SOIL TYPE	SEISMIC ZONE FACTOR, Z					logic
	0.075	0.150	0.200	0.300	0.400	
$S_A$	0.06	0.12	0.16	0.24	0.32	0
$S_B$	0.08	0.15	0.20	0.30	0.40	0
$S_C$	0.09	0.18	0.24	0.33	0.40	0
$S_D$	0.12	0.22	0.28	0.36	0.44	5
$S_E$	0.19	0.30	0.34	0.36	0.36	0
$S_F$ Soil requiring evaluation						0

$C_a$  0.36 unitless

$C_a$  The coefficient that defines the short period ground motion for structures with a fundamental period  $< C_v / 2.5 C_a$ .

**SEISMIC COEFFICIENT  $C_v$  97 UBC TABLE 16 R**

SOIL TYPE	SEISMIC ZONE FACTOR, Z					logic
	0.075	0.150	0.200	0.300	0.400	
$S_A$	0.06	0.12	0.16	0.24	0.32	0
$S_B$	0.08	0.15	0.20	0.30	0.40	0
$S_C$	0.13	0.25	0.32	0.45	0.56	0
$S_D$	0.18	0.32	0.40	0.54	0.64	5
$S_E$	0.26	0.50	0.64	0.84	0.96	0 row 50
$S_F$ Soil requiring evaluation						0

$C_v$  0.54

$C_v$  The coefficient that defines the longer period constant velocity ground motion.

The first five soil profile types are based upon soil shear wave velocity. Values for SF require a soil specific evaluation to establish site coefficients.

row 60



# SEISMIC CALCULATIONS TANK SUPPORT

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A B C D E F G H I J K L M N  
NEAR-SOURCE FACTOR  $N_a$  97 UBC TABLE 16 S ZONE 4 CALCULATION  $V = 0.304 W_{Ultimate} = 0.217 W_{working stress}$

Distance 5 Km 3.11 miles -- Closest distance to known seismic source in Km  
type C Seismic source type

The near source factors  $N_a$  and  $N_v$  apply to Zone 4 calculations UBC 1628 Symbols and Notations

### SEISMIC SOURCE TYPE 97 UBC TABLE 16 U

- A Faults that can produce large magnitude events and have a high rate of activity
- B All faults other than A or C
- C Faults that are not capable of producing large magnitude events and have a low rate of activity

row 70

#### CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE (Km)

	2.00	5.00	10.00	and greater
SEISMIC SOURCE TYPE	0	1	1	
A	1.50	1.20	1.00	1.00
B	1.30	1.00	1.00	1.00
C	1.00	1.00	1.00	1.00

$N_a$  1.00

$N_a$  The acceleration based factor for short period structures

logic  
0  
0  
4  
4

### NEAR-SOURCE FACTOR $N_v$ 97 UBC TABLE 16 T ZONE 4 APPLICATION

Distance 5 Km 3.11 miles -- Closest distance to known seismic source in Km  
type C Seismic source type

#### CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE (Km)

	2.00	5.00	10.00	15.00	and greater
SEISMIC SOURCE TYPE	0	1	1	1	
A	2.00	1.60	1.20	1.00	
B	1.60	1.20	1.00	1.00	
C	1.00	1.00	1.00	1.00	

$N_v$  1.00

$N_v$  The velocity based factor for ground motion periods > 1 second

choose  
5  
10  
5  
5  
1

### NEAR-SOURCE CALCULATIONS

- $C_a$  0.36 unitless soil type factor 97 UBC Table 16Q
- $N_a$  1.00 unitless near source factor from above
- $C_a * N_a$  0.36 unitless  $C_a * N_a$  in Zone 4 UBC 1628 Symbols IF(0.3 zone = 0.4 , 1.00 \* 0.36 , 0.36 )
- $C_v$  0.54 unitless seismic coefficient 97 UBC Table 16R
- $N_v$  1.00 unitless near source factor from above
- $C_v * N_v$  0.54 unitless near source factor  $N_v$  used in Zone 4 IF(0.3 = 0.4 , 0.54 \* 1.00  $N_v$  , 0.54 ) see UBC 1628 Symbols and Notations

Check with the local Building Official as to which seismic zone and near source factors may be required.

Parts of the Oregon coast have been reclassified to Zone 4. More of western Oregon and Washington may be reclassified to Zone 4 in the future.

row 90  
logic  
0  
0  
4  
4  
4  
1  
1  
5  
1  
1  
row 110



# SEISMIC CALCULATIONS TANK SUPPORT

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**SEISMIC CALCULATION WORKSHEET -- Continued** V = 0.304 W\_Ultimate = 0.217 W\_working stress

Z soil 0.3 unitless SD alpha zone acceleration factor from above soil type Stiff soil R The structure response factor based upon the structure configuration, stiffness, and force amplification characteristics in an earthquake leading to a ratio of seismic base shear to the ability of the structure to absorb energy and inelastic deformations without collapse.

R 2.9 unitless **TABLE 16-P - R FACTORS for NONBUILDING STRUCTURES** 11. All other structures not otherwise covered.

Note that the structure may be rendered useless by the seismic event that it was designed for under this system. However, some designs account for inelastic deformations and the continued use of the structure with or without repairs.

I 1.25 unitless importance factor

h<sub>n</sub> 75 ft building height  
C<sub>t</sub> 0.030 unitless building period factor based upon construction style 97 UBC 1630.2.2  
C<sub>t</sub> = 0.030 for reinforced concrete moment-resisting frames and eccentrically braced frames.

importance factor

T 0.765 seconds C<sub>t</sub> \* h<sub>n</sub><sup>0.75</sup> (30-8) natural period .. T > 0.06 Flexible nonbuilding structure .. use UBC 1630.5 V = Ft + sum Fi .. row 130

V rigid 0.315 \* W 0.7 \* C<sub>a</sub> \* I \* W (34-1) 0.7 \* 0.36 \* 1.25 \* W V lateral force, \* W

**1630.2.2**

C<sub>t</sub> = 0.035 for steel moment resisting frames  
C<sub>t</sub> = 0.030 for reinforced concrete moment-resisting frames and eccentrically braced frames.  
C<sub>t</sub> = 0.020 for all other buildings

V flexible 0.304 \* W C<sub>v</sub> \* I / (R \* T) \* W (30-4) 0.54 \* 1.25 / (2.9 \* 0.765) \* W

V 0.304 \* W flexible structure ..

row 140

V<sub>max</sub> 0.388 \* W 2.5 \* C<sub>a</sub> \* I / R \* W (30-5) 2.5 \* 0.36 \* 1.25 / 2.9 \* W maximum lateral force

V<sub>min</sub> 0.050 \* W 0.11 \* C<sub>a</sub> \* I \* W (30-6) 0.11 \* 0.36 \* 1.25 \* W this value sets the lower bounds for long period structures C<sub>a</sub> is multiplied by N<sub>a</sub> in Zone 4 calculations

Structure 1 input 0 = building structure 0.8 in (30-7), 1 = non building structure 1.6 in (34-3) row 150

V<sub>min\_4a</sub> 0.252 \* W 0.56 \* C<sub>a</sub> \* I \* W (34-2) 0.56 \* 0.36 \* 1.25 \* W for non-building structures C<sub>a</sub> is multiplied by N<sub>a</sub> in Zone 4 calculations  
1 logic for flexible nonbuilding structures 1634.5

row 160



# SEISMIC CALCULATIONS TANK SUPPORT



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SEISMIC CALCULATION WORKSHEET -- Continued  $V = 0.304 W_{Ultimate} = 0.217 W_{working stress}$

1.00 unitless near source factor for Zone 4 calculations  
Vmin\_4b 0.207 \*W 0.8 in (30-7), 1.6 in (34-3) \* Z \* N<sub>v</sub> \* I / R \* W (34-3)  
1.6 \* 0.30 \* 1.00 \* 1.25 / 2.9 \* W

zone 0 logic 0.3 = 0.4 is not Zone 4 ..

V\_applied<sub>u</sub> 0.304 \*W\_ultimate strength  
T > 0.06 Flexible nonbuilding structure ..

V\_applied<sub>w</sub> 0.217 \*W\_working stress  
T > 0.06 Flexible nonbuilding structure ..

**TABLE 16-P - R FACTORS for NONBUILDING STRUCTURE**

1.	Tanks, vessels or pressurized spheres on braced or unbraced legs	2.2	2.0
5.	Inverted pendulum type structures Cantilevered column building systems	2.2	2.0
9.	Signs and billboards	3.6	2.0
11.	All other structures not otherwise covered.	2.9	2.0

**Non-Building Structures at Grade UBC 1634**

V 0.217 \*W applied

For nonbuilding structures at / or below grade  
weight 60000 lbs gross weight of item  
CG 240 in  
M\_ot 3131288 in-lbs 0.217 g \* 240.00" \* 60,000 lbs  
bolt\_brg 90 in bolt to bearing to resist overturning  
CG\_rt 30.00 in arm in plan view to cg of gross weight  
M\_rt 1530000 in-lbs 0.85 \* 60,000 lbs\* 30.00 in  
Bolts t 2  
tension 8896 lbs ( 3,131,288 - 1,530,000 ) in-lbs / 90.00 in / 2 bolts  
Bolts v 4  
shear 3262 lbs 0.217 \* 60,000 lbs / 4 bolts

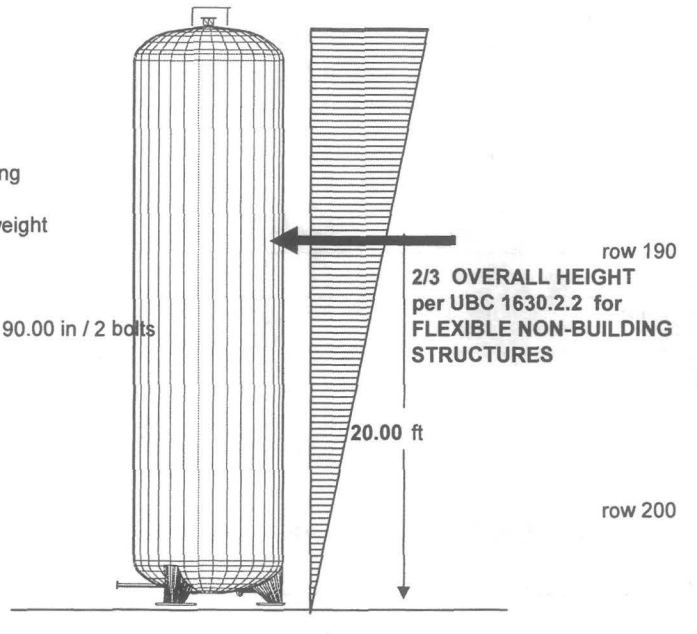


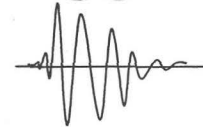
Figure 38-1 FLEXIBLE STRUCTURE

#####



# SEISMIC CALCULATIONS ASCE/SEI 7-02 and 7-05 TANK SUPPORT

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39 Seismic ASCE 7-02\_05.xls

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SEISMIC ASCE/SEI 7-02 and 7-05

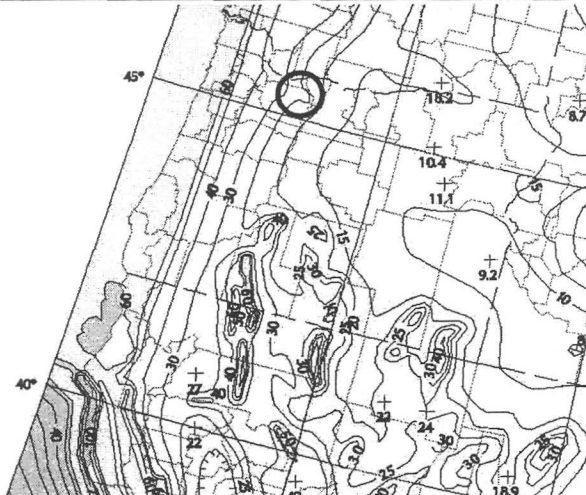


Figure 39-1 This is the map for the 1.0 second spectral response acceleration.



Figure 39-2 This is the map for the 0.2 second spectral response acceleration.

Note: USGS maps are 5% of Critical Damping, Site Class B. Near source factors  $N_a$  and  $N_v$  are accounted for in the seismic maps and lookup tables

ASCE 7-02 and 7-05 callouts are presented as 7-02 / 7-05 for ease of cross-referencing

Site Class	D	Site Classification	Tables 1-1, 9.13 and 9.14 / Tables 1-1 and 11.5-1	
D Stiff soil		600 < vs < 1,200	15 < N < 50	1,000 < su < 2,000
SUG	III	Seismic Use Group	Table 9.1.4 / Table 1-1	row 40
$I_E$	1.25	unitless	occupancy importance factor	

$S_S$	0.9692 $g_{ultimate}$	mapped maximum spectral response acceleration at short periods for Site Class B
$F_a$	1.1123 unitless	Velocity Based Site Coefficient for short periods Table 9.4.1.2.4a / Table 11.4-1
$S_{MS}$	1.0781 $g_{ultimate}$	$1.1123 * 0.9692$ $F_a S_S$ Eq. 9.4.1.2.4-1 / Eq. 11.4-1
$S_{DS}$	0.7187 $g_{ultimate}$	$2/3$ 1.0781 $2/3 S_{MS}$ design response acceleration at short periods Eq. 9.4.1.2.5-1 / Eq. 11.4-1

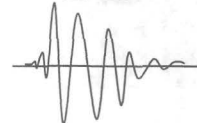
$S_1$	0.3584 $g_{ultimate}$	mapped maximum response acceleration at $T = 1.0$ sec Table 9.4.1.2.4b / Table 11.4-2	row 50
$F_v$	1.6832 unitless	Velocity Based Site Coefficient at $T = 1.0$ sec Table 9.4.1.2.4b / Table 11.4-2	
$S_{M1}$	0.6033 $g_{ultimate}$	$1.6832 * 0.3584$ $F_a S_1$ Eq. 9.4.1.2.4-1 / Eq. 11.4-2	
$S_{D1}$	0.4022 $g_{ultimate}$	$2/3$ 0.6033 $2/3 S_{M1}$ design response acceleration at short periods Eq. 9.4.1.2.5-2 / Eq. 11.4-2	

row 60



# SEISMIC CALCULATIONS SEI/ASCE 7-02 and 7-05 TANK SUPPORT

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### EQUIVALENT LATERAL FORCE PROCEDURE 9.5.5

ASCE 7-02 and 7-05 callouts are presented as 7-02 / 7-05 for ease of cross-referencing

R	3 unitless	response modification coefficient	Tables 9.5.2.2 and 9.14.5.1.1 / Table 12.1-1
$\Omega_o$	3 unitless	system over-strength factor	
$C_d$	2.5 unitless	deflection amplification factor	
	4 lookup	Site Classification	Table 9.4.1.2 / ??????
	0 logic	(4 > 5) lookup selection for Site Class Categories A, B, C, D	Eqs. 9.5.5.2.1 - 2 & 3
		Site Class A has been removed from ASCE 7-05	

row 70

$S_{D1}$	0.4022 $g_{ultimate}$	IF(0, 0.900 ASCE 9.4.1.3.4, 0.402 ASCE 9.4.1.2.4b )
$S_{DS}$	0.7187 $g_{ultimate}$	IF(0, 0.090 ASCE 9.4.1.3.4, 0.719 ASCE 9.4.1.2.4a)

$C_s$  1      0.2995  $g_{ultimate}$        $S_{DS} / (R_1 / I)$  Seismic design coefficient (Eq 9.5.5.2-1)  
0.719 / (3.0 / 1.25)

$C_s$  2 max      1.6757  $g_{ultimate}$        $S_{D1} / T_1 / (R_1 / I)$  (Eq. 9.5.5.2.1-2)  
0.402 / 0.100 / (3.00 / 1.25)

row 80

$C_s$  3 min      0.0395  $g_{ultimate}$        $0.044 * S_{DS} * I$  (Eq. 9.5.5.2.1-3)  
 $0.044 * 0.719 * 1.25$

$C_s$  4 min      0.0747  $g_{ultimate}$        $0.5 * S_1 / (R_1 / I)$  (Eq 9.5.5.2.1-4) for design categories E and F  
 $0.5 * 0.358 / (3.0 / 1.25)$

Site Class      4 lookup      Table 9.4.1.2 Site Classification

0.040      IF(4 < 6, 0.040, 0.075 Site Classes E & F)

row 90

$C_s$	<b>0.299</b> $g_{ultimate}$	MAX( MIN(0.299, 1.676), 0.040) seismic response coefficient, ultimate strength for $V = C_s W$ Eq. 9.5.5.2-1 / Eq. 12.8-1
	<b>0.214</b> $g_{ASD}$	0.299 / 1.4 seismic response coefficient, working stress

Values from the '97 UBC are:

**0.304 Ultimate**      **98.5 %**  
**0.217 Allowable Stress Design**

For errata to the ASCE 7-02, click on:

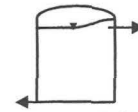
- [7-02 Errata](#)
- [7-02 Symbols](#)
- [7-02 Updated Snow Diagram](#)
- [7-02 Updated Snow Diagram](#)
- <http://www.ice-or.com>

row 100

For maps

- <http://eqhazmaps.usgs.gov/html/wus2002.html>
- <http://neic.usgs.gov/neis/states/oregon/>

row 110



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### OUTPUT SUMMARY

Wave Action in a Tank Per the AMERICAN PETROLEUM INSTITUTE (API)  
Standard 620 Tenth Edition, February 2002

tank_full	5753 k	weight of full tank
$W_T$	5012 k	weight of liquid
$W_{s\ tare}$	741 k	weight of empty tank, tare
H	66.70 ft	maximum design liquid height
D	47.50 ft	tank diameter
G	0.83 unit	specific gravity of stored product
density	0.0518 k/ft <sup>3</sup>	0.83 * 0.0624 density of stored product
circ	149.23 ft	47.50 * $\pi$ shell circumference
$W_{\text{tank}}$	4.97 k/ft	741 / 149.23 tank shell per foot of circumference
V	118196 ft <sup>3</sup>	$\pi * (47.50 / 2)^2 * 66.70$ volume of tank
		118,196 * 7.48052 = 884,168 gallons

### OVERTURNING MOMENT

Not all of the liquid works to overturn the tank + contents. Much of the potential force is taken out as wave action so that not all of the liquid moves in the same direction of the tank but, instead, much of the liquid moves vertically against the loaded wall.

D/H	0.71 unitless	diameter / height 47.50 / 66.70
$k_1$	0.57	$-0.0008 * 0.71^3 + 0.0122 * 0.71^2 - 0.0062 * 0.71 + 0.5699$
k	0.59	IF(factor for D/H)
T	4.07 sec	period of first mode sloshing $0.59 * \sqrt{47.50}$
S	1.50	site amplification factor from API Table L-2
$C_{2a}$	0.28	$0.75 * 1.50 / 4.07$ for $T \leq 4.5$ API L.3.3.2
$C_{2b}$	0.31	$3.375 * 1.50 / 4.07^2$ for $T > 4.5$ API L.3.3.2
$C_2$	0.28	lateral seismic force coefficient IF(4.07 $\leq$ 4.5, 0.28, 0.31)
$W_1 / W_T$	0.84	$0.0183 * 0.59^2 - 0.251 * 0.59 + 0.9798$

$W_1$	4200 k	weight of the effective mass of the tank contents that moves with the tank, see figure API L-2 $0.84 * 5,012$ k
-------	--------	--

$W_2 / W_T$	0.14	$0.001 * 0.71^3 - 0.0264 * 0.71^2 - 0.2481 * 0.71 - 0.6$ weight of the effective mass of the first mode sloshing of tank contents, see API Figure L-2
-------------	------	--

$W_2$	686 k	weight of effective mass of the first mode sloshing $0.14 * 5,012$ k
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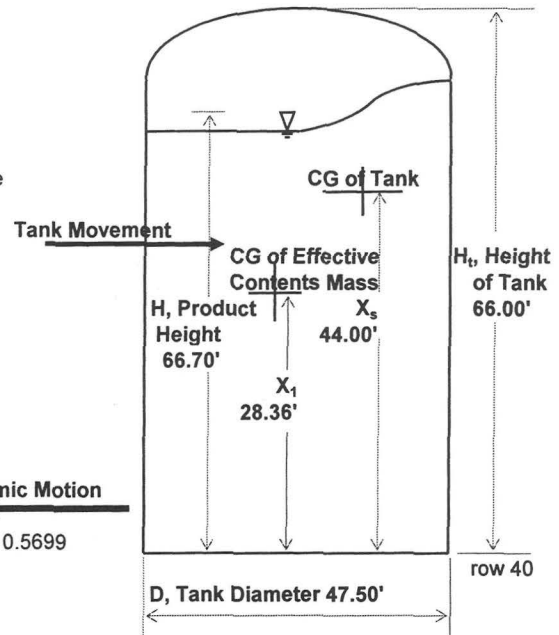


Figure 40-1 Tank elevation and forces.

<b>Site Coefficients</b>	<b>S</b>
Rock, shear-wave velocity >2500 fps	
Stiff or dense soil depth < 200 ft	1.00
Stiff or dense soil depth > 200 ft	1.20 row 50
Soil depth > 70 ft containing 20 ft or more of soft to medium stiff clay but not more than 40 ft of soft clay	1.50
More than 40 ft of soft clay where shear-wave < 500 fps	2.00

row 60

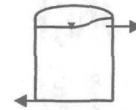
row 70



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**OVERTURNING MOMENT -- Continued**

$X_1/H$	0.43	$D/H * -0.07692 + 0.48$ $0.71 * -0.07692 + 0.48$	<b>Seismic Zone Coefficients</b>
			1 0.075
			2A 0.15
$X_1/H$	0.43		2B 0.2
$X_1$	28.36 ft	height to the centroid of lateral seismic force of tank contents that move in unison with the tank, $W_1$	3 0.3
			4 0.4
$X_2/H$	0.80	$0.0005 * D/H^4 - 0.0116 * D/H^3 + 0.0952 * D/H^2 - 0.3437 * D/H + 1$	
$X_2$	53.32 ft	height to the centroid of the tank contents sloshing mass, $W_2$	
Z	0.30 unitless	seismic zone coefficient	
I	1.25 unitless	importance factor	
$W_r$	0 k	total weight of tank roof and insulation, 0 when included in $W_s$	
$H_t$	66.00 ft	total height of tank shell	
$X_s$	44.00 ft	height to the CG of the shell usually taken as $2/3 H_t$ for flexible structures	
$C_1$	0.6 unitless	arbitrary factor	

**Importance Factor**

Generally the importance factor  $I = 1.00$ .  
Use  $I = 1.25$  for tanks containing toxic or explosive chemicals.  
Many building departments consider cryogenic materials to be hazardous and  $I = 1.25$ .  
The IBC (International Building Code) Table 1604.5 may require  $I = 1.50$ .

**Overtuning Moment Applied to Bottom of Tank**

19562	$C_1 W_s X_s$	$0.60 * 741 * 44.00$
0	$C_1 W_r H_t$	$0.60 * 0 * 66.00$
71481	$C_1 W_1 X_1$	$0.60 * 4,200 * 28.36$
10115	$C_2 W_2 X_2$	$0.60 * 686 * 53.32$
<b><math>M_{ot}</math></b>	<b>37934 k-ft</b>	<b><math>Z I (C_1 W_s X_s + C_1 W_r H_t + C_1 W_1 X_1 + C_2 W_2 X_2)</math></b>
445 k	$C_1 W_s$	$0.60 * 741$
0	$C_1 W_r$	$0.60 * 0$
2520	$C_1 W_1$	$0.60 * 4,200$
190	$C_2 W_2$	$0.28 * 686$
<b>W sum</b>	<b>1183 k</b>	<b>for lateral forces</b>
<b>W arm</b>	<b>32.1 ft</b>	<b><math>37,934 / 1,183</math> vertical arm to lateral forces</b>

Ratio loads for midline frame  
midline 5 columns  
total 21 columns  
0.238095 ratio

**E 282 k-ft**

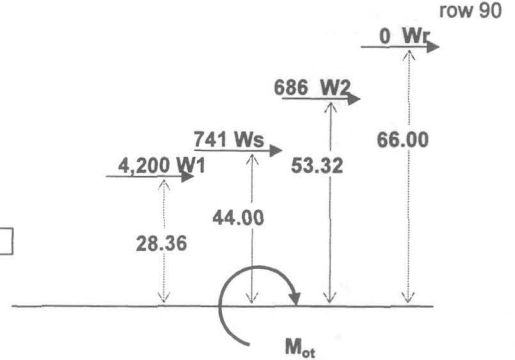


Figure 40-2 Tank overturning forces.

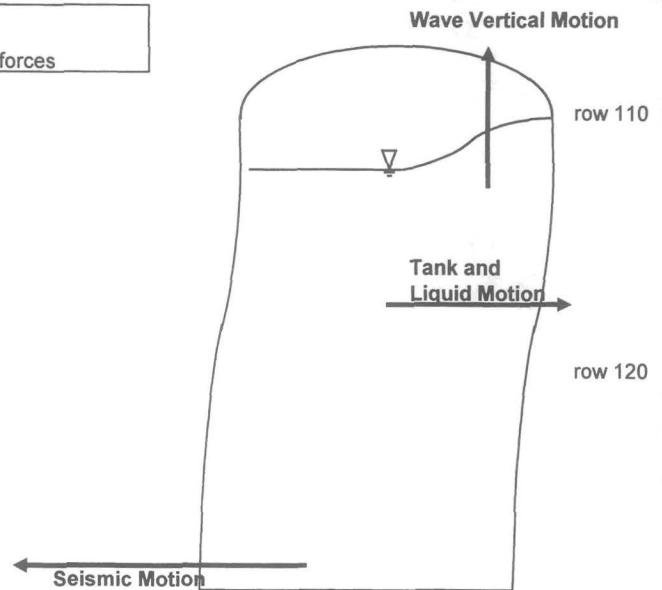


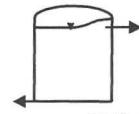
Figure 40-3 Tank in overturning and deformation.



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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>RIGHTING MOMENT</b>														
$t_b$		0.25 in		thickness of bottom of tank										
$t_s$		0.25 in		shell thickness										
$F_{by}$		36.0 k/in <sup>2</sup>		minimum yield strength of the bottom shell										
$W_L 1$		9659 lbs/ft		$7.9 * t_b * \sqrt{F_{by} * G * H}$ $7.9 * 0.25 * \sqrt{36.0 * 1000 * 0.83 * 66.70 * 12}$ in/ft										
$W_{L max}$		3287 lbs/ft		$1.25 * G * H * D$ $1.25 * 0.83 * 66.70 * 47.50$										
$W_L$		3287 lbs/ft		weight of contents to resist tank shell overturning										
$W_{shell}$		4576 lbs/ft		weight of shell and insulation										
$W_{rt}$		491 k		$3,287 * 47.50 \text{ PI}() / 1000$ contributing liquid 683 $4,576 * 47.50 * \text{PI}() / 1000$ shell 0 total weight of tank roof and insulation,										
$\Sigma W_{rt}$		1173 k												
$M_{rt}$		27866 k-ft		$47.50 / 2 * 1,173$										
		0 logic		!!! 27,866 < 37,934 k-ft Mot										

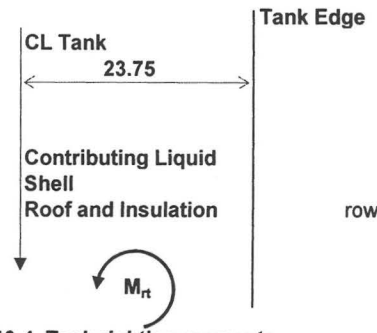


Figure 40-4 Tank righting moments.

**For Anchored Tank**

$b$	4597 lbs/ft	$4,576 + 1.273 * 37,934 / 47.50^2$ of shell circumference										
$\sigma$	1532 lbs/in <sup>2</sup>	$4,597 / (12 * 0.25)$ longitudinal stress at bottom of the shell										
factor	1998532 0 logic	$0.83 * 66.70 * 47.50^2 / 0.25^2$ factor > $10^6$										
$F_a$	4386 lbs/in <sup>2</sup>	$10,000,000 * 0.25 / (47.50 * 12)$ shell longitudinal stress										
$F_a$	6219 lbs/in <sup>2</sup>	$10,000,000 * 0.25 / (2.5 * 47.50 * 12) + 600 * \sqrt{0.83 * 66.70}$										
$F_a$	6219 lbs/in <sup>2</sup>	IF(0, 4,386, 6,219)										
	1 logic	OK 6,219 ≥ 4,386										

**Wave Height**

$d_{wave}$	1.93 ft	$1.124 * Z * I * C_2 * T^2 * \tanh(4.77 * \sqrt{H/D})$ $1.124 * 0.30 * 1.25 * 0.28 * 4.07^2 * \tanh(4.77 * \sqrt{66.70 / 47.50})$										
------------	---------	--	--	--	--	--	--	--	--	--	--	--

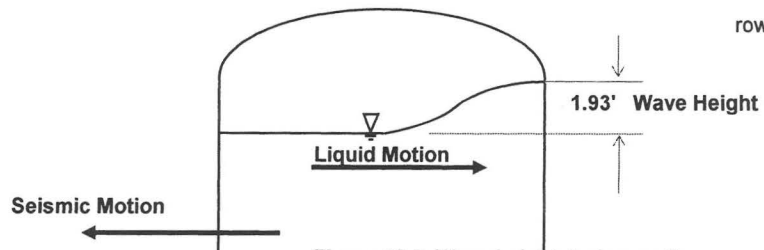
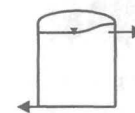


Figure 40-5 Wave height during motion.



**APPROXIMATIONS of API TABLES**

The **Trendline** command with the **Display equation** and **R-squared Values** on chart were used to approximate the API table values so that the chart values can be automatically calculated. This does, in fact, reduce errors. The **Trendline** values closely approximate chart values.

D/H	0	1	2	2.8	3	4	5	6	7	8	
W1/W <sub>T</sub>	1	0.74	0.53	0.41	0.38	0.28	0.2	0.15	0.12	0.13	row 200
W2/WT	0.0	0.22	0.4	0.51	0.53	0.63	0.7	0.75	0.77	0.79	

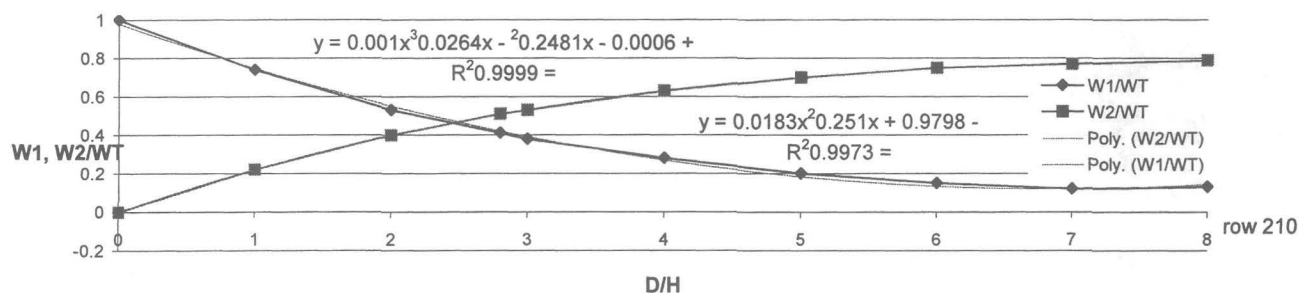


Figure 40-6 Diameter/Height versus W1, W2/WT, the effective mass of the first mode sloshing of tank contents API L-2.

D/H	0	1	1.3	2	3	4	5	6	7	8	
X2/H	1	0.74	0.69	0.61	0.55	0.54	0.53	0.52	0.51	0.50	row 220
X1/H	0.48	0.41	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	

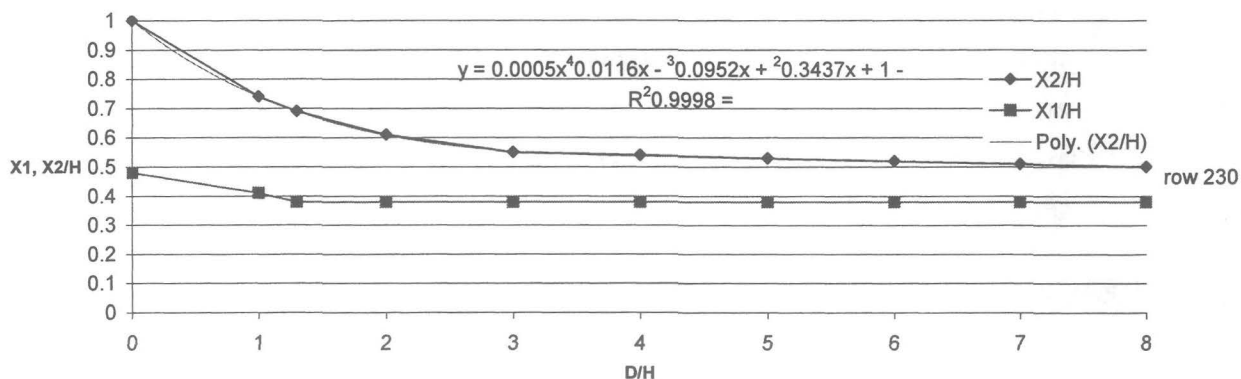


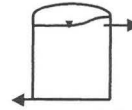
Figure 40-7 Diameter/Height versus X1, X2/H, the height to the centroid of the tank contents sloshing mass, W<sub>2</sub> API L-3.



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**APPROXIMATIONS of API TABLES -- Continued**

D/H	1.7	2	3	4	5	6	7	8
k	0.59	0.6	0.64	0.69	0.74	0.8	0.85	0.89

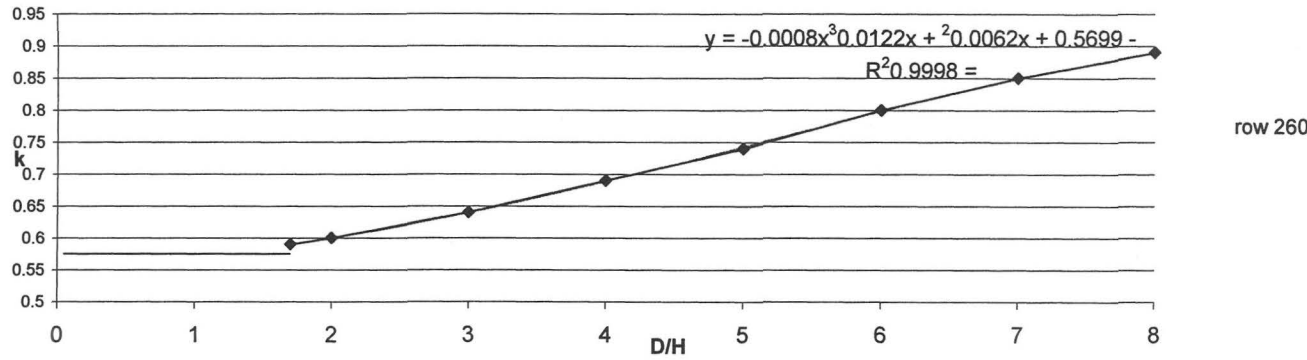


Figure 40-8 Diameter/Height versus factor k API L-4.

$M_{nt} / (D^2 * (W_t + W_{shell})) * 1000$	0.7	0.9	1	1.1	1.2	1.3	1.4	1.49
$(b + w_L) / (w_t + w_L)$	2	2.2	2.2	2.5	3	3.8	5.5	7.7

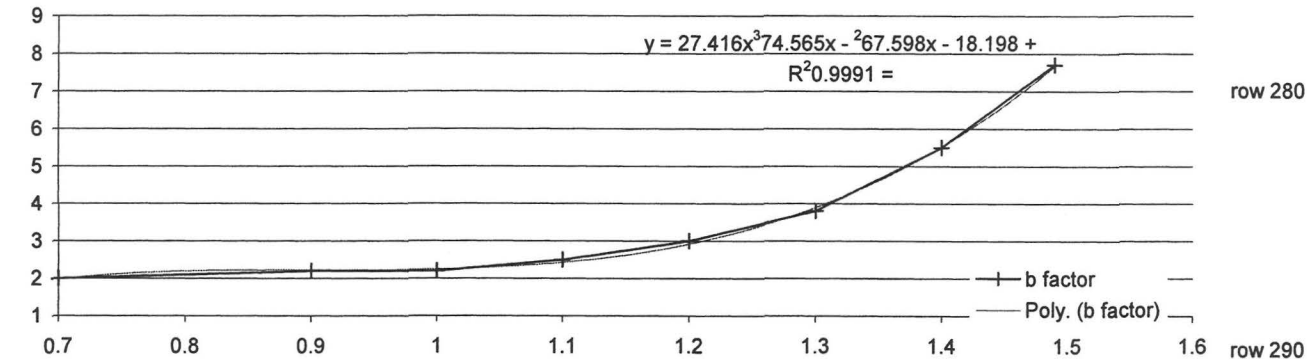


Figure 40-9 Maximum longitudinal compressive force at the bottom of the shell API L-5.

row 260

row 270

row 280

row 290

row 300

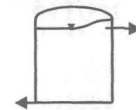
row 310



**CELERITY: WAVE ACTION  
TANK SUPPORT**

**40**

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>Unanchored Tanks for Reference</b>														
limit		2.138		$M_{nl} / (D^2 * (W_1 + W_{shell})) * 1000$ $37,934 / (47.50^2 * (4,576 + 3,287)) * 1000$										
b		4597 lbs/ft		4,576 + 1.273 * 37,934 / 47.50 <sup>2</sup> of shell circumference										
σ		1532 lbs/in <sup>2</sup>		4,597 / (12 * 0.25) longitudinal stress at bottom of the shell										
		0 logic		2.138 < 0.785										
b		4629 lbs/ft		4,576 + 27.416 * limit3 - 74.565 * limit2 + 67.598 * limit - 18.198										
		1 logic		2.138 > 0.785										
		0 logic		2.138 < 1.5										
						row 320								
b		#NUM! lbs/ft		$4,576 + 1.490 / \sqrt{1 - (0.637 * Mot * 1000 / (D2 * (Wshell + WL)))}$										
		1 logic		2.138 > 1.5										
		0 logic		2.138 < 1.57										
b		#NUM! lbs/ft		Unanchored tank may be unstable										
		1 logic												
						row 330								
σ		#NUM! lbs/in <sup>2</sup>		#VALUE!										

Note: #NUM indicates the square root of a negative number, in this case.

row 340

row 350



**LOAD RESISTANCE  
FACTOR DESIGN  
TANK SUPPORT**

**LRFD**

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**LRFD FACTORING '97 UBC**

1612.2.1 Basic load combinations with exception 2 -- multiply loads with 1.1 for loads including seismic forces

D	100.0	dead load -- max DL righting moment
L	0	live load or earth pressure -- max LL righting moment used in seismic
L <sub>r</sub>	0	roof live load
S	0	snow
W	0	wind
E	0.0	seismic -- when derived from the UBC, use E/1.4 for working (service level) values
T	0	differential settlement
H	0	earth pressure
F	0	fluid pressure, load factor = 1.4
max	100.0	
f 1	1.0	1.0 floors in public assembly, LL >100 psf, garage 0.5 of other live loads
f 2	0.2	0.7 roofs that can't shed snow, 0.2 other

97 UBC 1612.2.1

E <sub>1</sub>	1.1 multiplier	use 1.1 for concrete and masonry subjected to seismic forces	
12-1	154	1.1 * 1.4 D	<b>MOST CONSERVATIVE</b>
12-2	132	1.1 * (1.2D + 1.6*L + 0.5* (L or S))	
12-3	132	1.1 * (1.2D + 1.6(L <sub>r</sub> or S) + (f <sub>1</sub> L or 0.8W))	
12-4	132	1.1 * (1.2D + 1.3W + f <sub>1</sub> L + 0.5(L <sub>r</sub> or S))	
12-5a	132	1.1 * (1.2D + 1.0E + (f <sub>1</sub> LL <sub>1</sub> + f <sub>2</sub> S))	
12-6a	99	1.1 * (0.9D + 1.0E or 1.3W)	1.32 D + 1.1 E + 1.1 (f <sub>1</sub> L or 0.88 W) + 1.43F
12-6b	99	1.1 * (0.9D - 1.0E or 1.3W)	0.99 D + 1.1 E or 1.43 W
max	154	ratio	0.99 D - 1.1 E or 1.43 W

97 UBC 1909.2 values

Where E is included in the design, use UBC 1612.2.1 per UBC 1909.2.3

9-1	140	1.4D + 1.7L	
9-2a	105	0.75 (1.4D + 1.7L + 1.7W)	1.05 D + 1.275 L + 1.275 W
9-3a	90	0.9D + 1.3W	
9-4a	140	1.4D + 1.7L + 1.7H	
9-4b	90	0.9D + 0L + 1.7H	
9-5	105	0.75 (1.4D + 1.4T + 1.7L)	1.05 D + 1.05 L + 1.275 L
9-6	140	1.4 (D + T)	1.4 D + 1.4 T
max	140	ratio	1.400

99 ACI Values

Where E = UBC seismic value / 1.4

E UBC	0	UBC E / 1.4	
9-1a	140	1.4 D + 1.7 L	
9-1b	140	1.4 D + 1.7 L + 1.4 F	
9-2a	120	1.2 D + 1.6 L + 1.7 W	
9-2b	105	1.05 D + 1.28 L + 1.4 E	
9-3a	90	0.9 D + 1.43 E	
9-3b	90	0.9 D + 1.7 H	
9-4a	140	1.4 D + 1.7 L + 1.7 H	
9-4b	90	0.9 D + 1.7 H	
9-5	105	1.05 D + 1.4 T + 1.275 L	
9-6	140	1.4 D + 1.4 T	
max	140	ratio	1.400

For lateral force calculations:

E            0.462            0.30 x 1.4 x 1.1            structure

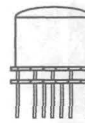
LN2 and tank are calculated separately per API and added to the structure lateral force



# PILE FOUNDATION TANK SUPPORT

# 42

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80' Driven Length, 24" Piling

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SUMMARY for TANK and FOUNDATION

tare	741 k	tank
test	6254 k	water weight
LN <sub>2</sub>	5012 k	liquid weight full

test	6995 k	tank + weight at test
Normal	5753 k	normal max operating weight
W contents	4200 k	contents that move w/ tank during an event

diameter	53 ft	approximate loaded diameter	60'
area	2206 ft <sup>2</sup>	(53/2) <sup>2</sup> * PI()	
q operate	2.61 k/ft <sup>2</sup>	Normal /area	

**3.5' Elevated Deck**

h	3.5 ft	
DL	1839 k	from AutoCAD massprop calculations
area	3503 ft <sup>2</sup>	1,839 / (42 / 12 * 0.15)

**Piling**

Top	1.59 k	24"Φ x 1/2" wall steel casing
		0.5 * 24 * PI() / 144 * 485 * 12.5 / 1000
	5.89 k	concrete top 12.5'
		12 <sup>2</sup> * PI() / 144 * 0.15 * 12.5
	7.48 k	per arbitrary 12.5' trib length of composite pile

columns	21 each	above the pile cap
	157 k	sum of piling weight above pile cap

**4.0' Pile Cap**

h	4 ft	wt steel	485 lb/ft <sup>3</sup>
DL	2102 k	wt conc.	150 lb/ft <sup>3</sup>
		1 k	1000 lbs

gross opr	5753 k	tank + contents operating weight	Liquid
	1839 k	top deck	
	157 k	columns	
	2102 k	pile cap	

sum	9851 k	operating load to bottom of pile cap
sum	11093 k	test load H <sub>2</sub> O

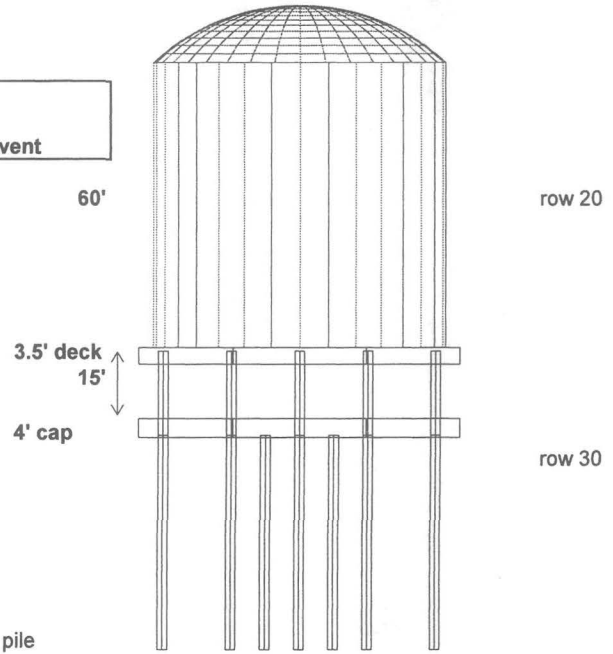


Figure 42-1 Tank and structure elevation.

A flat bottom 60 foot diameter, 60 foot tall, liquid nitrogen storage tank is supported on a pile foundation at 15' above grade.

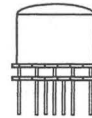
Pile foundation and pedestal structure to support:  
Tank and contents normal operating weight of 5,753,000 lbs.  
Test weight of 6,995,000 Lbs.

Life of the structure is 30 years.

Planar tilt is limited to 1/2" in 60' during the life of the structure. Out-of-plane, differential settlement is limited to 1/8" in 30' and 1/4" in 60' during the life of the structure.'

Settlements will govern this design as much or more than seismic and wind forces.

80' Driven Length, 24" Piling



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### DESIGN LOADS for FRAME ANALYSIS PROGRAM

This frame is an elastic ordinary moment resisting frame. The design is for elastic response only and does not use yielding of any member for energy absorption. The value of R for ordinary moment resisting frames is the same as the R for elevated tanks on unbraced legs.

#### Estimate story shear (V story) to the top of the pile cap

C <sub>a</sub>	0.36	factor for vertical accelerations
I	1.25	importance factor
V	0.304 *W	from seismic worksheet
p estimate	1	estimated redundancy factor
C factor	1.1	'97 UBC 1612.2.2.1 Exception 2 for concrete columns

row 80

	seismic DL shear ult		
tank	741		
W contents	5012		
E tank and contents	692		
deck	1839	769	
col/piles	157	66	
V story	7749	1527 k ult	to top of deck
pile cap	2102	879	
D	9851	2405 k ult	approximate DL + Liquid to top of piling

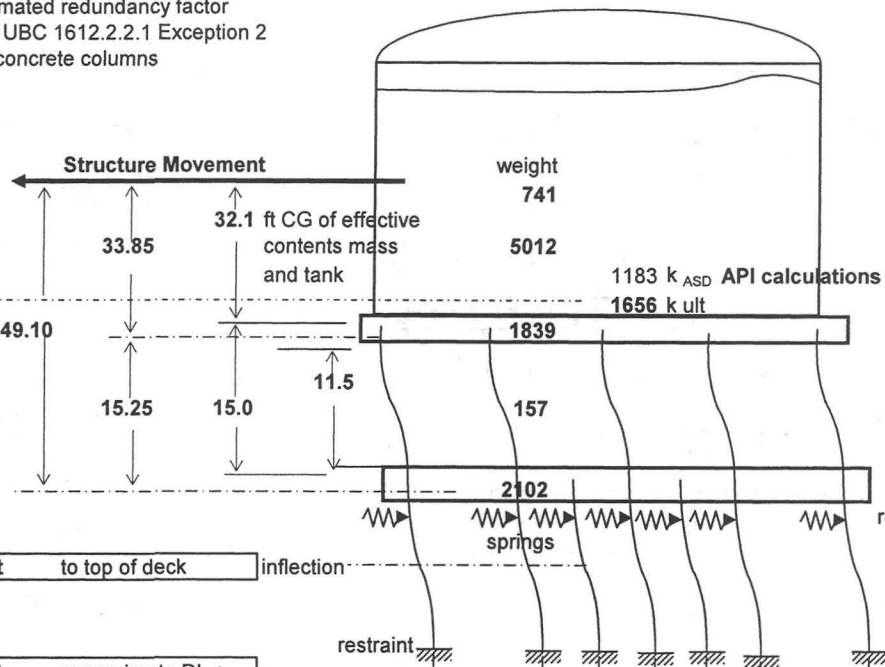


Figure 42-2 Tank and structure with seismic forces.

row 110

#### Check Redundancy

Overly simplify the model: apply loads to the nodes of the mid-line frame.

Area 3503 ft<sup>2</sup> surface area of the deck and/or the pile cap

Redundancy factor for an ordinary moment frame ASCE 7-02 9.5.2.4.2

Item 3  $\Sigma$  any two adjacent column shears / story shear

column 4	110 k ult	from preliminary frame analysis
column 7	112 k ult	
sum cols	222	112 + 110
V story	1527 k ult	

row 120

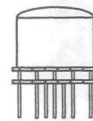
r 0.145 222 / 1,527 ratio of any two adjacent column shears to the sum of all column shears

P -0.324 2 - 20 / (r<sub>max</sub> \*  $\sqrt{A_x}$ ) 1.0 ≤ p ≤ 1.5 max  
2 - 20 / [0.145 \* 3,503<sup>0.5</sup>]

P 1 unitless minimum required p redundancy factor

row 130

80' Driven Length, 24" Piling



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**EXTEND PILING THROUGH PILE CAP to DECK**  
**Pile Lateral Resistance**

45 piling total

Pile lateral **90 k** → at 8 diameters through 1" deflection

pile @ 14' **17** each  
82 k/each  
1387 k

pile @ 7' **28** each  
52 k/each  
1457 k

pile sum	<b>2843 k service</b>	pile soil lateral
----------	-----------------------	-------------------

soil lat **250** pcf  
face **78** ft  
depth **4** ft  
soil p **156** k

pile cap resistance

pile cap	<b>2999 k ASD</b>	sum soil and pile lateral resist
----------	-------------------	----------------------------------

V pile cap **2405 k ult** from calculations above

compare **1** logic

V pile cap	<b>1718 k ASD</b>	$2,405 / 1.4 = 1,718 < 2,999$ OK
------------	-------------------	-------------------------------------

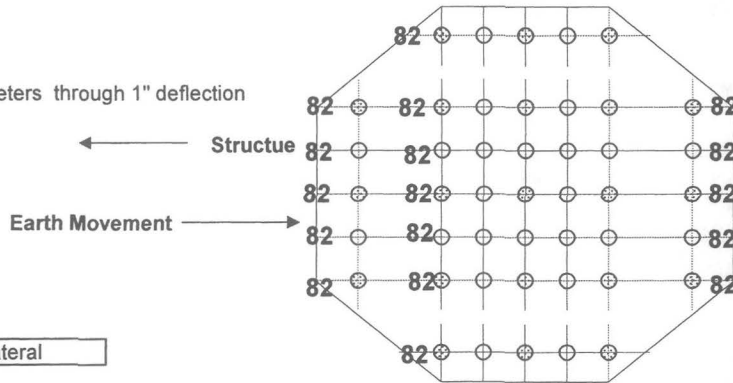


Figure 42-3 This is the piling plan view.

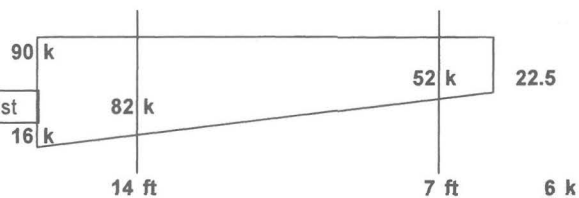


Figure 42-4 Piling lateral resistance -- spacing versus capacity.

Piling below the pile cap is considered to be buoyant.

Top of piling fixed within pile cap.

Spring restraint to resemble soil lateral resistance applied at soil/pile cap interface.

Concrete and rebar cage top 25' of pile.

The deck is designed as a two-way slab supported by 21 columns.

For this analysis, S-Frame 3D finite analysis program was used to calculate moments, axial loads, and deflections along the midline of the structure.

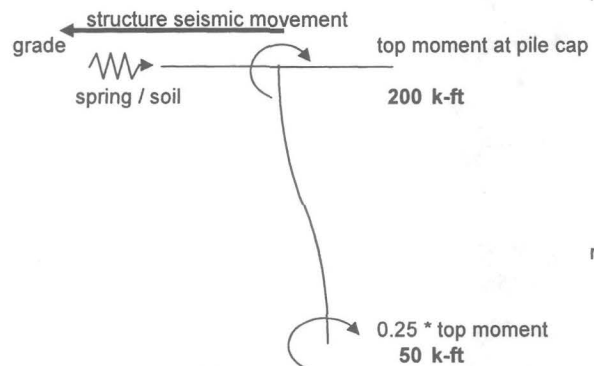


Figure 42-5 Piling applied moments under seismic forces.

row 150

row 160

row 170

row 180

row 190

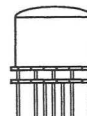


# PILE FOUNDATION TANK SUPPORT

80' Driven Length, 24" Piling

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**LOADS to DECK MID-LINE**

Design for the '97 UBC ultimate strength of columns. Spring values at grade are given an arbitrary factor of 1.0.

$E = \rho E_h + E_v = \rho V D + 0.5 C_a I D$  multiply this by 1.1 for concrete '97 UBC 1612.2.2.1 Exception 2

	horizontal component		vertical component
E	$1.0 * 1,527 * 1.1$	+	$0.5 * 0.360 * 1.25 * 9,851 * 1.1$
	1679	+	2438

row 200

Basic Load Combinations '97 UBC 1612  
ratio **0.238** = 5 mid-line columns /21 columns total

D	horizontal component	vertical component
2345 ↓	400 ←	581 ↓

Create load cases for D,  $E_h$ , and  $E_v$  where: note that D = D + stored liquid

hence:

$E_h$	$0.170 * D$	$E_h / D$	
		400 /2,345	row 210

and

$E_v$	$0.248 * D$	$E_v / D$	
		581 /2,345	

Per '97 UBC (12-1)

	1.4 D				
(12-5)	1.2 D	+	1.0 $E_h$	+	1.0 $E_v$
(12-6)	0.9 D	±	1.0 $E_h$	±	1.0 $E_v$

row 220

The load cases are:

1 (12-1)	1.4 D						
2 (12-5)	1.2 D	+	0.170 D horizontal	+	1.0 E per API calc	+	0.248 D vertical
3 (12-6) a	0.9 D	+	0.170 D horizontal	+	1.0 E per API calc	+	0.248 D vertical
4 (12-6) b	0.9 D	+	0.170 D horizontal	+	1.0 E per API calc	-	0.248 D vertical

row 230

row 240

row 250

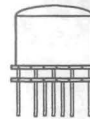


# PILE FOUNDATION TANK SUPPORT

80' Driven Length, 24" Piling

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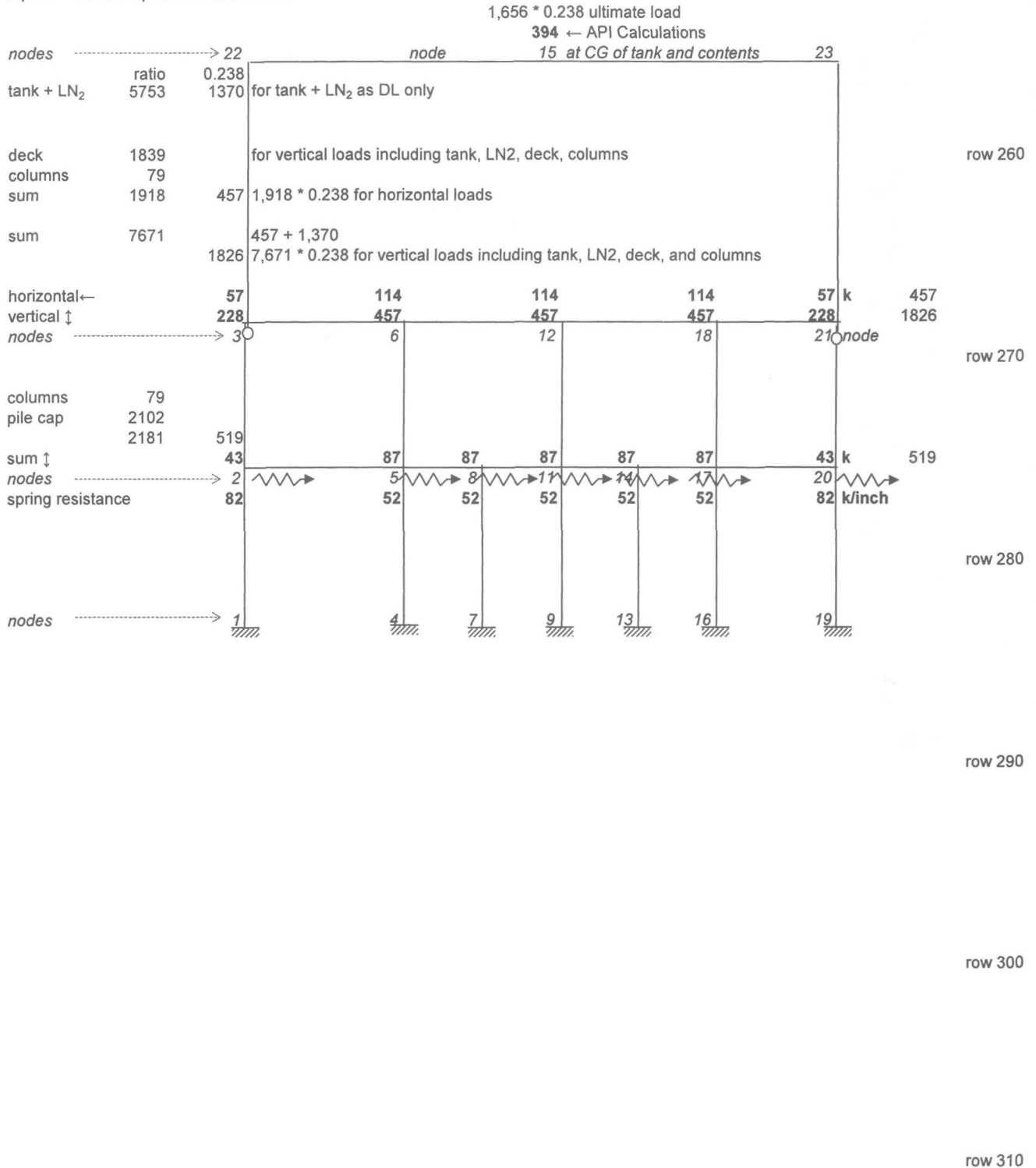


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### SUMMARY of LOADS to DECK MID-LINE for FINITE ELEMENT ANALYSIS

Input D + stored liquid for these nodes:

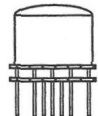




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**LOADS to DECK MID-LINE by CASE and LOAD COMBINATIONS per '97 UBC**

Load combinations are:

<b>1</b>	<b>(12-1)</b>	<b>1.4 D</b>								
1.4 x Case 1 D only		228		457		457		457		228
node		3		6		12		18		21
		43		87	87	87	87	87	87	43
node		2		5	8	11	14	17		20

row 320

<b>2</b>	<b>(12-5)</b>	<b>1.2 D</b>	<b>+</b>	<b>0.170 D horizontal</b>	<b>+</b>	<b>0.248 D vertical</b>				
1.448 x Case 1 D		228		457		457		457		228
0.148 x Case 2 E		57		114		114		114		57
1.0 x Case 3 E API						394				
node		3		6	15	12		18		21
1.448 x Case 1 D		43		87	87	87	87	87	87	43
0.148 x Case 2 E		43		87	87	87	87	87	87	43
node		2		5	8	11	14	17		20

where: 1.2 + 0.248

where: 1.2 + 0.248

<b>3</b>	<b>(12-6) a</b>	<b>0.9 D</b>	<b>+</b>	<b>0.170 D horizontal</b>	<b>+</b>	<b>0.248 D vertical</b>				
1.148 x Case 1 D		228		457		457		457		228
0.148 x Case 2 E		57		114		114		114		57
1.0 x Case 3 E API						394				
node		3		6	15	12		18		21
1.148 x Case 1 D		43		87	87	87	87	87	87	43
0.148 x Case 2 E		43		87	87	87	87	87	87	43
node		2		5	8	11	14	17		20

where: 0.90 + 0.248

where: 0.90 + 0.248

<b>4</b>	<b>(12-6) b</b>	<b>0.9 D</b>	<b>+</b>	<b>0.170 D horizontal</b>	<b>-</b>	<b>0.248 D vertical</b>				
0.652 x Case 1 D		228		457		457		457		228
0.148 x Case 2 E		57		114		114		114		57
1.0 x Case 3 E API						394				
node		3		6	15	12		18		21
0.652 x Case 1 D		43		87	87	87	87	87	87	43
0.148 x Case 2 E		43		87	87	87	87	87	87	43
node		2		5	8	11	14	17		20

where: 0.90 - 0.248

where: 0.90 - 0.248

row 350

Axial and moment forces were generated from a subsequent computer run.  
These loads are:

axial            460 k ult  
moment        1174 k ult

row 360

row 370

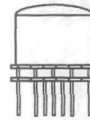


# PILE FOUNDATION TANK SUPPORT

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**LOADS to DECK MID-LINE USING ASCE 7-02 STRENGTH DESIGN**

This frame is an elastic ordinary moment resisting frame.

$\rho$	1.0 unitless	from above
$S_{DS}$	0.719 $g_{ult}$	short period spectral response 9.4.1.2.5-1
$C_s$	0.299 $g_{ult}$	seismic response coefficient 9.5.5
D	9851 k	from above
Vert story	1417 k <sub>ult</sub>	$0.2 * 0.719 * 9,851$
V story	2945 k <sub>ult</sub>	$0.299 * 9,851$

row 380

Basic Load Combinations ASCE 7-02  
ratio 0.238 = 5 mid-line columns /21 columns total

	D 2345 $0.238 * 9,851$	horizontal component 701 $0.238 * 2,945$	vertical component 337 $0.238 * 1,417$	ratioed loads
$E_{p1}$	$\rho Q_E + 0.2 S_{DS} D$	Eq. 9.5.2.7 - 1		
Case 5 <sub>2.3.2</sub>	1.2 D 2845 vertical $1.2 * 2,345$	$\pm$ $\rho E_{p1}$ $\pm$ 701 horizontal $1.0 * 701$	$\pm$ 0.2 $S_{DS} D$ $\pm$ 337 vertical 337	

row 390

$E_{p2}$	$\rho Q_E - 0.2 S_{DS} D$	Eq. 9.5.2.7 - 2		
Case 8 <sub>2.3.2</sub>	0.9 D 2111 vertical $0.9 * 2,345$	$\pm$ $\rho E_{p2}$ $\pm$ 701 horizontal $1.0 * 701$	$\pm$ 0.2 $S_{DS} D$ $\pm$ 337 vertical 337	

row 400

Create load cases for D,  $Q_E$ , and  $0.2 S_{DS} D$

where:  $\rho Q_E / D = 701 / 2,345 = 0.299 * D$   
and  $0.2 S_{DS} D / D = 337 / 2,345 = 0.144 * D$

These factors are to be used in the computer finite element analysis "Load Combinations."

row 410

The load cases are:

1 D only	1.4 D				
2 5 <sub>2.3.2</sub>	1.2 D	+	0.299 D horizontal	+	1.0 E per API calc
				+	0.299 D vertical
3 8 <sub>2.3.2 a</sub>	0.9 D	+	0.299 D horizontal	+	1.0 E per API calc
				+	0.144 D vertical
4 8 <sub>2.3.2 b</sub>	0.9 D	+	0.299 D horizontal	+	1.0 E per API calc
				-	0.144 D vertical

row 420

These results are slightly less conservative than the '97 UBC results above

row 430

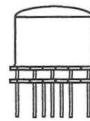


# PILE FOUNDATION TANK SUPPORT

80' Driven Length, 24" Piling

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**LOADS to DECK MID-LINE USING ASCE 7-05 STRENGTH DESIGN for Comparison**

This frame is an elastic ordinary moment resisting frame.

$\rho$  1.00 unitless from above

$S_{DS}$  0.719  $g_{ult}$  short period spectral response 9.4.1.2.5-1  
 $C_s$  0.299  $g_{ult}$  seismic response coefficient 9.5.5

D 9851 k from above

Vert story 1417  $k_{ult}$  0.2 \* 0.719 \* 9,851 7-05 0.2 SDS D 12.4-4 and 12.14-6  
 V story 2945  $k_{ult}$  0.299 \* 9,851 7-05 V =  $C_s W$  12.8-1

row 440

Basic Load Combinations ASCE 7-05 Where 12.4.2.3 is used in lieu of 2.3.2  
 ratio 0.238 = 5 mid-line columns / 21 columns total

D	horizontal component	vertical component	
2345	701	337	← ratioed loads
0.238 * 9,851	0.238 * 2,945	0.238 * 1,417	

row 450

Case 5  $(1.2 + 0.2 S_{DS}) D + \rho QE + L + 0.2 S$

1.2 D	±	$\rho E_{p5}$	±	0.2 $S_{DS} D$
2815 vertical	±	701 horizontal	±	337 vertical
1.2 * 2,345		1.0 * 701		337

Case 6  $(0.9 - 0.2 S_{DS}) D + \rho QE + 1.6 H$

0.9 D	±	$\rho E_{p6}$	±	-0.2 $S_{DS} D$
2111 vertical	±	701 horizontal	±	337 vertical
0.9 * 2,345		1.0 * 701		337

row 460

Create load cases for D,  $Q_E$ , and 0.2  $S_{DS} D$

where:  $\rho Q_E / D = 701 / 2,345 = 0.299 * D$   
 and  $0.2 S_{DS} D / D = 337 / 2,345 = 0.144 * D$

These factors are to be used in the computer finite element analysis "Load Combinations."

row 470

The load cases are:

1 D only	1.4 D						
2 Case 5	1.2 D	+	0.299 D horizontal	+	1.0 E per API calc	+	0.299 D vertical
3 Case 6	0.9 D	+	0.299 D horizontal	+	1.0 E per API calc	+	0.144 D vertical

row 480

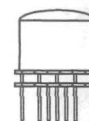
row 490



# PILE FOUNDATION TANK SUPPORT

## 42

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**GENERATE ASD ASCE 7-02 LOADS for DEFLECTION CALCULATIONS**

$\rho$  1.0 unitless from above

$S_{DS}$  0.719  $g_{ult}$  short period spectral response

$C_s$  0.299  $g_{ult}$  seismic response coefficient

$D$  9851 k from above

Vert story 1417 k  $_{ult}$   $0.2 * 9,851 * 0.719$

V story 2945 k  $_{ult}$   $9,851 * 0.299$

row 500

Basic Load Combinations ASCE 7-02

ratio 0.238 = 5 mid-line columns /21 columns total

$D$	horizontal component	vertical component
2345	701	337

$E_{p1}$   $\rho Q_E + 0.2 S_{DS} D$  Eq. 9.5.2.7 - 1

row 510

Case 5 <sub>2.4.1</sub>	1.0 $D$	$\pm$	0.7 $E_{p1}$	+	0.2 $S_{DS} D$
	2345 vertical		491 horizontal		337 vertical

$E_{p2}$   $\rho Q_E - 0.2 S_{DS} D$  Eq. 9.5.2.7 - 2

Case 8 <sub>2.4.1</sub>	0.6 $D$	$\pm$	0.7 $E_{p2}$	-	0.2 $S_{DS} D$
	1407 vertical	$\pm$	491 horizontal	-	337 vertical

row 520

Create load cases for  $D$ ,  $Q_E$ , and  $0.2 S_{DS} D$

Note that the reciprocal of 0.7 is approximately 1.4. This is the standard way to reduce LRFD seismic to ASD levels.

where:  $\rho Q_E / D = 491 / 2,345 = 0.209 * D$   
and  $0.2 S_{DS} D / D = 337 / 2,345 = 0.144 * D$

The load cases are:

row 530

1 5 <sub>2.4.1</sub>	1.0 $D$	+	0.209 $D$ horizontal	+	0.144 $D$ vertical
2 8 <sub>2.4.1 a</sub>	0.6 $D$	+	0.209 $D$ horizontal	+	0.144 $D$ vertical
3 8 <sub>2.4.1 b</sub>	0.6 $D$	+	0.209 $D$ horizontal	-	0.144 $D$ vertical

Use these applied strength design (ASD) loads to compute deflections in the computer finite element analysis "Load Combinations."

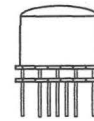
row 540



# PILE FOUNDATION TANK SUPPORT

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**GENERATE ASD ASCE 7-05 LOADS for DEFLECTION CALCULATIONS for Comparison**

P	1.0	unitless	from above		
S <sub>DS</sub>	0.719	g <sub>ult</sub>	short period spectral response		
C <sub>s</sub>	0.299	g <sub>ult</sub>	seismic response coefficient		
D	9851	k	from above		
Q <sub>E</sub>	2945	k <sub>ult</sub>	9,851 * 0.299	where Q <sub>E</sub> = V	row 550
Basic Load Combinations ASCE 7-05 Where 12.4.2.3 is used in lieu of 2.4.1					
ratio	0.238		= 5 mid-line columns / 21 columns total		
	D		horizontal component		
	2345		701		

Case 5	(1.0 + 0.14 S <sub>DS</sub> ) D + H + F + 0.7 ρQ <sub>E</sub>				
	1.0 D	+	0.7 Q <sub>E</sub>	+	0.2 S <sub>DS</sub> D
	2345 vertical		491 horizontal		337 vertical
					row 560

Case 6	(1.0 + 0.105 S <sub>DS</sub> ) D + H + F + 0.525 ρQ <sub>E</sub> + 0.75 L + 0.75 (L <sub>r</sub> or S or R)				
	1.0 D	+	0.525 Q <sub>E</sub>	+	0.105 S <sub>DS</sub> D
	2345		368		177

Case 8	(1.0 - 0.14 S <sub>DS</sub> ) D + 0.7 ρQ <sub>E</sub> + H				
	0.6 D	+	0.7 Q <sub>E</sub>	-	0.14 S <sub>DS</sub> D
	1407 vertical	+	491 horizontal	-	236 vertical
					row 570

Note that the reciprocal of 0.7 is approximately 1.4. This is the standard way to reduce LRFD seismic to ASD levels.

The load cases are:

1 Case 5	1.0 D	+	0.209 D horizontal	+	0.144 D vertical	row 580
2 Case 6	0.6 D	+	0.157 D horizontal	+	0.075 D vertical	
3 Case 8	0.6 D	+	0.209 D horizontal	-	0.101 D vertical	

Use these applied strength design (ASD) loads to compute deflections in the computer finite element analysis "Load Combinations."

row 590

row 600

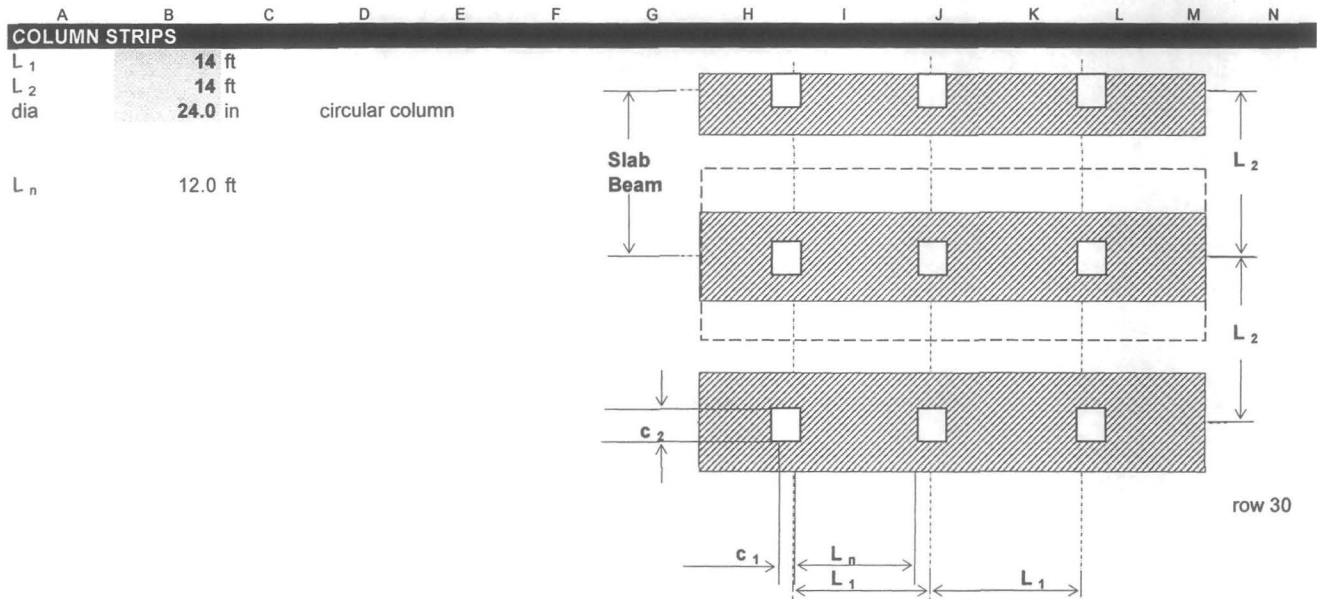


Figure 43-1 FRAMING LAYOUT PLAN

### TWO WAY SLAB LOADING

Column strips are set at a 7' x 12' = 84" width.  
 Column strips serve as beams to resist lateral forces.

DL + Fluid + Seismic moments are added to column induced moments

#### Concrete

Col Strip      3.5 ft  
                   2.0 ft  
                   0.15 k/ft<sup>3</sup>  
                   1.05 k/ft

#### Tri Max

3.5 ft  
 12.0 ft  
 0.15 k/ft<sup>3</sup>  
 6.3 k/ft      mid-point

#### Load

Col Strip      2.0 ft  
                   2.61 k/ft<sup>2</sup>  
                   5.22 k/ft      column strip

#### Tri Max

12.0 ft  
 2.61 k/ft<sup>2</sup>  
 31.32 k/ft      mid-point

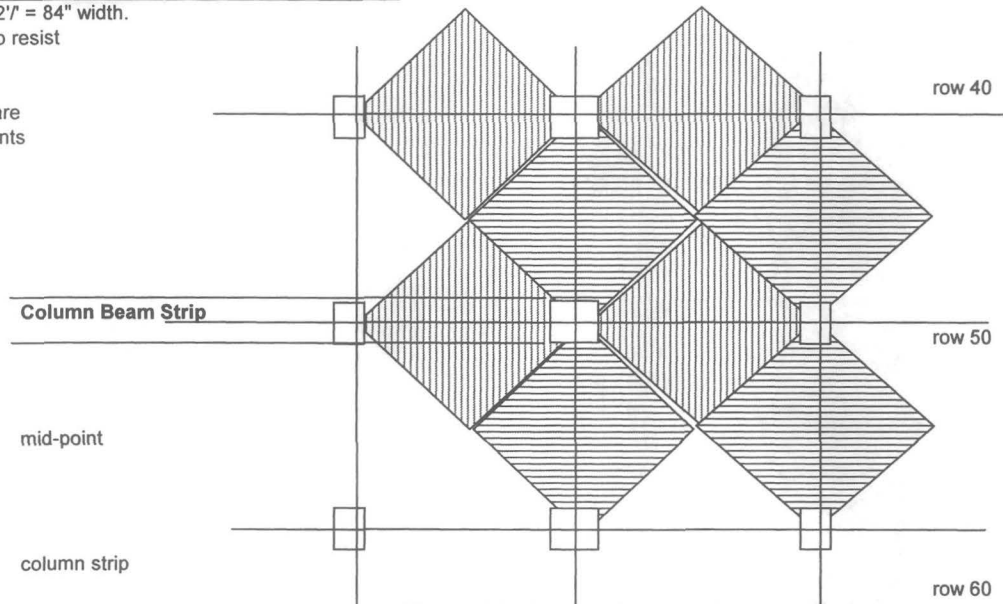


Figure 43-2 Load configuration for each direction.

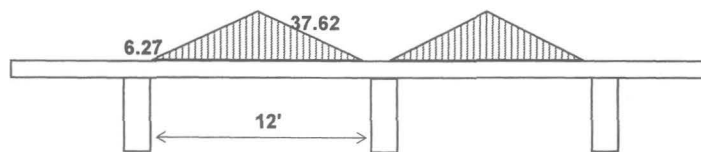
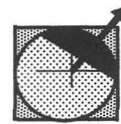


Figure 43-3 Elevation view of loads on the slab.

row 70



# CONCRETE BIAxIAL COLUMN: INTRODUCTION TANK SUPPORT



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A B C D E F G H I J K L M N  
**FLOW DIAGRAM**

**YOU MUST HAVE A COPY OF AMERICAN CONCRETE INSTITUTE'S ACI 318-MOST RECENT (2002) TO FOLLOW THIS DESIGN PROCESS.**  
<http://www.aci-int.org/general/home.asp>

This text refers you to ACI 318 code and commentary. The commentary includes background on code provisions, clarifying language, and diagrams.

Professional judgement must be exercised when using this example or the template for any application. This is not a reproduction of the ACI 318 code or a shortcut on know-how.

Please note that much of the text in this printed chapter is not included in the template.

Numbering in ACI 2002 is somewhat different than numbering in ACI 1999. This template follows the ACI 2002 numbering system.

**INPUTS**  
Dimensions and reinforcing  
Lengths, k, P<sub>U</sub>, and M<sub>U</sub> required in x and y directions

**COLUMN SUMMARY**  
Iterate for eccentricity e and compression block C  
General values

**COLUMN SLENDERNESS and MOMENT MAGNIFIER**  
  
M<sub>1</sub> smaller factored end moment  
M<sub>2</sub> larger factored end moment  
M<sub>2S</sub> factored load due to loads causing appreciable sidesway  
  
Q  $\Sigma P_U \Delta_o / (\Sigma V_U L_C) \leq 0.05$  then non-sidesway

**MOMENT MAGNIFIER for NON-SWAY FRAMES**  
  
C<sub>m</sub> factor for moment magnification for members without transverse loads  
 $0.6 + 0.4 M_1 / M_2 \geq 0.4$  ACI 10.12.3.1 (10-4)  
where: M<sub>2, minimum</sub>  $\geq P_u k_{ult} * (0.6 + 0.03h)$  in where  $0.6 + 0.03h = e_{minimum}$   
  
K L / r  $\leq 34 - 12 * M_{U1} / M_{U2} \leq 40$  M magnifier not required ACI (10-8)  
  
EI  $(E_c I / 5 + 29000 I_s) / (1 + \beta_d)$  ACI (10-12)  
or  $0.4 E_c I_g / (1 + \beta_d)$  ACI (10-13)  
  
P<sub>C</sub>  $\pi^2 EI / (k_{braced} L)^2$  Euler buckling load ACI 10.12.3 (10-11)  
  
d<sub>ns</sub>  $C_m / (1 - P_U / (0.75 * P_C)) \geq 1.0$  ACI (10-10)  
  
M<sub>C</sub> d<sub>ns</sub> M<sub>2</sub> end moment for non-sway frame

Figure 44-1 Flow Diagram

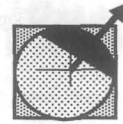
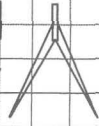
row 20

row 30

row 40

row 50

row 60



A B C D E F G H I J K L M N  
FLOW DIAGRAM -- Continued

MOMENT MAGNIFIER for SIDESWAY FRAMES	
Q	$\Sigma P_U * \Delta_o / (\Sigma V_U * \ell_c) \leq 0.05$ ACI 10.11.4.2 (10 - 7)
sway	$k \ell_u / r \leq 22$ non-sway frame ACI 10.13.2
$\beta_d$	ratio of sustained axial load to maximum axial load for non-sidesway condition ratio of the maximum sustained shear to the maximum shear within a story for sidesway condition
$EI_{\text{minnum}}$	$((E_C I / 5) + 29000 I_s) / (1 + \beta_{dx})$ ACI (10-12) or $0.4 E_c I_g / (1 + \beta_d)$ ACI (10 - 13)
$\Sigma P_C$ 's	sum of critical column axial loads
$P_C$	$\pi^2 * EI / (k \text{ unbraced } * \ell_u)^2$ sidesway ACI 10.12.3 (10-11)
$d_s M_s$	$M_s / (1 - Q) \geq M_s$
	$d_s M_{2s} / M_{2s} \leq 1.5$ ACI 10.13.4.2
$d_s M_s$	$\max(M_s, M_s / (1 - \text{Sum}P_{Ux} / (0.75 \text{Sum}P_{Cx})))$
$M_1$	$M_{1ns} + \delta_s M_{1s}$
$M_2$	$M_{2ns} + \delta_s M_{2s}$

row 70

row 80

COLUMN COMBINED LOADINGS for BIAXIAL ANALYSIS	
$e_{\text{required}}$	trial value
$\beta_1$	concrete strength reduction factor
$c_b$	maximum balanced compression block
$a_{\text{max}}$	maximum allowable compression block

row 90

REINFORCING AREA and LAYOUT	
Tables that organize data for the following calculations	

row 100

PLASTIC CENTROID INERTIA CALCULATIONS	
CG	center of gravity
$I_g$	gross moment of inertia for concrete
PC	plastic centroid which yields uniform strain all across column

Figure 44-2 Flow Diagram

row 110



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FLOW DIAGRAM -- Continued

**PLASTIC CENTROID STRAIN CALCULATIONS**  
  
C\_TEST input from C\_test in the summary window  
Ø tied / spiral columns  
STL\_COMP compression compatibility user input, usually 1

row 120

**For [Pn]\*en**  
  
T<sub>s</sub> arm tension reinforcing from the centroid  
C<sub>s</sub> arm compression reinforcing from the centroid  
C<sub>c</sub> arm compression block concrete  
P<sub>n</sub>e<sub>n</sub> T<sub>s</sub> arm + C<sub>s</sub> arm + C<sub>c</sub> arm  
  
e<sub>n</sub> calculated eccentricity at balanced strain condition

row 130

**MATH for RECTANGULAR ROTATING COMPRESSION BLOCK**

**MATH for SEMICIRCULAR ROTATING COMPRESSION BLOCK**

Figure 44-3 Flow Diagram Continued

row 140

row 150

row 160



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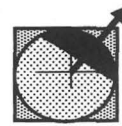
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**NOTATIONS**

Notations and text are repeated in the text for your convenience.

<p><math>\beta</math> the moment created by the combined, magnified <math>M_{C2x}</math> and <math>M_{C2y}</math> moments, radians</p> <p><math>\beta_1</math> reduction factor for concrete strengths greater than 4000 psi, unitless</p> <p><math>\beta_d</math> ratio of maximum factored sustained axial load to maximum factored axial load for non-sidesway condition ratio of the maximum sustained shear to the maximum shear within a story for sidesway condition <math>\beta_d</math> is generally 0 for sway deflections due to wind and earthquake <math>\beta_d</math> will be greater than 0 for sway conditions resulting from conditions such as a retaining structure</p> <p>CG center of gravity of an area (mass), or a combination of areas.</p> <p><math>C_m</math> a factor adjusting the applied moments to an equivalent applied uniform moment, <math>0.6 + 0.4 * (M1 / M2)</math>, cannot be less than 0.4 <math>C_m = 1</math> for transverse loads, unitless ACI 10.12.3.1</p> <p><math>C\_TEST</math> the user input for the depth of the compression block, in</p> <p><math>d</math> distance from a point, usually the CG of a mass to the CG of a finite element used in <math>Ad^2</math>, in</p> <p><math>\Delta o</math> relative lateral deflection between the top and bottom of a story due to <math>V_u</math> as calculated by a first-order analysis, in</p> <p><math>\delta_{bx}</math> <math>C_m / (1 - P_{Ux} / (0.75 * P_{Cx}))</math> magnification factor for a braced frame</p> <p><math>d_{nsx}</math> moment magnification factor for braced frame / no sidesway, unitless</p> <p><math>\delta_{sx}</math> <math>M_s / (1 - \text{Sum}P_{Ux} / (0.75 * \text{Sum}P_{Cx}))</math> magnification factor for an unbraced (sway) frame</p> <p><math>E_c</math> concrete modulus of elasticity, ksi</p> <p><math>e</math> eccentricity -- <math>M_n / P_n</math> <math>e = 0</math> vertical axis, P <math>e \leq \infty</math> horizontal axis, M Axial and moment loads are converted to a single load at an eccentricity.</p> <p><math>e_{minx} \uparrow</math> minimum eccentricity of applied axial load, in</p> <p><math>e_n</math> <math>e_b</math> eccentricity at balanced strain condition, in</p> <p><math>\phi_1</math> strength adjustment factor, unitless Tied columns = 0.7, Spiral tied columns = 0.75 ACI 9.3.2.2</p> <p><math>I_{gxx} \uparrow</math> gross moment of inertia including reinforcing, in<sup>4</sup> the <math>\uparrow</math> refers to the direction (not the vector) of the value</p> <p><math>k</math> effective height factor, unitless</p>	<p>1.0 0.65 fixed fixed braced</p> <p>0.7 0.8 pinned fixed braced</p> <p>1.0 1.2 fixed fixed lateral translation</p> <p>1.0 1 pinned pinned braced</p> <p>2.0 2.1 pinned fixed lateral translation</p> <p>&gt; 2.0 2.4 fixed pinned lateral translation</p>	<p>row 170</p> <p>row 180</p> <p>row 190</p> <p>row 200</p> <p>row 210</p>
--	---	--

Figure 44-4 Vaues for the effective height factor



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**NOTATIONS -- Continued**

$L_{xx}$  horizontal dimension of the column in plan view, in

$L_C$  column length, usually center to center of floor slabs or beams, ft  
L is used in lieu of  $\ell$  because  $\ell$  does not appear in range names

$L_U$  unsupported length of column

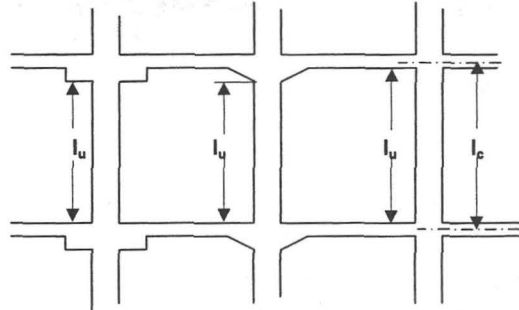


Figure 44-5 Definitions of column unsupported length.

$M_1$  smaller factored end moment -- positive in single curvature bending, negative in double curvature bending

$M_{1ns}$  factored end moment at end at which the smaller  $M_1$  moment acts without causing appreciable sidesway row 230

$M_{1s}$  factored end moment at end at which the smaller  $M_1$  moment acts causing appreciable sidesway

$M_{2ns}$  factored end moment at end at which  $M_2$  acts without causing appreciable sidesway

$M_{2s}$  factored end moment at end at which  $M_2$  acts causing appreciable sidesway

$M_{C1}$  smaller factored moment to be used in column design

$M_{C2}$  larger factored moment to be used in column design

$M_b$  moment at balanced strain conditions row 240

$M_c$  factored moment to be used for the design of a compression member

$M_{cr}$  moment causing flexural cracking

$M_n$  nominal moment strength at a given load eccentricity

$M_o$  nominal moment strength at 0 axial load

$M_U$  factored moment, k-ft ult

$P_b$  nominal axial load strength at balanced strain conditions

$P_C$   $\pi^2 * EI / (k \text{ braced} * L_U)^2$  Euler buckling load ACI (10-10), k

PC plastic centroid which yields uniform strain all across column, in

$P_n$  nominal load strength at a given load eccentricity row 250

$P_o$  nominal axial load strength at 0 eccentricity

$P_U$  LRFD factored applied axial load, k-ultimate

Q stability index for a story ACI 10.11.4.2

$\rho$   $A_s / A_{gross}$  density of reinforcing, unitless

$r_x \uparrow$  radius of gyration of the column used in the slenderness calculation  $k L / r$ , in

$W_{yy}$  vertical dimension of column in plan view row 260



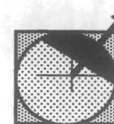
# CONCRETE BIAXIAL COLUMN: INTRODUCTION TANK SUPPORT

# 44

Christy

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12/20/05



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## CALCULATIONS

Convergence is used to calculate this template because the template always works as a biaxial column template. You must balance the column's axial capacity and moment capacity against axial and moment demands. The result must fall within the interaction diagram. There is almost never an exact answer.

For  $P_U = 0$ , use  $C_{Test} \leq a_{max}$  and design the column as a beam

Iteration for a tension column is done by hand so that  $P_n e_n = -P_n e$  which occurs at -200% convergence. Input tension values as positive. These values serve as comparison aids in the summary sheet.

row 270

The area of steel must provide the tension resistance.  
 $\phi$  axial tension = 0.90 ACI 9.3.2.1  
For TENSION Columns,  $-P_n > P_{u\_req}$  and  $M_{up} > M_{u\_req}$  to show that required capacity is within the capacity envelope.

row 280

row 290

row 300

row 310



# CONCRETE BIAXIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT



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45 Concrete Column.xls

**CONCRETE CIRCULAR COLUMN DESIGN** Circular,  $\beta = 90.00^\circ$

L input → 24 in diameter for circular columns  
 W input ↑ 24 in **Rectangular**  
 Shape **Circular** **Circular**  
 0 logic

$f_y$  60 ksi  
 $f_c$  4 ksi  
 Bar Size# 9  
 1.00 in<sup>2</sup> area of bar  
 Bar Qty 16 bars

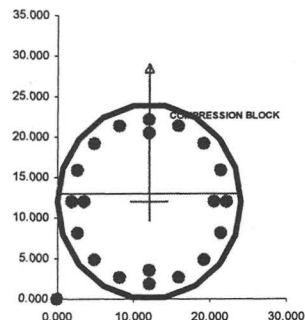


Figure 45-1 Direction of loads and reinforcing placement.

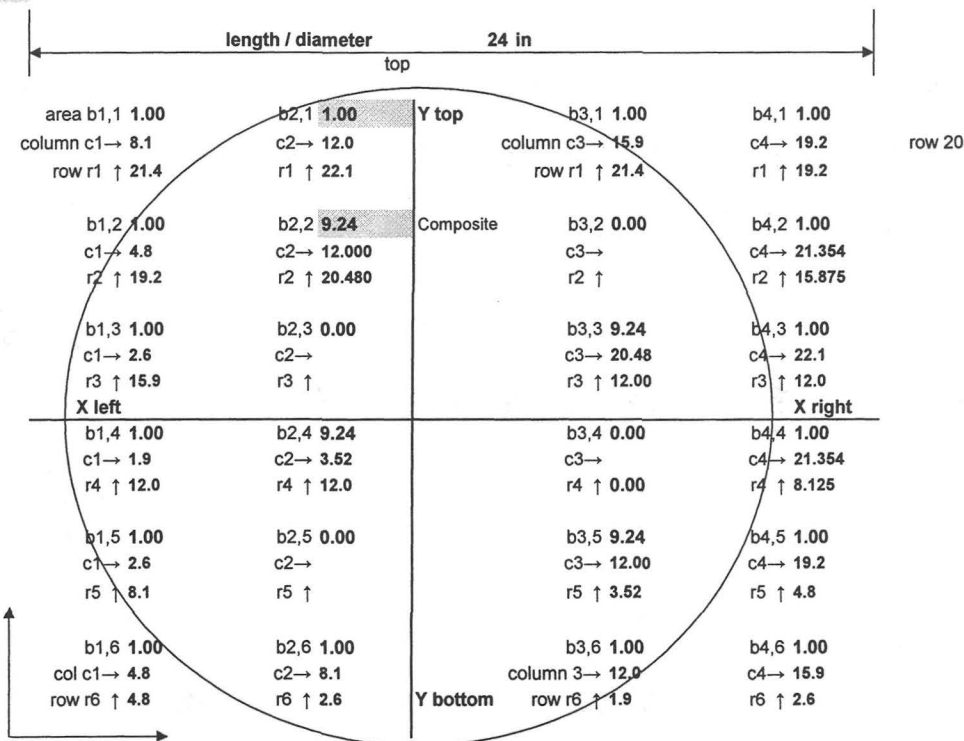


Figure 45-2 Input reinforcing and check for placement.

Tied 0 0 = spiral, 1 = tied  
 Tie Size# 3  
 0.11 in<sup>2</sup> area of tie  
 Cover 1.50 in clear distance of rebar from face of column  
 See ACI 7.7 clearances, ACI 7.10.4 spirals, ACI 7.10.5 ties, ACI 10.9.3  $\rho_{spiral}$   
 symmetrical yes yes = symmetrical in both directions, no = not symmetrical

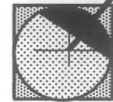
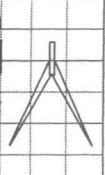
Input rebar areas and check distances for placement.

**Reinforcing  
Lookup Table**

Bar Size#	Area
10M	0.16
15M	0.31
20M	0.46
25M	0.77
30M	1.09
35M	1.55
45M	2.32
55M	3.87
0	0
3	0.11
4	0.20
5	0.31
6	0.44
7	0.60
8	0.79
9	1.00
10	1.27
11	1.56
14	2.25
18	4.00

White space is left for your input diagrams/drawings.

row 70



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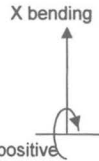
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45 Concrete Column.xls

#### XX COLUMN LENGTHS and LOADS for BENDING ABOUT the X-AXIS

Circular:  $\beta = 90.00^\circ$

$L_x$	14 ft	center-to-center beam-column joints
$k_x$	1.0 unitless	
$L_{u_x}$	13.25 ft	unsupported length of column

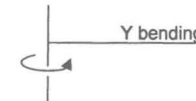


#### FACTORED LOADS

$P_u$	465 k ult	factored axial load
$M_{2ux}$	1176 k-ft ult	factored largest moment, always positive

#### YY COLUMN LENGTHS and LOADS for BENDING ABOUT the Y-AXIS

$L_y$	14 ft	center-to-center beam-column joints
$k_y$	1.0 unitless	
$L_{u_y}$	13.25 ft	unsupported length of column



#### FACTORED LOADS

$M_{2uy}$	0 k-ft ult	factored largest moment, always positive
-----------	------------	--

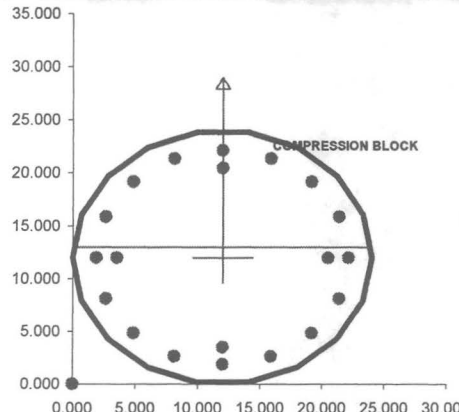


Figure 45-3 Direction of loads with reinforcing location and compression block.

#### BIAXIAL COLUMN SUMMARY

$P_{U \text{ required}}$	465 k-ult	required axial load
$P_o$	4536 k	nominal axial load at $e = 0$
$P_n$	641 k	$P_n$ provided
$\phi_3 P_n \text{ provide}$	481 k-ult	OK $\phi_3 P_n \text{ provided} > 465 \text{ k-ult required}$
$M_U \text{ applied}$	1176 k-ft ult	combined applied moments
$M_C \text{ required}$	1176 k-ft ult	magnified moments
$M_U \text{ provided}$	1202 k-ft	OK $M_U \text{ provided} > 1,176 \text{ k-ult } M_C \text{ required}$
$e_n$	29.99 in	

$C\_Test$	11.000 in	input value to determine compression block "a"
max diag	24.00 in	0 OK $k L_u/r 19 \leq 100$ see ACI 10.10.5 braced frame and ACI 10.11.1 0 OK $k L_u/r 19 \leq 34 - 12 * M1/M2$ no moment magnifier ACI 10.12.2
$\rho$	0.0919 unitless	$A_s / A_{gross}$ density of reinforcing
logic	1 OK 0.0100 $\rho \text{ minimum} \leq 0.0919 \rho \text{ provided}$ ACI 10.9.1	
logic	0 !!! 0.0919 $\rho \text{ provided} \geq 0.0800 \rho \text{ maximum}$ ACI 10.9.1	

OK  $k L_u/r_x 18.9 \leq 100$  see ACI 10.10.1 braced frame ACI 10.11.5  
 OK  $18.9 \leq 40.0$  no moment magnifier in the X direction  
 non-sidesway in the X direction ACI 10.22.4.2  
 OK  $18.9 k L/r_y \leq 100$  ACI 10.11.5  
 OK  $18.9 \leq 34.0$  no moment magnifier in the Y direction  
 non-sidesway in the Y direction ACI 10.11.4.2

$\beta$	1.571 radians	resulting beta from combined, magnified $M_{C2x}$ and $M_{C2y}$
	0	$ATAN(1,176 / 0)$
	90.0000 degrees	rotation of neutral axis counter clockwise from x-axis

$I_{g_{xx}} \uparrow$	16286 in <sup>4</sup>	gross concrete
$I_{xx} \uparrow$	18435 in <sup>4</sup>	includes $\pm A_s$

$I_{g_{yy}} \rightarrow$	16286 in <sup>4</sup>	gross concrete
$I_{yy} \rightarrow$	18435 in <sup>4</sup>	includes $\pm A_s$

$E_c$	3605 ksi	$57000 * \sqrt{f'_c}$ $57000 * 4,000^{0.5} / 1000$
-------	----------	---

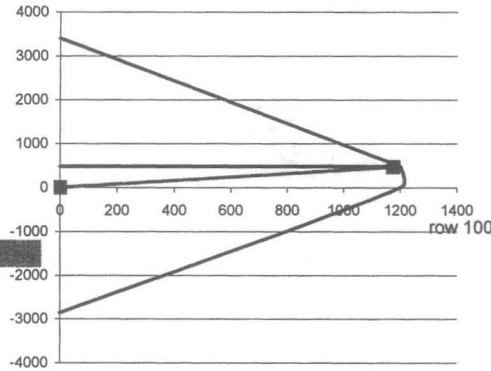


Figure 45-4 Axial and moment capacities in the interaction diagram.

As  $M_u$  changes,  $M_{U \text{ provided}}$  will change as a function of  $e_n * P_u$ .

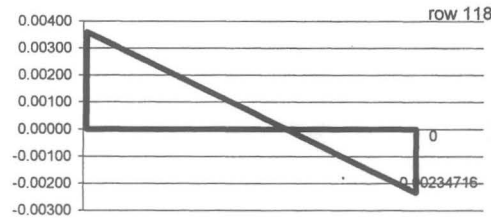


Figure 45-5 Strain profile.



# CONCRETE BIAxIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT

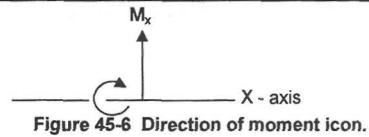


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**COLUMN SLENDERNESS and MOMENT MAGNIFIER for the X-AXIS Non-Sway** Circular.  $\beta = 90.00^\circ$

length	24 in	referenced from above	
$L_x$	14 ft		
$k_x$	1.0 unitless		
$P_u$	465 k ult		
$E_c$	3605 ksi		
$M_{1x}$	-838 k-ft ult	smaller factored end moment, + in single curvature bending (, - in double curvature bending )	
$M_{2x}$	1176 k-ft ult	larger factored end moment, always positive, referenced from above	row 140
		M1 < M2 OK	
$C_m$	0.400 unitless	$0.6 + 0.4 * (M_1 / M_2)$ , cannot be less than 0.4 $C_m = 1$ for transverse loads ACI 10.12.3.1	
$C_{m_x}$	0.400 unitless	for transverse loading condition	$C_m$ applies to both the minimum $e_{min} P_u$ moment and the $M_{c2}$ moments.
$r_x$	7.2 in	0.3 * h rectangular column ACI 10.11.2 0.3 * 24.00 in	<b>Note:</b> Greek, italic and math symbols from chapter 6 are used as much as possible to avoid format errors in Greek K, Symbol SH, and Symbol when things are moved around. Super and subscripting must still be redone -- but those errors are more obvious.
$r_x$	6.0 in	0.25 * diameter for circular columns	
$r_x \uparrow$	8.4 in	computed $r_y$ or input $r_y$ as for composite column or other section ACI (10 - 21) where the ACI quick calculation in ACI 10.11.2 is overly conservative	
$k L_{ux} / r_x$	18.9 unitless	$k_x * L_{ux} / r_x$ 1.0 * 13.25 ft / 8.4 in * 12 in/ft	<b>Note Also:</b> Symbols from chapter 6 appear as range names when Insert, Name, Define is used. Use L instead of $\ell$ because $\ell$ does not show up as a range name.
	0 logic	OK $k L_{ux} / r_x \leq 100$ see ACI 10.10.1 braced frame ACI 10.11.5	
Non-sidesway frames may neglect moment magnifier if:			
Limit_x	40.0 unitless	$34 - 12 * Mu_1 / Mu_2 < 40$ ACI 10.12.2 (10-7) $min(40, 34 - 12 * -838 / 1,176)$	<b>Subscript Lux rather than LUX which would be the more traditional choice. This is because range naming does not recognize formatted characters. A subscripted Lux which looks like <math>L_{ux}</math> is more recognizable as a range name.</b>
	0 logic	OK $18.9 \leq 40.0$ no moment magnifier in the X direction	
$EI_{xx}$	11804527 k-in <sup>2</sup>	$((E_c * I_g / 5) + 29000 * I_b) / (1 + \beta_{d,x})$ ACI 10.12.3 (10-11) $((3,605 \text{ ksi} * 16,286 \text{ in}^4 / 5) + 29 \text{ ksi} * 2,149.0 \text{ in}^4) / (1 + 0.00)$	
$EI$	23484413 k-in <sup>2</sup>	$0.4 * E_c * I_g / (1 + \beta_d)$ ACI 10.12.3 (10 - 12) $0.4 * 3,605 \text{ ksi} * 16,286 / (1 + 0.00)$	
$EI_{min x}$	11804527 k-in <sup>2</sup>	$min(23,484,413, 11,804,527)$	row 170
$P_{C_x}$	4128 k	$\pi^2 * EI / (k_x \text{ braced} * L_{ux})^2$ Euler buckling load ACI 10.12.3 (10-10) $9.870 * 3,605 * 16,286 \text{ k-in}^2 / (1.00 * 14.00 \text{ ft} * 12 \text{ in/ft})^2$	
$\delta_{ns,xx}$	0.471	$C_m / (1 - P_u / (0.75 * P_{C_x}))$ ACI 10.12.3 (10-9) $0.40 / [1 - 465 / (0.75 * 4,128)]$	$P_c$ , the column critical axial load, is ratioed against $P_u$ . This is used to reduce the stiffness factor EI which is important when column axial load is high.
$\delta_{ns,x}$	1.000 unitless	$max(1.0, \delta_{ns,xx} * Limit_x \text{ logic})$ $max(1, 0.471 * 0)$ M magnification factor for braced frame / no sidesway	
$e_{min x} \uparrow$	1.32 in	$0.6 + 0.03 * h$ minimum allowable e ACI 10.12.3.2 (10-14) $0.6 \text{ in} + 0.03 * 24.00 \text{ in}$	row 180
$e_{min} P_u$	51.15 k-ult	$\delta_{ns,x} * e_{min x} * P_u / 12 \text{ in/ft}$ minimum required $1.000 * 1.32 * 465 / 12$	
$\delta_{ns} M_{c2x}$	1176 k-ft ult	$\delta_{ns} M_{2x}$ required $1.000 * 1,176$	The $\delta_{ns}$ moment magnifier applies to both $e_{min} * P_u$ moment and applied $M_{c2}$ moment. The greater moment governs.
	1176 k-ft ult		row 190





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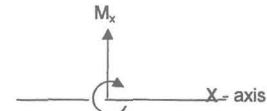


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**COLUMN SLENDERNESS and MOMENT MAGNIFIER for the X-AXIS -- SIDESWAY** Circular,  $\beta = 90.00^\circ$

$\Sigma P_{Ux}$  **7749** k ult sum of factored axial loads for all columns resisting sidesway  
 $\Sigma V_{Ux}$  **1527** k sum of story horizontal shear  
 $M_{2sx}$  **1174** k-ft ult larger factored moment due to loads causing appreciable sidesway  
 0 !!! input the larger factored end moment



Icons are frequently used to help the designer and reviewer identify where they are in the calculations.

$D_{ox}$  **0.8** in relative lateral deflection

row 200

A story can be considered as non-sidesway if:

$Q_x$  0.024165 unitless  $\Sigma P_{Ux} * \Delta_o / (\Sigma V_{Ux} * L_c) \leq 0.05$  ACI 10.11.4.2 (10-6)  
 $7,749 * 0.80 / (1,527.00 * 14.00 \text{ in} * 12)$   
 1 logic  $Q \leq 0.05$  is nonsway in the X direction  
 non-sidesway in the X direction ACI 10.22.4.2

Member slenderness in a frame not braced against sidesway can be neglected if:

sway x 1 logic  $k L_U / r \leq 22$  ACI 10.13.2  
 neglect column slenderness  $k L_U / r = 18.9$

row 210

$\beta_{dx}$  **0.00** unitless ratio of maximum factored sustained axial load to maximum factored axial load for non-sidesway condition  
 ratio of the maximum sustained shear to the maximum shear within a story for sidesway condition

Note: If the column is braced against sidesway or meets the conditions of ACI 10.11.4.2 (10-6) story sidesway, use the non-sidesway moment magnifier.

row 220

$P_{cx}$  **4128** k referenced from above  
 columns **5** each number of columns resisting sway

$\Sigma P_{cx}$  **20640** k ult sum of  $P_c$ 's for columns in a story resisting sidesway, for  $d_s$  sidesway calculation

row 230

$\delta_s M_{2sx}$  1203 k-ft ult  $M_{2s} / (1 - Q)$  ACI 12.13.4.2 (10-17)  
 $1,174 / (1 - 0.02417)$

ratio 1.023 unitless  $d_s M_{2s} / M_{2s}$   
 $1,203 / 1,176$   
 0 logic  $1.023 \leq 1.5$  ACI 10.13.4.2

The sum of column  $P_c$ 's is ratioed against the sum of column  $P_U$ 's in sidesway calculations to reflect the interaction of all sway resisting columns in a story.

$\delta_s M_{2sx}$  2351 unitless  $\max(M_s, M_s / (1 - \Sigma P_{Ux} / (0.75 * \Sigma P_{Cx})))$  ACI 10.13.4.3 (10-18)  
 $\max(1,174, 1,174 / (1 - 7,749 / (0.75 * 20,640 + 0.001)))$   
 $M$  magnification factor for unbraced frame subject to sidesway

$\delta_s M_{2sx}$  1203 k-ft ult IF ( 0, 2,351, 1,203 )

non-sidesway in the X direction ACI 10.22.4.2

$M_{c2x}$  1176 k-ft ult  $d_{ns} M_{2x} + d_s M_{2sx}$   
 $0 + 1,176$

row 250



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**COLUMN SLENDERNESS AND MOMENT MAGNIFIER for the Y-AXIS Non-Sway** Circular.  $\beta = 90.00^\circ$

width	24.0 in	referenced from above	
$L_y$	14 ft		
$k_y$	1.00 unitless		
$P_u$	465 k ult		
$E_c$	3605 ksi		
$M_{1y}$	0 k-ft ult	smaller factored end moment, + in single curvature bending ( , - in double curvature bending )	
$M_{2y}$	0 k-ft ult	larger factored end moment, always positive	
		$M1 < M2$ OK	row 260
$C_m$	0.600 unitless	$0.6 + 0.4 * (M_1 / M_2)$ , cannot be less than 0.4 $C_m = 1$ for transverse loads ACI 10.12.3.1	
$C_{m,y}$	1.00 unitless	for transverse loading condition	
$r_y \rightarrow$	7.2 in	0.3 * h rectangular column ACI 10.11.2 0.3 * 24.0 in	
$r_y$	6.0 in	0.25 * diameter for circular columns	row 230
$r_y$	8.4 in	computed $r_y$ or input $r_y$ as for composite column or FOR STEEL COLUMN other section ACI (10 - 21) where the ACI quick calculation in 10.11.2 is overly conservative	
$k L_{Uy} / r_y$	18.9 unitless	$k_y * L_{Uy} / r_y * 12$ $1.00 * 13.25 \text{ ft} / 8.4 \text{ in} * 12 \text{ in/ft}$	
	0 logic	OK $18.9 k L / r_y \leq 100$ ACI 10.11.5	
Non-sidesway frames may neglect moment magnifier if:			
Limit_y	34.0 unitless	$34 - 12 * \mu_1 / \mu_2 < 40$ ACI 10.12.2 (10-7) $\min(40, 34 - 12 * 0 / 0)$	row 280
	0 logic	OK $18.9 \leq 34.0$ no moment magnifier in the Y direction	
$EI_{yy}$	11804527 k-in <sup>2</sup>	$((E_c * I_g / 5) + 29000 * I_s) / (1 + B_{dy})$ ACI 10.12.3 (10-11) $((3,604.997 \text{ ksi} * 16,286 \text{ in}^4 / 5) + 29 \text{ ksi} * 2,149.0 \text{ in}^4) / (1 + 0.00)$	
$EI$	23484413 k-in <sup>2</sup>	$0.4 * E_c * I_g / (1 + b_d)$ ACI (10 - 12) $0.4 * 3,605 \text{ ksi} * 16,286 / (1 + 0.00)$	
$EI_{min,y}$	11804527 k-in <sup>2</sup>	$\min(23,484,413, 11,804,527)$	row 290
$P_{c,y}$	4128 k	$\pi^2 * EI / (k \text{ braced} * L_U)^2$ Euler buckling load ACI (10-10) $9.870 * 3,605 * 16,286 \text{ k-in}^2 / (1.00 * 14.00 \text{ ft} * 12 \text{ in/ft})^2$	
$\delta_{ns,yy}$	1.177	$C_m / (1 - P_U / (0.75 * P_{c,y}))$ ACI 10.12.3 (10-9) $1.00 / [1 - 465 / (0.75 * 4,128)]$	$P_C$ , the column critical axial load, is ratioed against $P_U$ . This is used to reduce the stiffness factor EI which is important when column axial load is high.
$\delta_{ns,y}$	1.000 unitless	$\max(1.0, \delta_{ns,xx} * \text{Limit}_x \text{ logic})$ $\max(1, 1.177 * 0)$ M magnification factor for braced frame / no sidesway	row 300
$e_{min,y} \rightarrow$	1.32 in	$0.6 + 0.03 * h$ minimum allowable e ACI 10.12.3.2 (10-14) $0.6 \text{ in} + 0.03 * 24.0 \text{ in}$	$e_y \rightarrow$ eccentricity distance of load from the centroid of the gross section contributing to $M_y$ moment, inches
$e_{min} P_u$	51.15 k-ult	$\delta_{ns,y} * e_{min,y} * P_U / 12 \text{ in/ft}$ $1.000 * 1.32 * 465 / 12$	
$\delta_{ns} M_{c2y}$	0 k-ft ult	$\delta_{ns} M_{2x}$ required $1.000 * 0$	The $\delta_{ns}$ moment magnifier applies to both the minimum $e_{min} * P_U$ moment and applied $M_{c2}$ moment.
	51 k-ft ult		The greater moment governs.
			row 310



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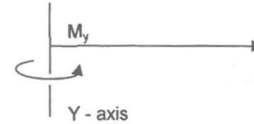


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**COLUMN SLENDERNESS and MOMENT MAGNIFIER for the Y-AXIS -- SIDESWAY** Circular,  $\beta = 90.00^\circ$

$\Sigma P_{Uy}$  0 k ult for  $d_{ns}$  no sidesway calculation, sum of  $P_U$  for all column loads in a story  
 $\Sigma V_{Uy}$  0 k  
 $M_{2sy}$  0 k-ft ult factored load due to loads causing appreciable sidesway  
 logic 1 .larger factored end moment



$D_{oy}$  0 in

row 320

A story can be considered as non-sidesway if:

$Q_y$  0 unitless  $\Sigma P_{Uy} * \Delta_o / (\Sigma V_{Uy} * L_c) \leq 0.05$  ACI 10.11.4.2 (10 - 6)  
 0.00 k \* 0.00 in / (0.00 k \* 13.25 in \* 12)  
 1 logic  $Q \leq 0.05$  is nonsway in the Y direction  
 non-sidesway in the Y direction ACI 10.11.4.2

Member slenderness in a frame not braced against sidesway can be neglected if:

sway y 1 logic  $k L_u / r \leq 22$   
 neglect column slenderness  $k L_u / r = 18.9$

row 330

$\beta_{dy}$  0.00 unitless ratio of maximum factored sustained axial load to maximum factored axial load for non-sidesway condition  
 ratio of the maximum sustained shear to the maximum shear within a story for sidesway condition

row 340

$P_{cy}$  4128 k referenced from above  
 columns 0 each number of columns resisting sway

$\Sigma P_{cy}$  0 k ult sum of  $P_c$ 's for columns in a story resisting sidesway, for  $d_s$  sidesway calculation

row 350

$\delta_s M_{2sy}$  0 unitless  $M_{2s} / (1 - Q)$  ACI 12,13,4,2 (10-17)  $\Sigma$ , sigma this means sum or the sum of  
 0 / (1 - 0.00000) for you liberal arts majors

ratio 0.000 unitless 0 / 0  
 0 logic 0.000  $\leq 1.5$  ACI 10.13.4.2  
 The sum of column  $P_c$ 's is ratioed against the sum of column  $P_u$ 's in sidesway calculations to reflect the interaction of all sway resisting columns in a story.

$\delta_s M_{2sy}$  0 k-ft ult  $\max(M_s, M_s / (1 - \Sigma P_{Ux} / (0.75 * \Sigma P_{Cx})))$  ACI 10.13.4.3 (10-18)  
 $\max(0, 0 / (1 - 0 / (0.75 * 0 + 0.001)))$   
 M magnification factor for unbraced frame subject to sidesway

row 360

$\delta_s M_{2sy}$  0 k-ft ult IF( 0, 0, 0 )

non-sidesway in the Y direction ACI 10.11.4.2  
 $M_{c2y}$  51 k-ft ult  $d_{ns} M_{2y} + d_s M_{2sy}$   
 0 + 51

row 370



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A	B	C	D	E	F	G	H	I	J	K	L	M	N
MOMENT MAGNIFIER LOGIC SIEVE												Circular. $\beta = 90.00^\circ$	

	X	Y	
$e_{min} P_U$	51.15	51.15	$e_{min} P_U$ is applied to only one axis at a time.
$\delta_{ns} M_{c2}$	1176	0	I have interpreted the provisions in ACI 10.12.3.2 to mean that if there is no moment applied in the X or Y axis, $e_{min} P_U$ will not be considered in that unloaded axis.
	1176	51	
logic	1	0	Where there is no applied moment, the largest $e_{min} P_U$ will be used in the moment magnifier calculations.
$M_{c req'd}$	1176	0	
$M_{c req'd}$	1176 k-ft ult	$\sqrt{1,176^2 + 0^2}$	row 380

### COLUMN COMBINED LOADINGS for BIAxIAL ANALYSIS

$M_U$ applied	1176 k-ft ult	$\sqrt{1,176^2 + 0^2}$	applied
$\Sigma M_1$	838 k-ft ult	$\sqrt{-838^2 + 0^2}$	
$\Sigma M_2$	1176 k-ft ult	$\sqrt{1,176^2 + 0^2}$	braced-frame
$\Sigma M_{2s}$	1174 k-ft ult	$\sqrt{1,174^2 + 0^2}$	sway-frame
$M_c$	1176 k-ft ult	$\sqrt{M_{c_x}^2 + M_{c_y}^2}$ $\sqrt{1,176^2 + 0^2}$	
$E_c$	3605 k/in <sup>2</sup>	$57000 * f'_c$ $57000 * 126.49 / 1000000$	
n	8.04 unitless	$E_{steel} / E_{concrete}$ 29000 ksi / 3,605 ksi	
	0.85 unitless	reduce the .85 factor by .05 for each 1000 psi over 4000 psi	
$\beta_1$	0.85 unitless	but not less than 0.65 ACI 10.2.7.3	

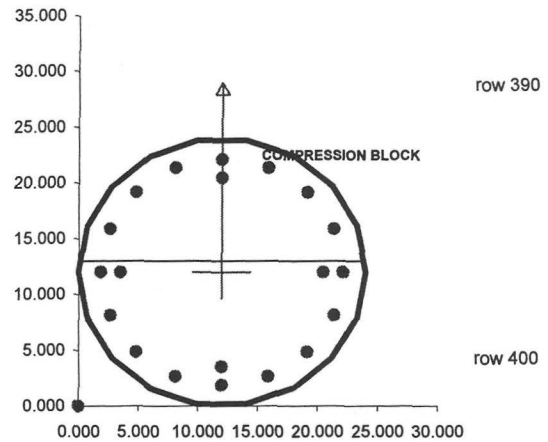


Figure 45-7 Load direction with reinforcing location and compression block.

### RENIFORCING AREA and LAYOUT

Reinforcing Nomenclature				Column					
b1,1	b2,1	b3,1	b4,1	8.125	12.000	15.875	19.158 in		
b1,2	b2,2	b3,2	b4,2	4.842	12.000	12.000	21.354		
b1,3	b2,3	b3,3	b4,3	2.646	-10.587	20.480	22.125		
b1,4	b2,4	b3,4	b4,4	1.875	3.520	6.000	21.354		
b1,5	b2,5	b3,5	b4,5	2.646	12.000	12.000	19.158		
b1,6	b2,6	b3,6	b4,6	4.842	8.125	12.000	15.875		
Row				Area steel	c1	c2	c3	c4	
21.354	22.125	21.354	19.158 in	A r1	c1	1.00	1.00	1.00	1.00 in <sup>2</sup>
19.158	20.480	-3.520	15.875	r2	1.00	9.24	0.00	1.00	
15.875	5.092	12.000	12.000	r3	1.00	0.00	9.24	1.00	
12.000	12.000	0.000	8.125	r4	1.00	9.24	0.00	1.00	row 420
8.125	17.625	3.520	4.842	r5	1.00	0.00	9.24	1.00	
4.842	2.646	1.875	2.646	r6	1.00	1.00	1.00	1.00	
$A_s$ sum	52.96 in <sup>2</sup>								
P tension	2860 k-ult	0.9 * 52.96 * 60 ksi							
A Circ	452 in <sup>2</sup>								
A Rect	576 in <sup>2</sup>								
A gross	452 in <sup>2</sup>								row 430



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**PLASTIC CENTROID INERTIA CALCULATIONS** Circular.  $\beta = 90.00^\circ$

For Gross Section Including Steel													
A	B	C	D	E	F	G	H	I	J	K	L	M	N
	-b1,1	b2,1	b3,1	b4,1	A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
An	8.04	8.04	8.04	8.04	32.18								
distance	21.354	22.125	21.354	19.158									
An*dist.	171.78	177.98	171.78	154.12		675.67							
d	9.35	10.13	9.35	7.16									
An d <sup>2</sup>	703.94	824.68	703.94	412.21			2644.76						
A*F <sub>y</sub>	482.66	482.66	482.66	482.66				1930.65					
dist.*A*F <sub>y</sub>	10307.03	10678.93	10307.03	9247.05					40540.04				row 440
Ad <sup>2</sup>	703.94	824.68	703.94	412.21						2644.76			
	b1,2	b2,2	b3,2	b4,2	A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
A	8.04	74.33	0.00	8.04	90.42								
distance	19.158	20.480	-3.520	15.875									
An*dist.	154.12	1522.28	0.00	127.70		1804.10							
d	7.16	8.48	15.52	3.87									
An d <sup>2</sup>	412.21	5345.11	0.00	120.78			5878.11						
A*F <sub>y</sub>	482.66	4459.81	0.00	482.66				5425.14					
dist.*A*F <sub>y</sub>	9247.05	91336.91	0.00	7662.20					108246.2				row 450
Ad <sup>2</sup>	412.21	5345.11	0.00	120.78						5878.11			
	b1,3	b2,3	b3,3	b4,3	A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
A	8.04	0.00	74.33	8.04	90.42								
distance	15.875	5.092	12.000	12.000									
An*dist.	127.70	0.00	891.96	96.53		1116.20							
d	3.87	6.91	0.00	0.00									
An d <sup>2</sup>	120.78	0.00	0.00	0.00			120.78						
A*F <sub>y</sub>	482.66	0.00	4459.81	482.66				5425.14					
dist.*A*F <sub>y</sub>	7662.20	0.00	53517.72	5791.96					66971.89				row 460
Ad <sup>2</sup>	120.78	0.00	0.00	0.00						120.78			
	b1,4	b2,4	b3,4	b4,4	A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
A	8.04	74.33	0.00	8.04	90.42								
distance	12.000	12.000	0.000	8.125									
An*dist.	96.53	891.96	0.00	65.36		1053.86							
d	0.00	0.00	12.00	3.87									
An d <sup>2</sup>	0.00	0.00	0.00	120.78			120.78						
A*F <sub>y</sub>	482.66	4459.81	0.00	482.66				5425.14					
dist.*A*F <sub>y</sub>	5791.96	53517.72	0.00	3921.72					63231.40				row 470
Ad <sup>2</sup>	0.00	0.00	0.00	120.78						120.78			
	b1,5	b2,5	b3,5	b4,5	A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
A	8.04	0.00	74.33	8.04	90.42								
distance	8.125	17.625	3.520	4.842									
An*dist.	65.36	0.00	261.64	38.95		365.95							
d	3.87	5.63	8.48	7.16									
An d <sup>2</sup>	120.78	0.00	5345.11	412.21			5878.11						
A*F <sub>y</sub>	482.66	0.00	4459.81	482.66				5425.14					
dist.*A*F <sub>y</sub>	3921.72	0.00	15698.53	2336.88					21957.13				row 480
Ad <sup>2</sup>	120.78	0.00	5345.11	412.21						5878.11			
	b1,6	b2,6	b3,6	b4,6	A*n	An*dist.	An d <sup>2</sup>	A*F <sub>c</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>			
A*n	8.04	8.04	8.04	8.04	32.18								
distance	4.842	2.646	1.875	2.646									
An*dist.	38.95	21.28	15.08	21.28		96.59							
d	7.16	9.35	10.13	9.35									
An d <sup>2</sup>	412.21	703.94	824.68	703.94			2644.76						
A*F <sub>y</sub>	482.66	482.66	482.66	482.66				1930.65					
dist.*A*F <sub>y</sub>	2336.88	1276.89	904.99	1276.89					5795.65				row 490
Ad <sup>2</sup>	412.21	703.94	824.68	703.94						2644.76			

cg	12		Ag	452.4	An*dist.	5429	An d <sup>2</sup>	0.000	A*F <sub>c</sub>	1809.6	dist.*A*F <sub>y</sub>	21714.7	Ad <sup>2</sup>	2148.99	I reinforcing only
d	0.00	ABS(12.00 - 12.00)	sum	878.4	10541	17287	4987.2	59845.9							

CG <sub>xx</sub>	12.00	in													
I <sub>rectangular</sub>	27648	in <sup>4</sup>	24.0 * 24.0 <sup>3</sup> /12												
I <sub>circular</sub>	16286	in <sup>4</sup>	pd <sup>4</sup> /64	3.14 * 24.0 <sup>4</sup> /64											
I <sub>g xx ↑</sub>	16286	in <sup>4</sup>	Circular												
PC <sub>x</sub>	12.00	in	plastic centroid which yields uniform strain all across column from bottom fiber												
I <sub>xx ↑</sub>	18435	in <sup>4</sup>	gross concrete includes ± AS												row 500



# CONCRETE BIAXIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT



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PLASTIC CENTROID INERTIA CALCULATIONS -- Continued											Circular: $\beta = 90.00^\circ$		
A	B	C	D	E	F	G	H	I	J	K	L	M	N
For Gross Section Including Steel													
	-b1,1	b2,1	b3,1	b4,1		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	8.04	8.04	8.04	32.18								
distance	8.125	12.000	15.875	19.158									
An*dist.	525.80	776.55	1027.30	1239.78	3569.42								
d	3.87	0.00	3.87	7.16									
An d <sup>2</sup>	971.61	0.00	971.61	3316.01			5259.2						
A*F <sub>y</sub>	482.66	482.66	482.66	482.66					1930.65				
dist.*A*F <sub>y</sub>	3921.72	5791.96	7662.20	9247.05						26622.93			row 510
Ad <sup>2</sup>	120.78	0.00	120.78	412.21							653.78		
	b1,2	b2,2	b3,2	b4,2		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	74.33	0.00	8.04	90.42								
distance	4.842	12.000	12.000	21.354									
An*dist.	313.31	7175.29	0.00	1381.90	8870.50								
d	7.16	0.00	0.00	9.35									
An d <sup>2</sup>	3316.01	0.00	0.00	5662.74			8978.74						
A*F <sub>y</sub>	482.66	4459.81	0.00	482.66					5425.14				
dist.*A*F <sub>y</sub>	2336.88	53517.72	0.00	10307.03						66161.63			row 520
Ad <sup>2</sup>	412.21	0.00	0.00	703.94							1116.15		
	b1,3	b2,3	b3,3	b4,3		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	0.00	74.33	8.04	90.42								
distance	2.646	-10.587	20.480	22.125									
An*dist.	171.20	0.00	12245.83	1431.76	13848.78								
d	9.35	22.59	8.48	10.13									
An d <sup>2</sup>	5662.74	0.00	42998.17	6634.01			55294.92						
A*F <sub>y</sub>	482.66	0.00	4459.81	482.66					5425.14				
dist.*A*F <sub>y</sub>	1276.89	0.00	91336.91	10678.93						103292.73			row 530
Ad <sup>2</sup>	703.94	0.00	5345.11	824.68							6873.72		
	b1,4	b2,4	b3,4	b4,4		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	74.33	0.00	8.04	90.42								
distance	1.875	3.520	6.000	21.354									
An*dist.	121.34	2104.75	0.00	1381.90	3607.98								
d	10.13	8.48	6.00	9.35									
An d <sup>2</sup>	6634.01	42998.17	0.00	5662.74			55294.92						
A*F <sub>y</sub>	482.66	4459.81	0.00	482.66					5425.14				
dist.*A*F <sub>y</sub>	904.99	15698.53	0.00	10307.03						26910.56			row 540
Ad <sup>2</sup>	824.68	5345.11	0.00	703.94							6873.72		
	b1,5	b2,5	b3,5	b4,5		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	0.00	74.33	8.04	90.42								
distance	2.646	12.000	12.000	19.158									
An*dist.	171.20	0.00	7175.29	1239.78	8586.27								
d	9.35	0.00	0.00	7.16									
An d <sup>2</sup>	5662.74	0.00	0.00	3316.01			8978.7						
A*F <sub>y</sub>	482.66	0.00	4459.81	482.66					5425.14				
dist.*A*F <sub>y</sub>	1276.89	0.00	53517.72	9247.05						64041.66			row 550
Ad <sup>2</sup>	703.94	0.00	0.00	412.21							1116.15		
	b1,6	b2,6	b3,6	b4,6		A	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
A * n	8.04	8.04	8.04	8.04	32.18								
distance	4.842	8.125	12.000	15.875									
An*dist.	313.31	525.80	776.55	1027.30	2642.95								
d	7.16	3.87	0.00	3.87									
An d <sup>2</sup>	3316.01	971.61	0.00	971.61			5259.23						
A*F <sub>y</sub>	482.66	482.66	482.66	482.66					1930.65				
dist.*A*F <sub>y</sub>	2336.88	3921.72	5791.96	7662.20						19712.76			row 560
Ad <sup>2</sup>	412.21	120.78	0.00	120.78							653.78		
cg	12				Ag	452.4	An*dist.	An d <sup>2</sup>	A*F <sub>y</sub>	dist.*A*F <sub>y</sub>	Ad <sup>2</sup>		
d	0.00				sum	878.4	10541.0	139065.8	30321.0	363851.5	2148.99	reinforcing only	
CG <sub>yy</sub>	12.00 in												
I <sub>rectangular</sub>	27648 in <sup>4</sup>												
I <sub>circular</sub>	16286 in <sup>4</sup>												
I <sub>g yy</sub>	16286 in <sup>4</sup>												
PC <sub>yy</sub>	12.00 in												
I <sub>w</sub>	18435 in <sup>4</sup>												

row 570

RADIUS OF GYRATION		Circular, $\beta = 90.00^\circ$	
$r_x \uparrow$	4.6 in	$\sqrt{I_{xx}/\text{area} \uparrow}$	
$r_y \rightarrow$	4.6 in	$\sqrt{I_{yy}/\text{area} \rightarrow}$	

PLASTIC CENTROID STRAIN CALCULATIONS		
$\beta$	1.5708 radians	counter clockwise from the x-axis
	90.0000	
$\sin \beta$	1.0000	
$\cos \beta$	0.0000	
$\tan \beta$	1.18E+11	

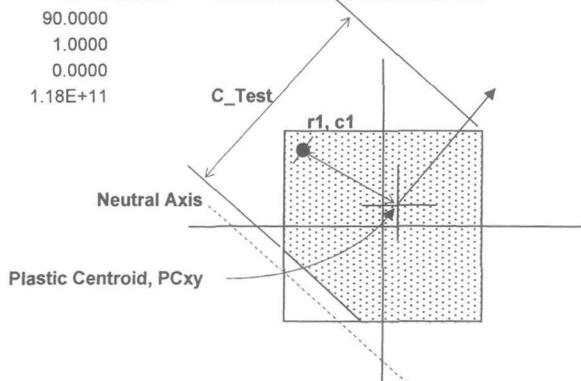


Figure 45-8 Plan view of compression block and reinforcing.

Distance of Reinforcing from PCxy

$$[(12.00 - 8.13)^2 + (12.00 - 21.35)^2]^{0.5}$$

	c1	c2	c3	c4
PC r1 c1	10.13	10.13	10.13	10.13
r2	10.12	8.48	15.52	10.13
r3	10.13	23.62	8.48	10.13
r4	10.13	8.48	13.42	10.13
r5	10.13	5.63	8.48	10.12
r6	10.12	10.13	10.13	10.13

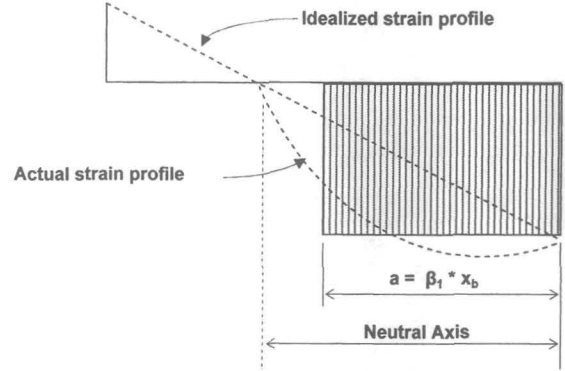


Figure 45-9 The strain profile diagram.

- $E_s$  Young's modulus of steel,  $\epsilon_s = \text{strain}$
- $\epsilon_s$  strain
- $\epsilon_{cu}$  concrete crushing strain, 0.003, unitless
- $\epsilon_y$  strain at first yield, unitless
- $\epsilon'_s$  strain in compression reinforcing, unitless row 600
- $\epsilon_t$  allowable tension reinforcing strain, unitless
- $x_b, x_{bal}$  distance of the neutral axis to the extreme fiber in compression noted as  $C\_test/\beta_1$  in this template, inches.

**$E_s \times \text{STRAIN}$**

**C\_TEST** 11.000 in referenced from the summary window to the extreme fiber (up and right) perpendicular to the axis through intersection of PCx and PCy  
Strain Profile See 02 ACI 318 10.3.2 and 10.3.3

$x_{bal}/d = \epsilon'_c = 0.003$

$\epsilon'_c + \epsilon_t = 0.003 + f_y/29,000$

$x_{bal} = 87 d / (87 + 60)$

row 610

8.125 - \$PCx

horizontal	c1	c2	c3	c4
r1	-3.875	0.000	3.875	7.158 inch
r2	-7.158	0.000	0.000	9.354
r3	-9.354	-22.587	8.480	10.125
r4	-10.125	-8.480	-6.000	9.354
r5	-9.354	0.000	0.000	7.158
r6	-7.158	-3.875	0.000	3.875

21.354 - \$PCy

vertical	c1	c2	c3	c4
r1	9.354	10.125	9.354	7.158 inch
r2	7.158	8.480	-15.520	3.875
r3	3.875	-6.908	0.000	0.000
r4	0.000	0.000	-12.000	-3.875
r5	-3.875	5.625	-8.480	-7.158
r6	-7.158	-9.354	-10.125	-9.354

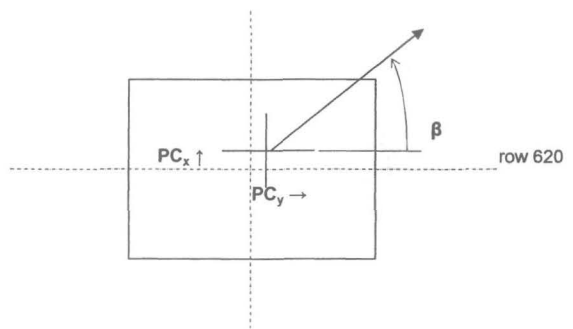


Figure 45-10 Rotation of the X-axis about PCxy.

row 630

REINFORCING LOCATION LOGIC Circular,  $\beta = 90.00^\circ$

Horizontal Direction

-1	1	1	1
-1	1	1	1
-1	-1	1	1
-1	-1	-1	1
-1	1	1	1
-1	-1	1	1

Vertical Direction

1	1	1	1
1	1	-1	1
1	-1	1	1
1	1	-1	-1
-1	1	-1	-1
-1	-1	-1	-1

add pi()/2 to vertical direction

0	0	0	0
0	0	1	0
0	-1	0	0
0	0	-1	1
-1	0	1	1
-1	-1	1	1

Angle of Reinforcing from PCxy Vertical

$$\text{ABS(ATAN(IF(0, 9.354 / (-3.875 + 0.000001), -3.875 / (9.354 + 0.000001))) - PI() / 2 * 0) * -1}$$

angle	c1	c2	c3	c4					
r1	-0.3927	0.0000	0.3927	0.7854	radians	-22.5	0.0	22.5	45.0 degrees
r2	-0.7854	0.0000	3.1416	1.1781		-45.0	0.0	180.0	67.5
r3	-1.1781	-1.8676	1.5708	1.5708		-67.5	-107.0	90.0	90.0
r4	-1.5708	-1.5708	-2.6779	1.9635		-90.0	-90.0	-153.4	112.5
r5	-1.9635	0.0000	3.1416	2.3562		-112.5	0.0	180.0	135.0
r6	-2.3562	-2.7489	3.1416	2.7489		-135.0	-157.5	180.0	157.5

Difference between  $\beta$  and Reinforcing Angle

$$\beta + R1 C1$$

$$1.5708 + -0.3927$$

	c1	c2	c3	c4					
r1	1.1781	1.5708	1.9635	2.3562		67.5	90.0	112.5	135.0 degrees
r2	0.7854	1.5708	4.7124	2.7489	radians	45.0	90.0	270.0	157.5
r3	0.3927	-0.2968	3.1416	3.1416		22.5	-17.0	180.0	180.0
r4	0.0000	0.0000	-1.1071	3.5343		0.0	0.0	-63.4	202.5
r5	-0.3927	1.5708	4.7124	3.9270		-22.5	90.0	270.0	225.0
r6	-0.7854	-1.1781	4.7124	4.3197		-45.0	-67.5	270.0	247.5

Distance of Rebar from Rotating X-axis Through PCxy

$$\text{SIN}(r1 c1) * \text{PC}_r1\_c1$$

$$\text{SIN}(1.1781) * 10.13$$

	c1	c2	c3	c4
r1	9.354	10.125	9.354	7.158 inch
r2	7.158	8.480	-15.520	3.875
r3	3.875	-6.908	0.000	0.000
r4	0.000	0.000	-12.000	-3.875
r5	-3.875	5.625	-8.480	-7.158
r6	-7.158	-9.354	-10.125	-9.354

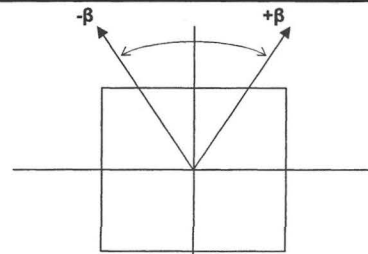


Figure 45-11 Numerical sign notation.

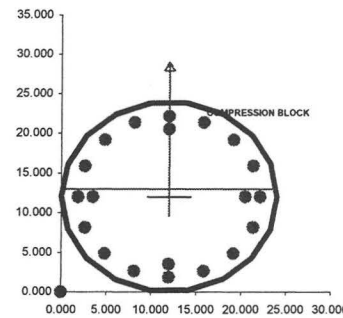


Figure 45-12 Direction of loads.

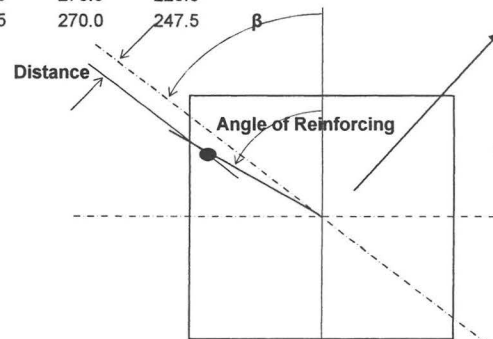


Figure 45-13 Distance of reinforcing from the rotating vertical axis through PCxy.



# CONCRETE BIAxIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT

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REINFORCING STRAIN Circular.  $\beta = 90.00^\circ$

C_Test	11.000 in	reference
$\beta_1$	0.85 unitless	reference
N.A.	12.941	11.000 / 0.85 neutral axis
strain u	0.002069 unitless	60 / 29000 strain to first yield, reference
$\beta$	1.571 radians	reference 90.0000 degrees

x top→pt	12.0000	x begin→	C_Test to PCxy 12.0000	0.0000	x begin→	N.A. to PCxy 12.0000	0.0000
y top ↑ pt	24.0000	y begin↑	13.0000	1.0000	y begin↑	11.0588	-0.9412

add xy	0.9412 in	
max diag c	24.000 in	max circular diagonal
Max Diag	24.000 in	

### Relative Strain

	9.354 / 12.941			
	c1	c2	c3	c4
r1	0.723	0.782	0.723	0.626 unitless
r2	0.553	0.655	-1.199	0.299
r3	0.299	-0.534	0.000	0.000
r4	0.000	0.000	-0.927	-0.299
r5	-0.299	0.435	-0.655	-0.553
r6	-0.553	-0.723	-0.782	-0.723

### Reinforcing

Where: 87 = 0.003 \* 29000

	87 * 0.723			
	c1	c2	c3	c4
r1	62.89	68.07	62.89	54.45 k
r2	48.12	57.01	-104.34	26.05
r3	26.05	-46.44	0.00	0.00
r4	0.00	0.00	-80.67	-26.05
r5	-26.05	37.82	-57.01	-48.12
r6	-48.12	-62.89	-68.07	-62.89

### LIMIT $f_y$

IF(ABS(Reinforcing) >  $F_y$ ,  $f_{s\_1}$ ,  $c1$  / ABS( $f_{s\_1}$ ,  $c1$ ) \*  $F_y$ ,  $f_{s\_1}$ ,  $c1$ )  
 IF(ABS(62.89) > 60, 62.9 / ABS(62.89) \* 60, 62.89)

	c1	c2	c3	c4
$f_{s\_1}$ c1	60.0	60.0	60.0	54.5 ksi
$f_{s\_2}$	48.1	57.0	-60.0	26.0
$f_{s\_3}$	26.0	-46.4	0.0	0.0
$f_{s\_4}$	0.0	0.0	-60.0	-26.0
$f_{s\_5}$	-26.0	37.8	-57.0	-48.1
$f_{s\_6}$	-48.1	-60.0	-60.0	-60.0

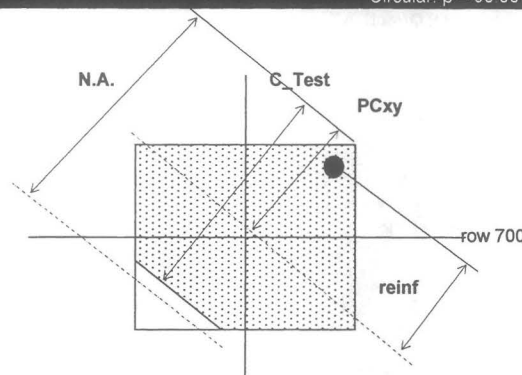


Figure 45-14 The extreme fiber to the neutral axis and the relative strain in the reinforcing.

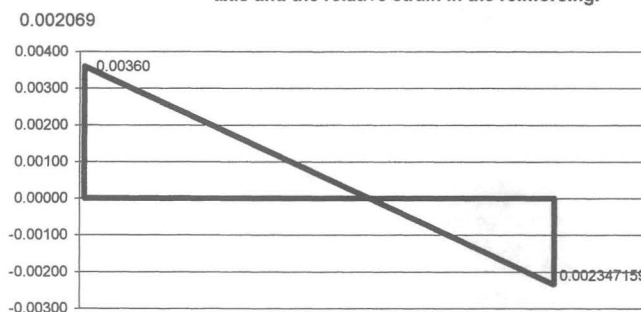


Figure 45-15 Strain Profile

### STRAIN DIAGRAM

X	0.01	1	1	0.01	0.01
Y	0.00360	-0.002347	0	0	0.0036

row 730

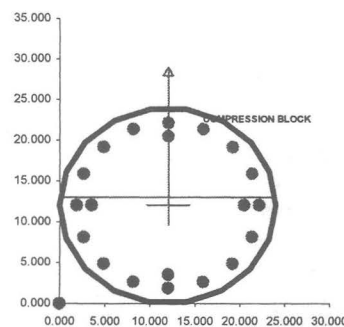


Figure 45-16 Load direction with reinforcing location and compression block.

row 740

row 750



# CONCRETE BIAxIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT



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45 Concrete Column.xls

For  $P_n$  Circular,  $\beta = 90.00^\circ$

### Tension Steel k

$A_{r1\_c1} * fs_{1\_c1} * (fs_{1\_c1} < 0)$					$PC_x \uparrow$
1.00 * 60.0 * (60.0 < 0)					$PC_y \rightarrow$
	c1	c2	c3	c4	
Ts_1	0.0	0.0	0.0	0.0 k	
Ts_2	0.0	0.0	0.0	0.0	
Ts_3	0.0	0.0	0.0	0.0	
Ts_4	0.0	0.0	0.0	-26.0	
Ts_5	-26.0	0.0	-526.8	-48.1	
Ts_6	-48.1	-60.0	-60.0	-60.0	

row 760

STL\_COMP 1 logic 1 for  $f'_s = E_s * e_s$  compression reinforcing compatibility switch  
0 for  $f'_s = 0$  when  $f'_s < f_y$

### Compression Steel k

$A_{r1\_c1} * fs_{1\_c1} * (fs_{1\_c1} > 0)$				
1.00 * 60.0 * (60.0 > 0)				
	c1	c2	c3	c4
Cs_1	60.000	60.0	60.0	54.5 k
Cs_2	48.1	526.8	0.0	26.0
Cs_3	26.0	0.0	0.0	0.0
Cs_4	0.0	0.0	0.0	0.0
Cs_5	0.0	0.0	0.0	0.0
Cs_6	0.0	0.0	0.0	0.0

row 770

### C\_Test $A_s$

Area  $C_c$  2.89 unitless Deduct the area of reinforcing  $A_s * \beta_1 * f'_c$  of steel for  $C_c$

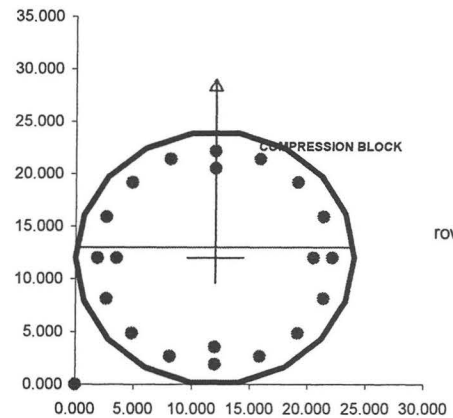


Figure 45-17 Load direction with reinforcing location and compression block.

row 780

### $T_s * arm$

$-Ts_{1\_c1} * PC_{r1\_c1}$					
-0.0 * 10.1					
	0.0	0.0	0.0	0.0 k-in	
	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	263.8	
	263.8	0.0	4466.9	487.2	
	487.2	607.5	607.5	607.5	

row 790

### $C_s * arm$

$Cs_{1\_c1} * PC_{r1\_c1}$					
60.0 * 10.1					
	607.5	607.5	607.5	551.2 k-in	
	487.2	4466.9	0.0	263.8	
	263.8	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	

row 800

row 810

A	B	C	D	E	F	G	H	I	J	K	L	M	N
For $P_n, e_n$												Circular, $\beta = 90.00^\circ$	

	0 logic	Circular
$T_s$ arm	7791 k-in	$T_s * \text{arm from centroid}$
$C_s$ arm	7855 k-in	
$C_c$ arm	3577 k-in	$C_c \text{ conc} * C_{L \text{ area}}$ $IF(0, 844.6 * 6.50, 634.6 * 5.64)$
$P_n, e_n$	19224 k-in	$T_s \text{ arm} + C_s \text{ arm} + C_c \text{ arm}$
	1602.0 k-ft	
$e_n$	29.99 in	$P_n, e_n / P_n$ $19,224.21 / 640.92$
Sym	1 logic	$+A_s = -A_s$ symmetry
$f_y \leq 60$	1 logic	$f_y \leq 60$

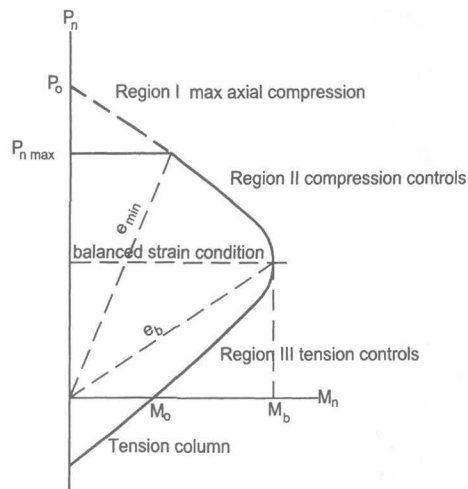


Figure 45-18 The interaction diagram for axial load and bending moment.

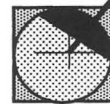
$Y_{xx} \uparrow$	0.844 unitless	$(h - d' - d_s) / h \geq 0.70$	ACI 9.3.2.2
$Y_{yy} \rightarrow$	0.844 unitless	$(h - d' - d_s) / h \geq 0.70$	
Y	1 logic	$Y_{xx}$ and $Y_{yy} \geq 0.70$	
$\phi_1$	0.75 unitless	Tied columns = 0.7, Spiral tied columns = 0.75	ACI 9.3.2.2
$\phi_1 P_n$	480.7 k	$\phi_1 * P_n$ $0.75 * 640.9$	
Tie	0.15	Tied columns = 0.2, Spiral tied columns = 0.15 $(0 = 1) * 0.2 + (0 = 0) * 0.15$	
$\_1 A_g f_c$	230 k	$0.10 * \text{length} * \text{width} * f_c$ ACI 9.3.2.2 $0.10 * 24.00 * 24.00 * 4$	
$\phi_2$	0.75 unitless	$\max(\phi_1, 0.90 - (\text{Tie} * \phi_1 P_n / \_1 A_g f_c))$ ACI 9.3.2.2 $\text{MAX}(0.75, (0.9 - (0.15 * 481 / 230)))$	
$\phi_2 P_n$	481 k	$\phi_2 * P_n$ $0.75 * 640.9$	
$\phi_3$	0.75	$\max(\phi_1, 0.90 - (\text{Tie} * \phi_2 P_n / \_1 A_g f_c))$ $\text{MAX}(0.75, (0.9 - (0.15 * 481 / 230)))$	
$\phi_3 P_n$	480.7 k	$\phi_3 * P_n * (\text{sum}(\text{Sym} + [f_y \leq 60] + Y) = 3)$ $0.75 * 641 * ((1 + 1 + 1) = 3)$ where conditions of symmetry, $f_y \leq 60$ , and $Y_{xx}$ & $Y_{yy} \geq 0.70$ are met	

Where:  
 $f_y \leq 60$  ksi  
and reinforcing is symmetrical  
 $(h - d' - d_s) / h \geq 0.70$   
 $\phi$  may be increased linearly to 0.90  
as  $\phi P_n$  decreases from  $0.10 f_c A_g$  to 0  
ACI 9.3.2.2



# CONCRETE BIAXIAL COLUMN: COMPOSITE CIRCULAR COLUMN TANK SUPPORT

45



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45 Concrete Column.xls

MATH for RECTANGULAR ROTATING COMPRESSION BLOCK Circular  $\beta = 90.00^\circ$

L	24.00 in	referenced from above
W	24.00 in	reference
$\beta_{input}$	1.5708 radians	reference
	90.0000 degrees	
$\tan \beta$	1.18E+11 unitless	
$\sin \beta$	1.0000 unitless	
$\cos \beta$	0.0000 unitless	
PCx	12.00 in	PCx top 12.00 in
PCy	12.00 in	PCy right 12.00 in
A diag	0.785 rad	
	45.000 deg	
diag	16.971 in	PC x, y to top right corner
sweep	1 logic	$\beta_{input} \geq A \text{ diag}$
diff	0.7854 rad	difference between diagonal and load direction
	45.0000 deg	

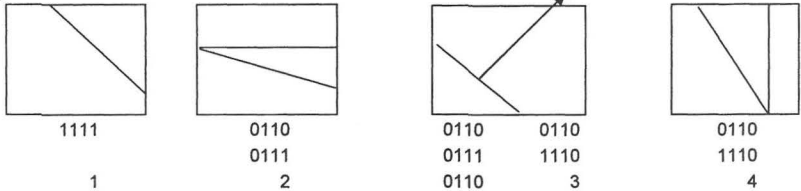


Figure 45-19 Area computation logic diagrams.

row 880

x top→pt	12.0000	0.0000	12.0000 pt	the extreme fiber up and right
y top ↑ pt	12.0000	12.0000	24.0000	

C_Test	11.000						
For 0 pressure line intersection with perimeter							
x top→pt	12.000	x diag→	0.0000				
y top ↑ pt	24.000	y diag↑	11.0000	x begin→	12.000	x top→	10999906
				y begin↑	13.000	y top ↑	0.000
						x bot→	24.000
						y bot ↑	0.000
logic	0110	0110					
logic	0111	1110					
x →	24.00	0.00		A triangle	1111	0111	0110
y ↑	11.000	24			24.000	24.000	24.000
A rect	264.0	0.0			11.000	0.000	13.000
					132.0	0.0	156.0
							288.0

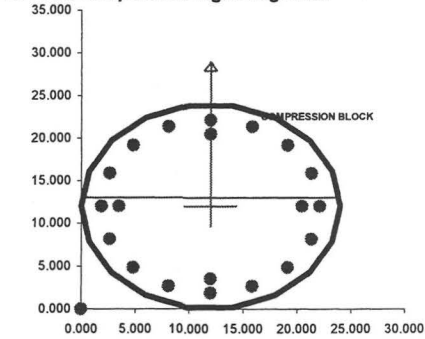


Figure 45-20 Load direction and compression block.

row 890

logic	1	0	0	1	0	0		
logic			0	2	0	0	sum A	2
A rect	264.0	0.0	0.0	0.0	0.0	0.0	264.00 in²	area of compression block
CG y→	12.00	24.00	16.00	16.00	16.00	16.00	in	
CG x ↑	18.50	12.00	20.33	13.00	8.67	16.00	in	
Ad y→	3168.0	0.0	0.0	0.0	0.0	0.0	sum Ad	CG from bottom left
Ad x ↑	4884.0	0.0	0.0	0.0	0.0	0.0	3168 in³	12 in→
CG PCy→	0.0000 in→							18.5 in ↑
CG PCx↑	6.5000 in ↑							CG from top right
								12 in←
								5.5 in ↓

row 910

CG PCxy 6.5000 in sum(d\*A) / AREA from PCx and y

C<sub>C</sub> concrete 845 k 0.85 \* f<sub>c</sub> \* AREA -sum(d < C<sub>TEST</sub> A<sub>s</sub>) w/o deduct for comp st'l area  
0.85 \* 4.00 \* 264.00 - SUM(52.96)

row 920

P <sub>n</sub>	851 k	T <sub>s</sub> + C <sub>s</sub> + C <sub>c</sub> the nominal axial load strength 19,946 k + 78,679 k + 845 k
Conc	1778 k	0.85 * f <sub>c</sub> * (L <sub>xx</sub> * W <sub>yy</sub> - sum(Area steel))
Steel <sub>rect</sub>	3177.6 k	f <sub>y</sub> * sum(Area steel)
P <sub>o</sub>	4956 k	Conc + Steel <sub>rectangular</sub>
P <sub>n max</sub>	3402 k	P <sub>o</sub> * φ <sub>1</sub> (Design Strength Factor)

row 930



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MATH for SEMICIRCULAR ROTATING COMPRESSION BLOCK Circular,  $\beta = 90.00^\circ$

$L_{xx}$	24.0 in	referenced from above
$W_{yy}$	24.0 in	
	24.0 in	
	33.9 in	
max diag	24.0 in	
C Test	11 in	compress block reference
For a bearing area as a partially loaded semicircle to full semicircle		
leg b	11.96 in	$((24.00 / 2)^2 - (24.00 / 2 - 11.000)^2)^{0.5}$
chord	23.92 in	
leg c	12.00 in	radius
angle $\alpha$	1.4874 radians	$\text{atan}(11.96 / (24.00 / 2 - 11.00))$
A segment	202.2 in <sup>2</sup>	$(24.00 / 2)^2 * (1.4874 - \text{SIN}(1.4874) * \text{COS}(1.4874))$
A semi c	226.2 in <sup>2</sup>	area of semicircle
A bearing 1	202.2 in <sup>2</sup>	
xc	5.64 in	cg of bearing area 1
xc semi c	5.09 in	
XC bearing 1	5.64 in	
For a bearing area as a loaded semicircle to fully loaded circle		
angle $\alpha$	4.6290 radians	
A segment	202.2 in <sup>2</sup>	
A bearing 2	428.4 in <sup>2</sup>	$A_{\text{semi c}} - A_{\text{segment}}$
xc seg	-5.64 in	
XC bearing 2	5.35 in	
A sum	202.2 in <sup>2</sup>	
xc sum	-5.70 in	

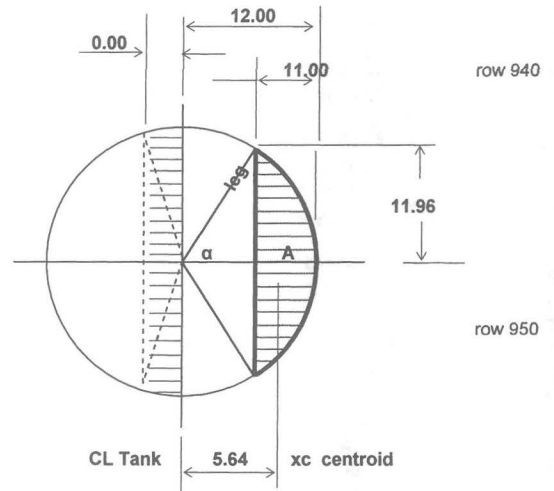


Figure 45-21 Diagram of a circular segment

$C_{L \text{ area}}$	5.64 in	to CG of compression area
$C_c \text{ concrete}$	635 k	$0.85 * f_c * \text{AREA} - \text{sum}(d < C_{\text{TEST}} A_s)$ w/o deduct for comp st'l area $0.85 * 4.00 * 202.22 - \text{SUM}(52.96)$
$P_n$	641 k	$T_s + C_s + C_c$ nominal axial load strength $-855 \text{ k} + 861 \text{ k} + 635 \text{ k}$
Conc	Circular	
Circular	1358 k	$0.85 * f_c * (p r^2 - \text{sum}(\text{Area steel}))$
Rectangle	1905	
	1358	
Steel	3178 k	$f_y * \text{sum}(\text{Area steel})$
$P_o$	4536 k	Conc + Steel <sub>circular</sub>
$P_n \text{ max}$	3402 k	$P_o * \phi_1$ (Design Strength Factor)

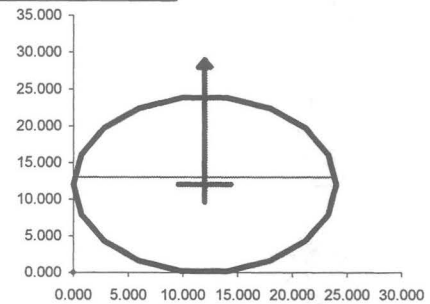


Figure 45-22 Direction of loads.

Rectangular / Circular Switch

Shape	C alpha	Circular
	0 Logic	0 = Circular, 1 = Rectangular
$C_{L \text{ area}}$	5.64	
$C_c \text{ concrete}$	635	
$P_n$	641 k	
Conc	1358 k	
St'l	3178 k	
$P_o$	4536 k	
$P_n \text{ max}$	3402 k	

row 960

row 970

row 980

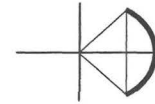
row 990



# CONCRETE BIAXIAL COLUMN PARTIAL SHELL TANK SUPPORT

## 46

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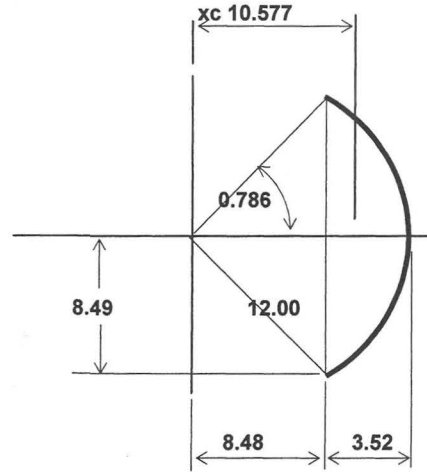
Segment for composite column calculation

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46 Partial Shell.xls

A B C D E F G H I J K  
**PARTIAL SHELL MATH**

diameter 1	24.00	inch	outside diameter of shell
b1 rise	3.52	in	depth of arc
t shell	0.50	in	thickness of shell
leg	8.48	in	
angle	0.7860	radians	$ACOS(8.48 / (24.00 / 2))$
	45.0	degrees	
xc	10.577	in	
area 1	113.19		
area 2	103.95		
area net	9.24	in <sup>2</sup>	area of segment
area gross	36.13	in <sup>2</sup>	
leg vert	8.49	in	



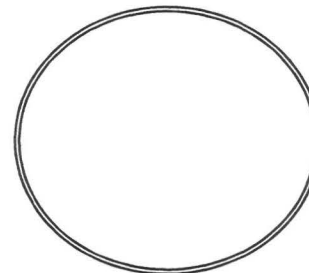
row 20

row 30

Figure 46-1 One quarter segment of a circle.

**ENTIRE SHELL MATH**

diameter	24.00	in	outside diameter of shell
t shell	0.50	in	thickness of shell
area	36.13	in <sup>2</sup>	
c	12.0	in	$24.00 / 2$
I	2549	in <sup>4</sup>	$PI() * (24.00^4 - (24.00 - 2 * 0.50)^4) / 64$
S	212.4	in <sup>3</sup>	$2,549 / 12.0$
r	8.40	in	$(2,549 / 36.13)^{0.5}$



row 40

Figure 46-2 The entire shell cross section

row 50

row 60

row 70



A B C D E F G H I J K L M N

CONSTRUCTION PHOTOGRAPHS



— These pile columns will support the elevated deck as well as the pile cap. The pile cap will distribute column loads to all of the piling.

row 20

— Vibratory compactor.

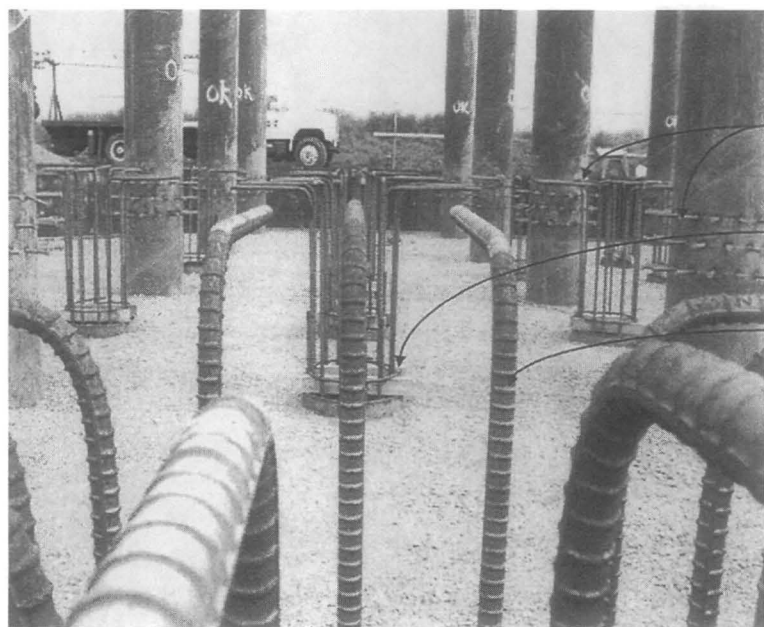
— Temporary caps to keep debris out of the piling.

— This gravel mat provides a clean, hard working surface as well as a quality subgrade for the concrete pile cap.

row 30

Figure 47-1 Compacting the gravel housekeeping mat.

row 40



— Headed weld studs on all through pile columns.

— Temporary wood braces to position the reinforcing cages.

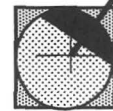
row 50

— Reinforcing cage inside of the piling. Bars have tails for better development and construction purposes.

row 60

Figure 47-2 This is a view of pile columns above grade and pile columns with rebar cages at grade.

row 70



A B C D E F G H I J K L M N

CONSTRUCTION PHOTOGRAPHS -- Continued



Figure 47-3 Two trucks are shown in position to load the pump hopper.

row 80

As one truck moves out another moves in. The concrete pumper is behind the trucks. 500 cubic yards of concrete were placed in about three hours.

row 90

row 100

The concrete pumper boom.

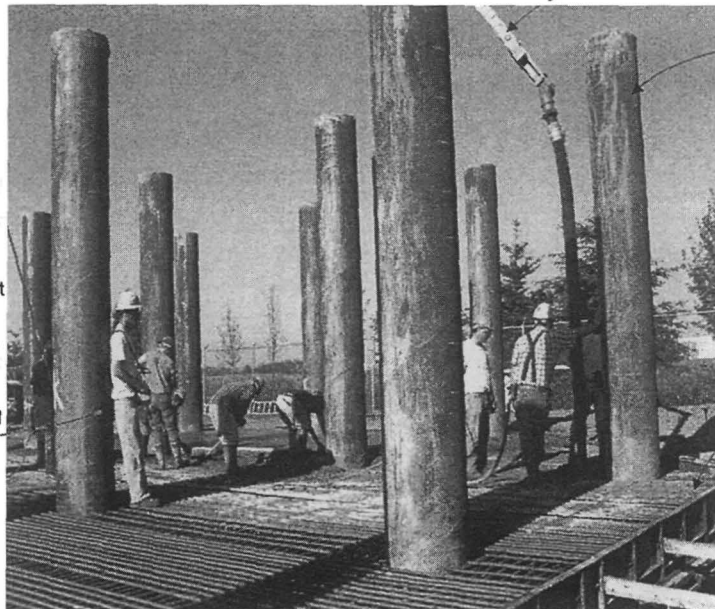


Figure 47-4 This view shows the concrete placers, the pump boom operator, and the concrete finishers (in the background).

row 110

These piling will relieve reinforcing cages and concrete in the next few days.

The man in the yellow hardhat and white shirt guides the boom with a radio transmitter. The transmitter has two control sticks much like the transmitter for radio controlled airplanes.

Formwork is tied off to the pile columns and buttressed against the sides of the excavation.

Pressure at the bottom of the forms will be 600 psf. Total force against the forms will be 1,200 Lb. / linear foot of length.

row 130

At column 39 to 139 Seismic

y

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48 Concrete Shear.xls

**BEARING ON CONCRETE**

$f'_c$	4 ksi	ultimate strength of concrete
Punching ratio	290 k_ult / 1 unitless	SEISMIC ultimate load LRFD factor required
$P_{ult}$	290.0 k_ult	
$f_{brg}$	3.4 ksi_ult	$0.85 * f'_c$ allowable bearing on concrete
$\Phi_{brg}$	0.7	
$A_1$ req'd	122 in <sup>2</sup>	11.0 in on a side minimum
$A_2$	452 in <sup>2</sup>	area of supporting surface not to exceed 2 ACI 10.17.1
multiplier	2.00	$A_1 / A_2$
$A$ req'd	61 in <sup>2</sup>	

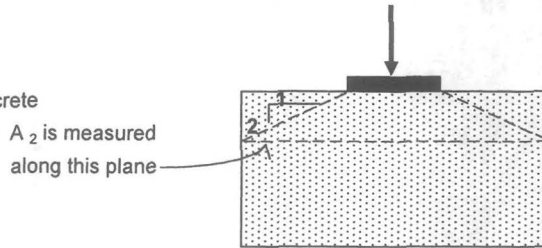


Figure 48-1 Bearing area and edge distance

**CIRCULAR PUNCHING SHEAR**

dia	24.00 in	
$A_{pl}$	452.4 in <sup>2</sup> 452 in <sup>2</sup> > 122 in <sup>2</sup>	
$P_{ult}$	290.0 k_ult	$1.0 * 290.0$
$\beta_c$	1.00 unitless	ratio = 1 for circular column
$d$	36.0 in	depth to tension reinforcing
$b_o$	188 in	$(dia + d) * \pi$
$A_o$	6786 in <sup>2</sup>	$b_o * d$ $36.0 * 188$
$V_c$ 33	2575 k	02 ACI 11.12.2.1 (11-33) $6 * (4 * 1000)^{0.5} / 1000 * 188 * 36.0$ where $(2 + 4/\beta_c) = 6$
$\alpha_s$	40 unitless	factor
$V_c$ 34	4137 k	$(\alpha_s d / b_o + 2) \sqrt{f'_c} b_o d$ 02 ACI 11.12.2.1 (11-34) $(40 * 36.0 / 188.5 + 2) * (4 * 1000)^{0.5} / 1000 * 188 * 36.0$
$V_c$ 35	1717 k	$A_o 4 \sqrt{f'_c}$ 02 ACI 11.12.2.1 (11-35) $6,786 * 4 * (4 * 1000)^{0.5} * 0.85 / 1000$

convert circular column to equivalent square

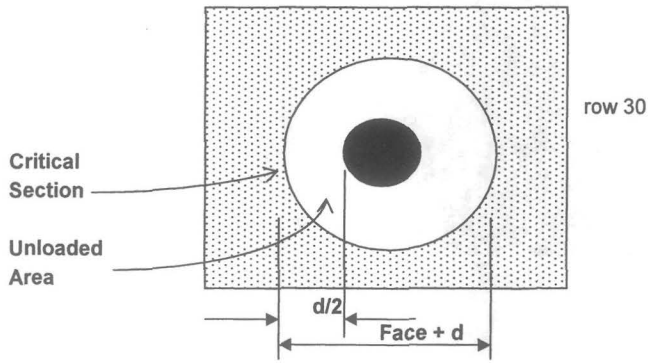


Figure 48-2 Shear punching in plan view.

$\alpha_s$  40 for interior columns  
30 for edge columns  
20 for corner columns

$V_c$ min	1717 k	Use minimum $V_c$ for punching shear.
-----------	--------	---------------------------------------

$\Phi_v$	0.85 unitless	strength reduction factor
$V_u$	1459 k ult OK	$\Phi V_c$ minimum
	290.0 < 1,459 k ultimate allowed	

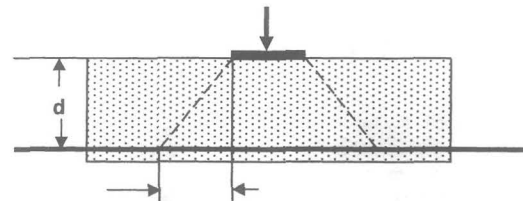


Figure 48-3 Shear cone dimensions in elevation view.

row 60

At column 39 to 139 Seismic

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48 Concrete Shear.xls

### STIRRUP REINFORCING

$b_1$	60.0 in	width of critical section
$s$	4.0 in	stirrup / tie spacing $\leq d/2$ or 24"
$f_y$	40 ksi	stirrup / tie yield strength
$A_v$	0 in <sup>2</sup>	sum of area for all vertical bars to resist shear
	=0.31*10	

Note: Calculation for  $A_v$  is done in the input cell. The actual calculation is copied to an adjacent cell and parked with the [space bar] to show the math.

$V_s$	0.0 k	$A_v F_y d / s$ ACI 11.5.6.2
		0.00 * 40 * 36.0 / 4.0

$V_u$	1459.2 k-ult	$\Phi (V_c \text{ minimum} + V_s)$
		0.85 * (1,717 + 0.0)
		OK 290.0 required < 1,459.2 k ultimate allowed

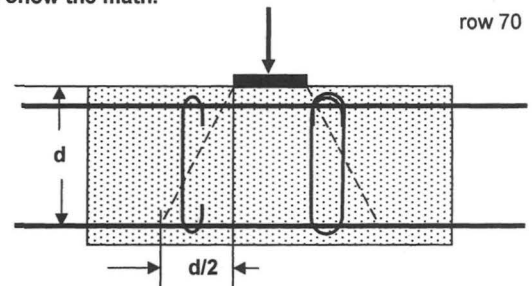


Figure 48-4 Shear reinforcing through the shear cone.

Per ACI Commentary R11.12.3 In slabs 10" and thinner, shear reinforcement should be enclosed stirrups with a longitudinal bar at each corner.

### INCLINED BAR REINFORCING

$f_c$	4 ksi
$V_u \text{ reqd}$	290.0 k ult
$d$	36.0 in
$V_c$	1716.7 k ult
$\Phi v$	0.85 unitless

$b_1$	60.0 in	width of critical section
$\alpha$	60.0 degrees 1.047 radians	angle of shear bars from the plane of beam/column reinforcing
$f_y$	60 ksi	stirrup / tie yield strength
$A_v$	9.6 in <sup>2</sup>	=0.6*12 sum of area for all bars to resist shear

$V_s$	498.8 k	$A_v F_y \sin \alpha$ ACI 11.5.6.5 (11-17)
		9.60 * 60 * sin 60.0

but not greater than:

$b_w$	72.0 in	width of tributary beam
$V_s$	491.8 k	$3 \sqrt{f_c} b_w d$
		$3 * (4.00 * 1000)^{0.5} * 72.0 * 36.00 / 1000$

$V_s \text{ use}$	491.8 k
-------------------	---------

$V_u$	1877.2 k-ult	$\Phi (V_c \text{ minimum} + V_s)$
		0.85 * (1,717 + 491.8)
		OK 290.0 required < 1,877.2 k ultimate allowed

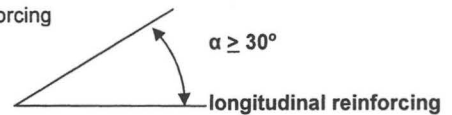


Figure 48-5 Inclined shear reinforcing.

row 110



At column 39 to 139 Seismic

y

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48 Concrete Shear.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
--	---	---	---	---	---	---	---	---	---	---	---	---	---	---

**TORSION**

Torsion per ACI 11.6.3

$T_u$  1006286 in-lb/ft ult  $= 1174 * 1000 * 12 / 14$   
ultimate torsional moment

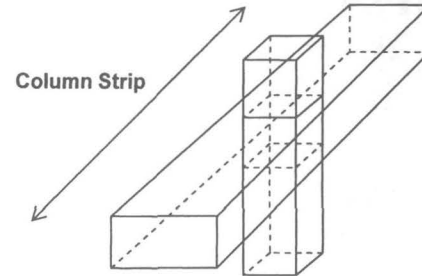
$f_c$  4 ksi

$\Phi_{torsion}$  0.75 factor

$A_{oh}$  3456 in<sup>2</sup>

$A_{cp}$  3456 in<sup>2</sup>

$p_{cp}$  264 in



row 120

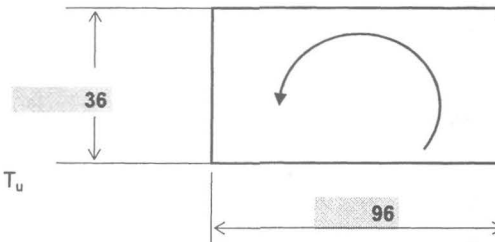
**For Nonprestressed members**

Torsional effects on bending and shear can be neglected when  $T_{u, Limit} < T_u$

$T_{u, Limit}$  2146025 in-lb ult  $\Phi \sqrt{f_c} (A_{cp}^2 / p_{cp})$   
1 logic

OK  $T_u$  limit  $\geq T_u$  required

**Torsion reinforcing not required**



row 130

Figure 48-6 Beam torsion shear.

$\rho_h$  0.007 unitless  $= 12 * 0.6 / (24 * 42)$   
ratio of horizontal shear reinforcing area to gross area of the vertical concrete section

$A_{oh}$  area enclosed by the centerline of the closed torsion reinforcement, in<sup>2</sup>

$A_{cp}$  area enclosed by the outside perimeter of the concrete cross section, in<sup>2</sup>

T 1 0.013  $(V_u / b_w d)^2$   
 $(290 / (72.0 * 36.0))^2$

$p_{cp}$  outside perimeter of the concrete cross section, in

T 2 0.000  $(T_u \rho_h / 1.7 A_{oh}^2)^2$   
 $(1,006,286 * 0.007 / (1.7 * 3,456^2))^2$

T required 0.11 k-in ult  $\sqrt{(V_u / b_w d)^2 + (T_u \rho_h / 1.7 A_{oh}^2)^2}$

T provided 0.99 k-in ult  $\Phi_v (V_c / b_w d + 8 \sqrt{f_c})$   
 $0.85 * (1,716.7 / (72.0 * 36.0) + 8 * (4 * 1000)^{0.5} / 1000)$

row 150

row 160

At column 39 to 139 Seismic

y

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48 Concrete Shear.xls

### BEAM SHEAR

V beam 230.0 k =460/2 column punching divided by 2 sides  
 ratio beam 1 unitless fluid + DL  
 V<sub>u</sub> req'd 230.0 k\_ult seismic

f<sub>c</sub> 4 ksi  
 d 36 in depth to reinforcing  
 b<sub>w</sub> 96 in width of beam or tributary slab

V<sub>c</sub> 437.2 k  $2 \sqrt{f_c} b_w \cdot d$  ACI 11.3.1.1  
 $2 * (4 * 1000)^{0.5} * 36.0 * 96 / 1000$

Φ 0.85 unitless strength reduction factor  
 V<sub>u</sub> allow 371.6 k\_ult 0.85 \* 437.2  
 1 logic  
 OK 371.6 > 230.0 k\_ult required

s 6.0 in stirrup / tie spacing ≤ d/2 or 24"  
 f<sub>y</sub> 40 ksi stirrup / tie yield strength  
 A<sub>v</sub> 0.00 in<sup>2</sup> sum of area for all bars to resist shear  
 =0.2\*12

A<sub>v</sub> req'd 0.72 in<sup>2</sup>  $50 * b_w \cdot s / f_y$  ACI 11.5.5.2  
 $50 * 96 * 6.0 / 40.00 / 1000$

V<sub>s</sub> 0.0 k  $A_v F_y d / s$  ACI 11.5.6.2  
 $0.00 * 40 * 36.0 / 6.0$

V <sub>u</sub> allow	371.6 k-ult	Φ (V <sub>c</sub> + V <sub>s</sub> ) 0.85 * (437.2 + 0)
----------------------	-------------	--

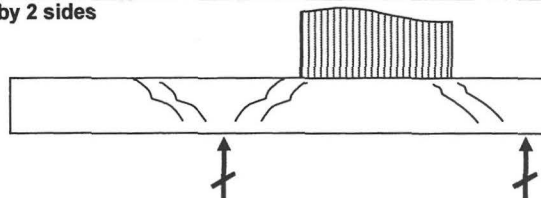


Figure 48-7 Beam shear elevation.

Bar Area	
10M	0.12
15M	0.27
20M	0.49
25M	0.76
30M	1.1
35M	1.49
45M	2.47
55M	3.68
0	0
3	0.11
4	0.20
5	0.31
6	0.44
7	0.6
8	0.79
9	1.00
10	1.27
11	1.56
14	2.25
18	4.00

row 180

row 190

### FOR MEMBERS SUBJECT TO SHEAR AND FLEXURE

A<sub>s</sub> 7.2 in<sup>2</sup> area of tension reinforcing  
 =0.6\*12

ρ<sub>w</sub> 0.0021 unitless density of tension reinforcing  
 M<sub>u</sub> 1174.0 k-ft ult factored ultimate moment

limit 7.1  $V_u d / M_u \leq 1.0$   
 1.0  $(1.9 \sqrt{f_c} + 2500 \rho_w V_u d / M_u) b_w d$  ACI 11.3.2.1

a 0.120  $1.9 * (4.0 * 1000)^{0.5} / 1000$   
 b 0.005  $2500 * 0.0021 * 1.0 / 1000$   
 V<sub>c</sub> 433.3 k  $(0.120 + 0.005) * 96.0 * 36.0$

V<sub>c</sub> limit 765.0 k  $3.5 \sqrt{f_c} b_w \cdot d$  ACI 11.3.2.1

V<sub>c</sub> 433.3 k minimum( V<sub>c</sub> limit, V<sub>c</sub> )

V<sub>u</sub> allow 368.3 k-ult Φ (V<sub>c</sub> + V<sub>s</sub>)  
 1 logic  
 OK 368.3 > 230.0 k\_ult required

row 200

row 210

A B C D E F G H I J K L M N  
PHOTOGRAPHS

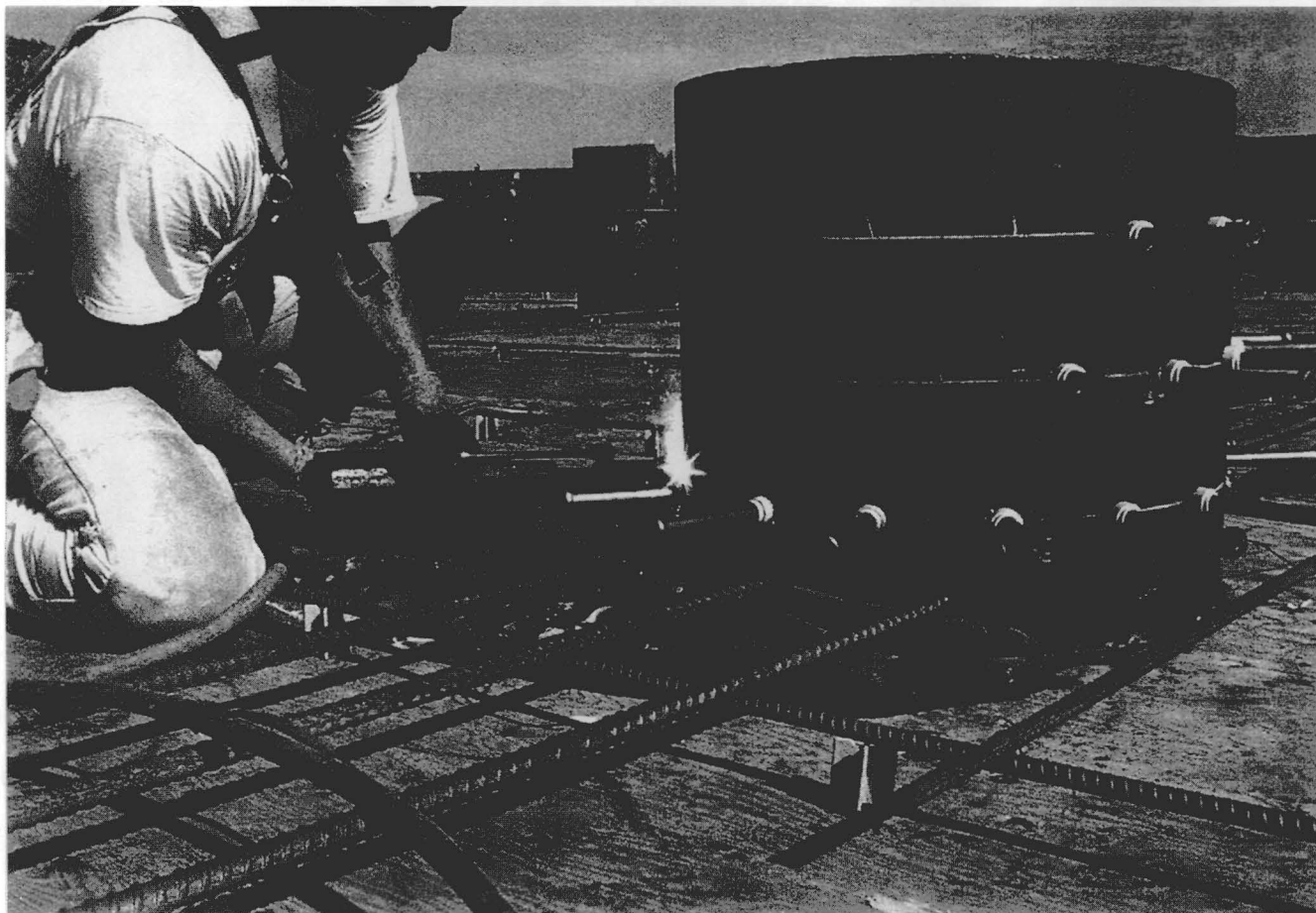


Figure 48-8 Weld stud application.

Weld stud application requires a large generator. The welded end of the stud contains the weld material and flux. The white, porcelain ferrules contain the electric arc, flux, and weld material.

After welding, the ferrule is broken off and discarded.

You can visit the Nelson Weld Stud site at:  
<http://www.nelsonstud.com>

For evaluation reports, go to the International Building Codes Evaluation Service website at:  
[http://www.icbo.org/ICBO\\_ES/](http://www.icbo.org/ICBO_ES/)

On February 1, 2003, ICBO ES formally joined with the National Evaluation Service, BOCAI evaluation services, and SBCCI PST & ESI in the new ICC Evaluation Service, Inc. (ICC-ES). ICC-ES is a subsidiary of the International Code Council. The web site address will change in time.

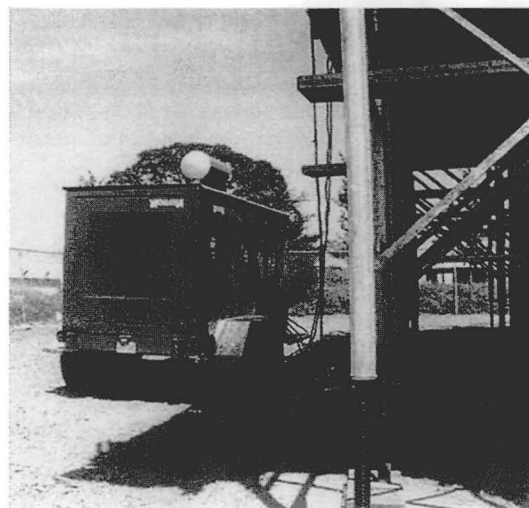
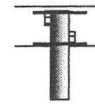


Figure 48-9 The big, portable weld stud generator. row 270



#### DESIGN FOR MOMENT TRANSFER WITHOUT THE SHEAR TRANSFER MECHANISM

In designing for moment transfer without shear transfer mechanism, the resulting answer will be more conservative.

Mu	1174 k-ft ult	
width	15.1 in	width of compression blocks
depth	12 in	depth of compression blocks
f <sub>c</sub>	4 ksi	
β	0.85	for 4 ksi concrete
block	10.2 in	0.85*depth
C <sub>c</sub>	524 k ult	
arm	2.24 ft	compare
	26.9 in	

Whitney's compression blocks act on the top and bottom of the pile and cage column. The width of 15.1" is an estimate of usable bearing width.

angle 0.56159 radians  
32.2 degrees

At the greatest angle, the bearing surface will be sloping away from the compression force by about 32 degrees.

The theoretical stress blocks are confined by the matrix of reinforcing top and bottom.

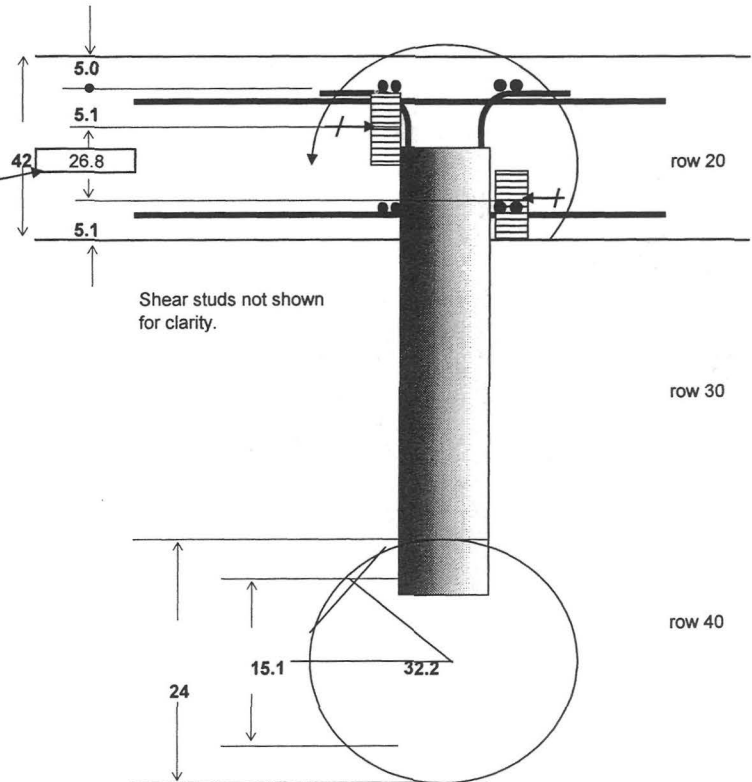


Figure 49-1 An elevation and plan view of the slab column moment transfer mechanism.

#### SHEAR STUD PUNCHING

Part of the punching shear is resolved by the traditional punching cone of **d\_bearing** depth. The rest of the punching shear is taken care of by the headed weld studs.

Because some of the moment from column to slab is transferred as a type of punching shear, this arrangement is also compared to the unit stress required on the critical column face times the punching area:

$$v_u \text{ sum} * (\text{column } \varnothing + d_{\text{studs}}) * \pi * d_{\text{studs}}$$

$v_u \text{ sum}$  (the unit shear) is determined in the Slab-Column Moment Shear Transfer calculations and can be found in the box just above row 70.

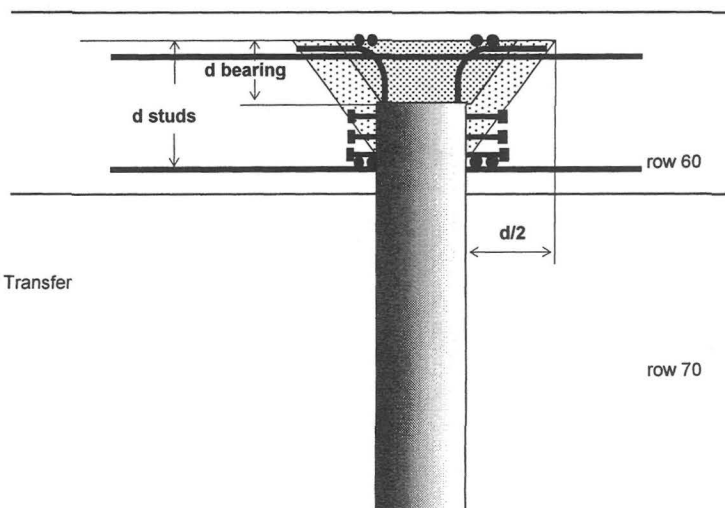
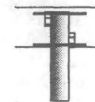


Figure 49-2 The two shear cones generated by the column.



PHOTOGRAPHS

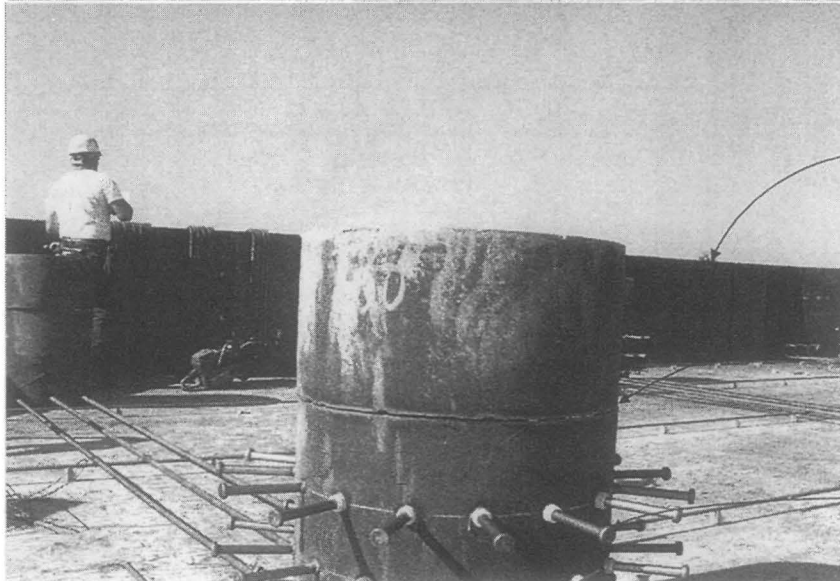


Figure 49-3 Column cut height and the shear stud pattern.

Upper deck forms.

row 90

Pile column cut height. This height was chosen for the depth of shear cone it would generate and still provide a column sufficient to resist seismicly generated moments.

row 100

The weld stud pattern. The white rings at the connection are ferrules which contain the flux and weld material during the application process. The ferrules are later broken off and swept away.

row 110



Figure 49-4 Testing the weld stud with a BFH (big fat hammer).

Bending this stud down is best done with a 10 pound hammer. The stud should withstand bending until it is parallel with the pile face. The ability to bend at this joint shows ductility and strength of the weld.

row 120

It is very unsettling to strike one of these studs and have it snap off. Usually, the craftsman breaks off studs and replaces them with a new, better connected stud.

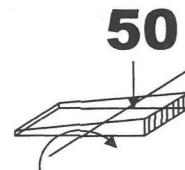
row 130

Hammer mark

row 140

row 150

Column Moment Transfer to Deck  
At column 39 to 139 Seismic



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50 Column Slab Moment Shear Transfer.xls

SHEAR		
L <sub>1</sub>	14 ft	
L <sub>2</sub>	14 ft	
dia	24.0 in	circular column
L <sub>n</sub>	12.0 ft	
d	36.0 in	
b <sub>1</sub>	60.0 in	
b <sub>o</sub>	188 in	shear cone perimeter ACI 11.12.1.2 perimeter needs not to approach the periphery of the loaded area closer than d/2
Mu req	1174 k-ft_ult	
Vu req	460 k_ult	
Vc	1459 k	as defined in ACI 11.12.2.1 per 11.12.6.2
Φ	0.85 unitless	strength reduction factor
Φ V <sub>n</sub>	0.183 ksi	members without shear reinforcement ACI 11.12.6.2 (11-40) 0.85 * 1,459 / (188 * 36.0)
V <sub>s</sub>	0.0 k	additional shear capacity due to stirrups and bent-up bars
Φ V <sub>n</sub>	0.183 ksi	Φ V <sub>n</sub> = v <sub>u</sub> 0.85 * (1,459.0 + 0.0) / (188.5 * 36.0)

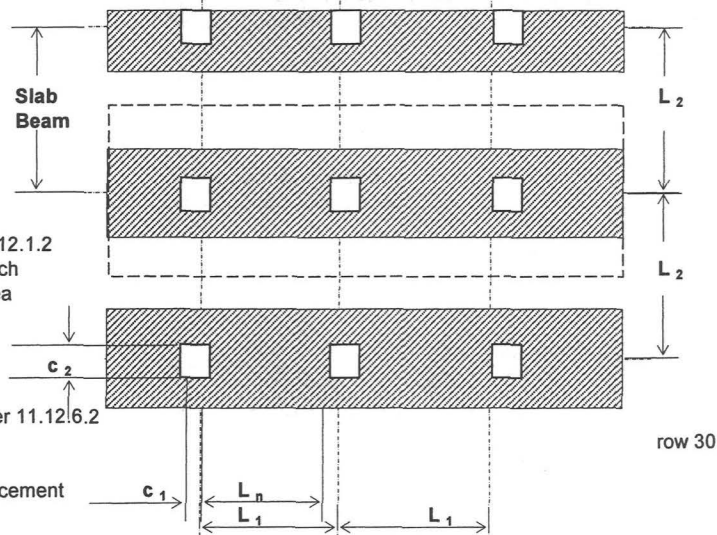


Figure 50-1 FRAMING LAYOUT PLAN

v <sub>u max</sub>	0.183 ksi_ult	maximum shear stress allowed
J <sub>c</sub>	1296000	36.0 * (24.0 + 36.0)^3 / 6
	466560	(24.0 + 36.0) * 36.0^3 / 6
	3888000	36.0 * (24.0 + 36.0) * (24.0 + 36.0)^2 / 2
J <sub>c</sub>	5650560 in <sup>4</sup>	polar moment of inertia
A <sub>c</sub>	6786 in <sup>2</sup>	punching shear area 188.5 * 36.0
γ <sub>f</sub>	0.60 ratio	% of moment transferred by flexure ACI 13.5.3.2 (13-1) 1 / (1 + 2/3 * √(1.0 / 1.0))
γ <sub>v</sub>	0.40 ratio	% of moment transferred by shear ACI 11.12.6.1 (11-41) 1 - 0.60
v <sub>u transfer</sub>	0.073 ksi	moment transferred by shear V <sub>u</sub> / A <sub>c</sub> + γ <sub>v</sub> M <sub>u</sub> b <sub>1</sub> / J <sub>c</sub> 460.0 / 6,786 + 0.40 * 1,174.0 * 60.0 / 5,650,560
V <sub>u</sub>	157.2 k_ult	0.073 * 36.0 * 60.0
v <sub>u punching</sub>	0.068 ksi_ult	460.0 / 6,786 required
v <sub>u sum</sub>	0.141 ksi_ult	v <sub>u transfer</sub> + v <sub>u punching</sub> required 0.068 + 0.073 OK 0.141 required < 0.183 allowed
	303.6 k_ult	v <sub>u</sub> b <sub>1</sub> d punching shear at critical face 0.141 * 60.0 * 36.0

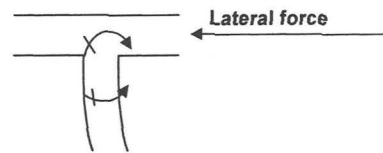


Figure 50-2 -- The column-slab joint applied force and reaction.

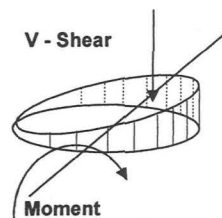
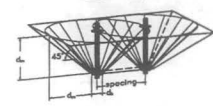


Figure 50-3 -- Shear stress at the critical section.

Note: This is similar to: P/A ± Mc/I

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51 Bolt Group Pullout.xls

**'ANCHORAGE TO CONCRETE, Tension -- fully encased bolt UBC 1923.2**

Inspect	1.3	unitless	inspection factor
T_tens	1.00	k_ult	required tension /bolt - ultimate
V_shear	358	k_ult	required shear /group - ultimate
	650	-292	shear cone at the top of the pile
P <sub>U</sub>	1.3	k_ult	tension
V <sub>U</sub>	465.4	k_ult	shear
d bolt	0.75	in	anchor shank diameter
A <sub>b</sub>	0.44	in <sup>2</sup>	net cross-section area of bolt
d <sub>e</sub>	10	in	edge distance toward loaded edge
Edge 2	3	in	edge distance away from loaded edge
	1	logic	
	0	logic	
Edge	0	logic	
f <sub>ut</sub>	58	k/in <sup>2</sup>	ultimate tensile strength
P <sub>ss</sub>	23.1	k_ult	0.9 * A <sub>b</sub> * f <sub>ut</sub> 0.9 * 0.44 in <sup>2</sup> * 58 ksi
V <sub>ss</sub>	19.2	k_ult	0.75 * A <sub>b</sub> * f <sub>ut</sub> 0.75 * 0.44 in <sup>2</sup> * 58 ksi
λ	1.00	unitless	concrete factor
d <sub>h</sub>	1.25	in	Tributary area of plate 1.2 in <sup>2</sup> or head Actual plate may be rectangular
d <sub>m</sub>	5.8	in	depth of embedded plate for pullout
f <sub>c</sub>	4	k/in <sup>2</sup>	compressive strength of concrete
A <sub>p</sub>	130	in <sup>2</sup>	effective area of projected cone onto the surface of the slab (1.3 + 2 * 5.8) / 2 <sup>2</sup> * π
P <sub>c</sub>	8.2	k_ult	λ * A <sub>p</sub> * √f <sub>c</sub> UBC 1923.3.2 1.00 * 130 in <sup>2</sup> * √4,000 /1000
V <sub>c</sub>	22.4	k_ult	800 * A <sub>b</sub> * √f <sub>c</sub> UBC 1923.3.3 800 * 0.44 * √4 * 1000 /1000 for bolts more than 10 diameters towards the loaded edge V <sub>c</sub> not governed by A <sub>b</sub>
V <sub>c</sub>	39.7	k_ult	2 π d <sub>a</sub> <sup>2</sup> λ f <sub>c</sub> 2 * π * 10.0 <sup>2</sup> * 1.00 * √4 * 1000 /1000
V <sub>c</sub>	39.7	k_ult	
φ	0.85	unitless	0.85 for confined anchor embedment 0.65 for unconfined anchor embedment UBC 1923.3.2 execution

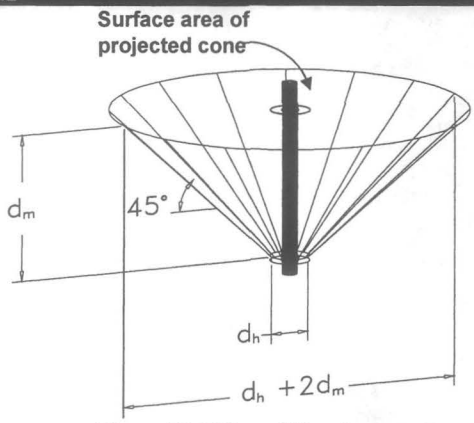


Figure 51-1 View of the shear cone.

**INSPECTION -- UBC 1923.2** row 30

- 1.3 Special inspection provided for bolts anchored in compression zone
- 2 No special inspection
- 2 Special inspection provided for bolts anchored in tension zone
- 3 No special inspection for bolts anchored in the tension zone

**λ UBC 1923.3.2** row 40

- 1.00 normal weight concrete
- 0.85 sand light weight concrete
- 0.75 all-light weight concrete

**Edge distance**

Shear loading more than 10 diameters from the loaded edge. row 50

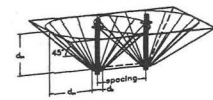
Tension or shear away from an edge more than 5 diameters away and with reinforcing to prevent concrete in tension failure.

Edge distance not less than 4 diameters in any case.

$$\frac{1}{\Phi} \left[ \left( \frac{P_{II}}{P_c} \right)^{5/3} + \left( \frac{V_{II}}{V_c} \right)^{5/3} \right] = \frac{1}{0.85} \left[ \frac{1.3}{8.2}^{5/3} + \frac{465.4}{39.7}^{5/3} \right] = 71.112 > 1.000 !!!$$

$$\left[ \frac{P_{II}}{P_{ss}} \right]^2 + \left[ \frac{V_{II}}{V_{ss}} \right]^2 = \left[ \frac{1.3}{23.1} \right]^2 + \left[ \frac{465.4}{19.2} \right]^2 = 586.478 > 1 !!!$$

row 70



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51 Bolt Group Pullout.xls

**UBC 1923.2 ANCHORAGE TO CONCRETE, Tension -- fully encased group of bolts**

For a group of connectors, use the area of a truncated pyramid projected onto the surface of the slab

Rectangular area of projected pyramid

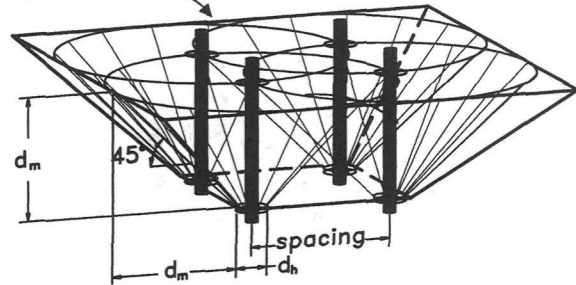


Figure 51-2 View of grouped shear cones.

P <sub>U</sub>	1.3 k <sub>ult</sub>	tension
V <sub>U</sub>	465.4 k <sub>ult</sub>	shear
spacing_	5.0 in	symmetrical in both directions 4, 9, 16, 25, etcetera
number_	42 unit	
	1 logic	OK 5.0 ≤ 2 * 5.8 Use Bolt Group
P <sub>ss</sub>	968.6 k <sub>ult</sub>	0.9 * A <sub>b</sub> * f <sub>ut</sub> * number_ 0.9 * 0.44 in <sup>2</sup> * 58 ksi * 42
V <sub>ss</sub>	807.1 k <sub>ult</sub>	0.75 * A <sub>b</sub> * f <sub>ut</sub> * number_ 0.75 * 0.44 in <sup>2</sup> * 58 ksi * 42
Length	40.25 in	2 * 5.8 dm + (5.0 spacing) * (√42 number - 1) + 1.25 dh
Width	40.25 in	2 * 5.8 dm + (5.0 spacing) * (√42 number - 1) + 1.25 dh
A <sub>b</sub>	1620.4 in <sup>2</sup>	Length * Width
P <sub>c</sub>	102.5 k <sub>ult.</sub>	1 * A <sub>b</sub> * √[UBC 1923.3.2 1.00 * 1,620 in <sup>2</sup> * (4,000 ksi) <sup>0.5</sup> ]
V <sub>c</sub>	1669.0 k <sub>ult.</sub>	V <sub>c</sub> * number 39.7 * 42

row 90

row 100

$$\frac{1}{\Phi} \left[ \left( \frac{P_U}{P_c} \right)^{5/3} + \left( \frac{V_U}{V_c} \right)^{5/3} \right] = \frac{1}{0.85} \left[ \left( \frac{1.3}{102.5} \right)^{5/3} + \left( \frac{465.4}{1669.0} \right)^{5/3} \right] = 0.141 < 1.000 \text{ OK}$$

$$\left[ \frac{P_U}{P_{ss}} \right]^2 + \left[ \frac{V_U}{V_{ss}} \right]^2 = \left[ \frac{1.3}{968.6} \right]^2 + \left[ \frac{465.4}{807.1} \right]^2 = 0.332 < 1.000 \text{ OK}$$

row 110

HILTI	F <sub>v</sub>	F <sub>u</sub>
HAS Std / A36	36	58
HAS Super /B7	105	125
HAS SS /A 304 SS	65	100

row 120

A307		60
A108 studs		65
A325 to 1" Grade 5, B7	92	120
A325-1 1 1/8" to 1 1/2"	81	105
A490 Gr 8, 1/2" - 1 1/2"	120	150
A354 Gr. BD 1/2" to 2 1/2"	120	150

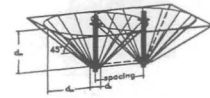
row 130



# BOLT GROUP PULLOUT TANK SUPPORT

# 51

Christy  
18:37  
12/20/05



At column 39 to 139 Seismic

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51 Bolt Group Pullout.xls

ANCHORAGE TO CONCRETE, Shear -- fully encased bolt UBC 1923.3.3

### PARSING UBC 1923.3.2 WHERE:

$A_p$  = the effective area of the **projection** of an assumed concrete failure surface upon the surface from which the anchor protrudes.

For a single anchor or for an anchor group where the distance between anchors is equal to or greater than twice their embedment length, the surface is assumed to be that of a truncated cone radiating at a 45 degree slope from the bearing edge of the anchor toward the surface from which the anchor protrudes.

row 140

The effective area is the **projection** of the cone on this surface.

For an anchor which is perpendicular to the surface from which it protrudes, the effective area is a circle.

For an anchor group where the distance between anchors is less than twice their embedment lengths, the failure surface is assumed to be that of a truncated pyramid radiating at a 45 degree slope from the bearing edge of the anchor group toward the surface from which the anchors protrude.

row 150

The effective area is the **projection** of this truncated pyramid on this surface.

In addition, for thin sections with anchor groups, the failure surface shall be assumed to follow the extension of this slope through to the far side rather than be truncated, and the failure mode resulting in the lower value of  $FP_c$  shall control.

row 160

Do you really think that you can understand this without diagrams?

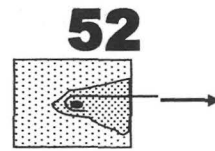
row 170

row 180

row 190



# EMBED TANK SUPPORT



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## TENSION DEVELOPMENT

# 7, fy 60 ksi, f'c 4

Bar_#	7	0.88" dia.	bar size	Fy 60 ksi/f'c 4.0 ksi see below
top bar	1	0/1 yes	no / yes	more than 12" concrete below bar
L available	63	in	available space for embed or hook (for flag)	
fy	60	k/in <sup>2</sup>	rebar yield strength	
f'c	4	k/in <sup>2</sup>	concrete compressive strength	

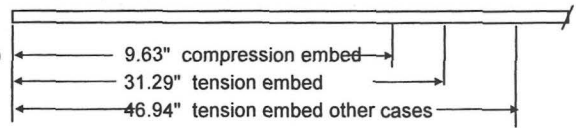


Figure 52-1 Reinforcing embed lengths.

cover	3	in	concrete side cover
	0	logic	
spacing	4	in !!	6" c-c spacing & 3" min. side cover require
	1	logic	
a	1.3	unit	1+ top_bar * 0.3

### Coating per 99 ACI 12.2.4

Epoxy coated bars and wire w/ less than 3 db cover or 6 db spacing	1.5
Other epoxy coated wire	1.2
Uncoated reinforcement	1.0

for epoxy bars use 1.5

b	1	factor	coating factor for plain and/or epoxy coated rebar ACI 12.2.4 not to exceed a * b = 1.7
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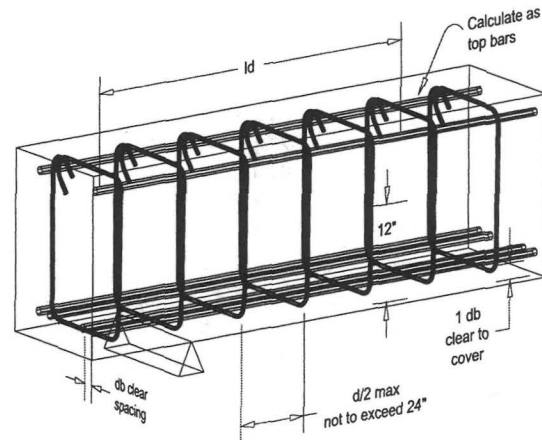


Figure 52-2 Reinforcing embed lengths.

ab	1.3	unitless	=MIN(b * TOP, 1.7)
g	1.0	unitless	bar size factor #3 to #6 = 0.8, #7 and larger = 1.0
l	1	factor	for lightweight concrete = 1.3 or f'ct factor, normalweight concrete = 1.0
A <sub>tr</sub>	0.6	in <sup>2</sup>	area of transverse reinforcing at spacing s 99 ACI 12.2.4
f <sub>vt</sub>	40	ksi	yield strength of transverse reinforcement, ties, and stirrups
s	6	in	spacing of transverse reinforcement
n	2	quantity	number of bars being developed
K <sub>tr</sub>	1.333	unitless	=A <sub>tr</sub> * f <sub>vt</sub> / (1500 s * n) K <sub>tr</sub> may = 0 for simplification even when transverse reinforcing is present

row 40

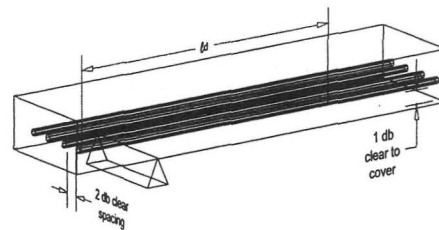


Figure 52-3 Reinforcing clearances in a beam.

Calculation 1 where spacing ≥ db, clear cover ≥ db, and stirrups or ties throughout ld at or better than code minimum

ld / db	49.3	$f_y * a * b * l / (25 * \sqrt{f'_c})$	tension for #3 - #6
ld / db	61.7	$f_y * a * b * l / (20 * \sqrt{f'_c})$	tension for #7 and larger

### Calculation 2 Other cases

ld / db	74.0	$3 * f_y * a * b * l / (50 * \sqrt{f'_c})$	tension for #3 - #6
ld / db	92.5	$3 * f_y * a * b * l / (40 * \sqrt{f'_c})$	tension for #7 and larger

Calculation 3 minimum for calculations 1 and 2 where minimum embed = 12" 99 ACI 12.2.3

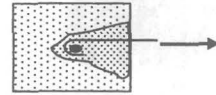
	2.5	=min((cover + K <sub>tr</sub> ) / (bar/8), 2.5)
ld / db	37.0	= 3/40 * f <sub>y</sub> * √(f'c) * ab * g * l / min((cover + K <sub>tr</sub> ) / (bar/8), 2.5)

row 60

As req / As	58 %	As required / As provided flexural reinforcing except:
	0.58	fraction member is a part of primary load resisting system 99 ACI 12.11.2
		required shrinkage and temperature reinforcement 99 ACI 7.12.2.3
		bottom bars within the column strip 99 ACI 13.3.8.5

37.9	tension for #3 - #6	=f <sub>y</sub> *1000/(25*√(f'c*1000))
47.4	tension for #7 and larger	

row 70



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**TENSION DEVELOPMENT -- Continued**

# 7, fy 60 ksi, f'c 4

**DEVELOPMENT TABLE Based Upon Fy 60 ksi, f'c 4 ksi, Beta 1.0, reinforcing above 12" of the bottom of the pour**

Bar Size#	Area in <sup>2</sup>	Tension		Tension		Calc 3 minimum	Compression		
		Calc 1 Basic	Other cases K <sub>tr</sub>	Calc 2	l <sub>db</sub> in		l <sub>db,c</sub> in		
0	0	0				92.5	0	0	
3	0.11	18.5	21.5	27.7	21.5	2.500	37.0	6.94	4.13
4	0.20	24.7	21.5	37.0	21.5	2.500	37.0	12.33	5.50
5	0.31	30.8	21.5	46.2	26.8	2.500	37.0	19.27	6.88
6	0.44	37.0	21.5	55.5	32.2	2.500	37.0	27.75	8.25
7	0.60	54.0	31.3	80.9	46.9	2.500	37.0	47.21	9.63
8	0.79	61.7	35.8	92.5	53.6	2.500	37.0	61.66	11.00
9	1.00	69.4	40.2	104.1	60.4	2.500	37.0	78.04	12.38
10	1.27	77.1	44.7	115.6	67.1	2.500	37.0	96.35	13.76
11	1.56	84.8	49.2	127.2	73.8	2.500	37.0	116.58	15.13
14	2.25	107.9	62.6	161.9	93.9	2.476	37.4	188.85	19.26
18	4.00	138.7	80.5	208.1	120.7	1.926	48.0	312.18	24.76

row 80

Area 0.60 in<sup>2</sup> for #7 bar  
 l<sub>d,table</sub> 31.3 in l<sub>db</sub> basic bar development length  
 l<sub>d,table</sub> 46.9 in l<sub>db</sub> bar development length for "other cases"

row 90

- Tension embedment 31.3 required <63.00" allowed
- Tension embedment 46.9 required <63.00" allowed for other cases

**COMPRESSION DEVELOPMENT**

l<sub>db,c</sub> is the basic compression development length without factors.

l <sub>db,c</sub>	16.6 in	=0.02 * bar / 8 * f <sub>y</sub> / f' <sub>c</sub> * 1000 * 1000	99 ACI 12.3.2
	15.8 in	=0.0003 * bar / 8 * f <sub>y</sub> * 1000	

As req / As 58 % As required / As provided compression reinforcing  
 0.58 fraction

Spiral / tie 1 factor where reinforcing is confined per 99 ACI 12.3.3.2  
 use 0.75 -- when reinforced with spirals or ties (per c)

l<sub>db</sub> 9.6 in

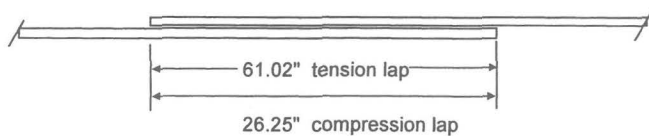


Figure 52-4 Reinforcing lap distances.

F <sub>y</sub>	60 ksi	yield strength of reinforcing
f' <sub>c</sub>	3 ksi	compressive strength of concrete
f <sub>ct</sub>	1 ksi	average splitting tensile strength of lightweight aggregate concrete
	1.0 factor	=MAX (6.7√f' <sub>c</sub> / f <sub>ct</sub> , 1.0)
l	1.0 factor	for lightweight concrete = 1.3 or fct factor, normalweight concrete = 1.0
P <sub>t</sub>	32.4 k <sub>ult</sub>	0.9 * F <sub>y</sub> * area

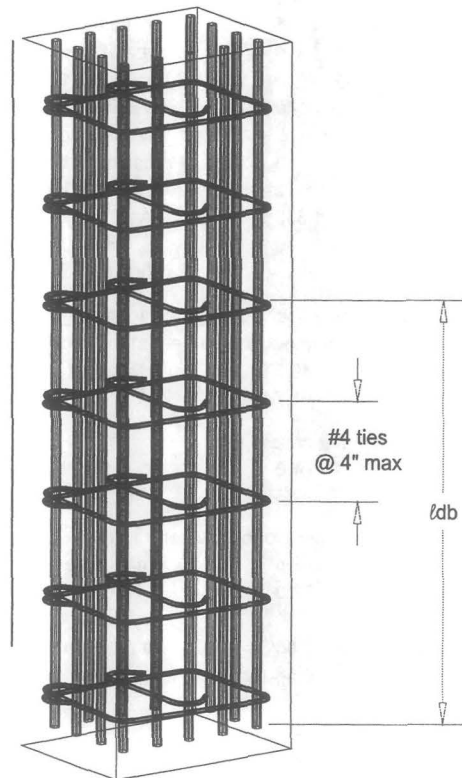
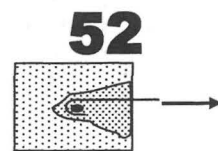


Figure 52-5 Compression reinforcement in a column.



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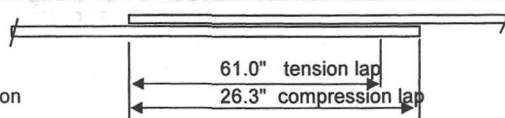
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### FLEXURAL REINFORCEMENT DEVELOPMENT

# 7, fy 60 ksi, f'c 4

$M_n$	16.3 k-ft / ft	Unfactored moment capacity
$V_u$ required	6.5 k-ult / ft	Required ultimate shear
d	9 in	depth of reinforcing
compression	0 / 0/1 no	no / yes confinement by compressive reaction



$[V_n]$	12 k-ult .	54% Provided shear capacity $\phi V_n$
%_cont	0 %	% of reinforcing after cutoff

99 ACI 11.1.1 (11 - 1) input the value for  $FV_n$   
Figure 52-6 Reinforcing lap distances.

### FLEXURAL DEVELOPMENT at SUPPORTS and POINTS OF INFLECTION

$l_a$	10.5 in	MAX(d, 12 * Bar_# / 8) at inflection point
$M_n$	16.33 k-ft	Unfactored moment capacity
$V_u$	6.5 k-ult	Required shear
$[M_n/V_u]$	30.1 in	$M_n / V_u * 12$
compression	1.00 unit	1+ comp * 0.30
$l_d$ positive	40.6 in	compression * $[M_n / V_u] + l_a$
$l_d'$	31.3 in	$l_d \leq l_d$ positive
	1 logic	OK

length beyond point of inflection or embedment length beyond the center of the support

0/1 no confinement by compressive reaction  
99 ACI 12.11.3 (12-2)

The 1.3 factor is useable only when the reaction confines the end of the reinforcement

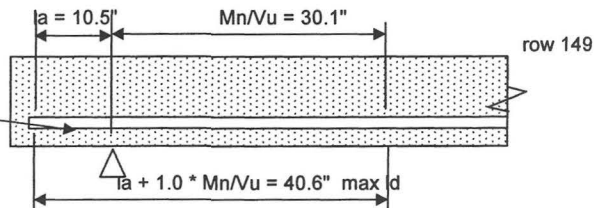


Figure 52-7 Reinforcing development at supports.

.Positive Moment Development 31.29 required <  $l_d$  31.29" provided

The 1.3 factor is useable only when the reaction confines the end of the reinforcement

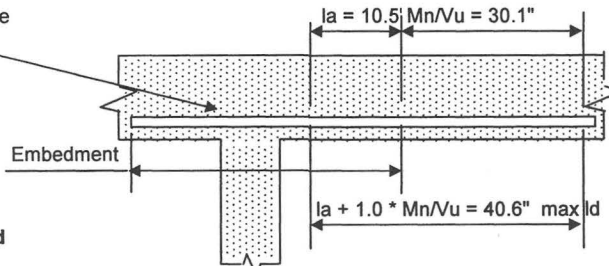


Figure 52-8 Reinforcing development at supports.

.Positive Moment Development 31.29 required <  $l_d$  40.65" provided

Flexural reinforcement terminated in a tension zone must satisfy:

$[V_u/V_n]$	0.542 .	Required $V_u / (\phi V_n) \leq 2/3$
Cond_1	1 logic	99 ACI 12.10.5.1

Tension zone development / embedment used in rebar cut-off where reinforcing is not required to resist moment.

$A_v$ excess	0	99 ACI 12.10.5.2 not included here
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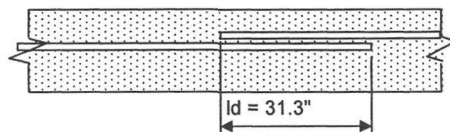


Figure 52-9 Flexural reinforcing in a tension zone. ACI 12.10.5.3

#11_max	1 logic	#11 and smaller bars
% cont'	0 logic	% after cutoff $\geq 2 * M_u$ required
$[V_u/V_n]'$	1 logic	Required $V_u / (\phi V_n)_{allow} \leq 3/4$
Cond_3	0 logic	$[V_u/V_n] * \#11\_max * \%\_cont'$

tens_emb	1 logic	1 = tension zone embedment allowed for this configuration
----------	---------	---

$V_u / (\phi V_n)$  54%  
 $M_u_{req'd} / M_u_{provided}$  0%  
Condition 1, .. has been met  
Tension embedment permitted

Tension embedment permitted

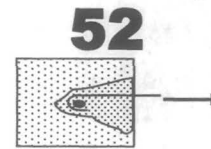
Condition 1, ..

0

row 189



# EMBED TANK SUPPORT



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A B C D E F G H I J K L M N # 7, fy 60 ksi, f'c 4

BAR DEVELOPMENT and HOOKS			
Bar_#	7 #	referenced from above	
fy	60 ksi	rebar yield strength	
f'c	4 ksi	concrete compressive strength	
As %	1 unit	0.00 - 1.00 As required / As provided = 100%	99 ACI 12.5.3.4
cover	3 in	concrete side cover	
cover_ext	3 in	concrete cover beyond end of bar or hook	
tie	0/1 no	no/yes ties -- see notes	
L	63 in	available space for embed or hook for flag	row 199

### TENSION HOOK

ldb	31.3 in	ld_Table basic case	Hooks cannot be applied in compression 99 ACI 12.5.5
ldh_min	7.0 in	MAX(bar_#, 6)	ldh is the basic development length of a hook in tension.
ldh	16.6 in	1200 * Bar_# / &sqrt; f'c for fy = 60 ksi	
fy_factor	1.00 unit	fy / 60000 99 ACI 12.5.3.1	ldh is development length of a standard hook. This value must be the max of 8 bar diameters, 6", or ldh * (applicable modification factors).
cover	2 in	concrete side cover	
cover_ext	2		Ties along ldh at 3*Bar_# / 8 spacing ACI 12.5.4
cover'	1.00 unit	1 - (bar_# <= 11) * (cover >= 2.5) * (cover_ext >= 2) * 0.3	
tie'	1.00 unit	1 - (bar_# <= 11) * (tie) * 0.2	
As %	1.00 unit	As required / As provided	
ldh	16.6 in	MAX(ldh_min, ldh * fy_factor * cover * tie * As %)	
[ldh <= L]	1 logic		
Area	0.60 in <sup>2</sup>		
T	36.1 k	As % & Area * Fy	Note: Iterate As % to make tension hook length equal to or less than length allowed.
T_ult	32.5 k-ult	0.9 * T	row 219

4db for #3 through #8 ≥ 2 1/2"  
5db for #9, #10, #11  
6db for #14, #18

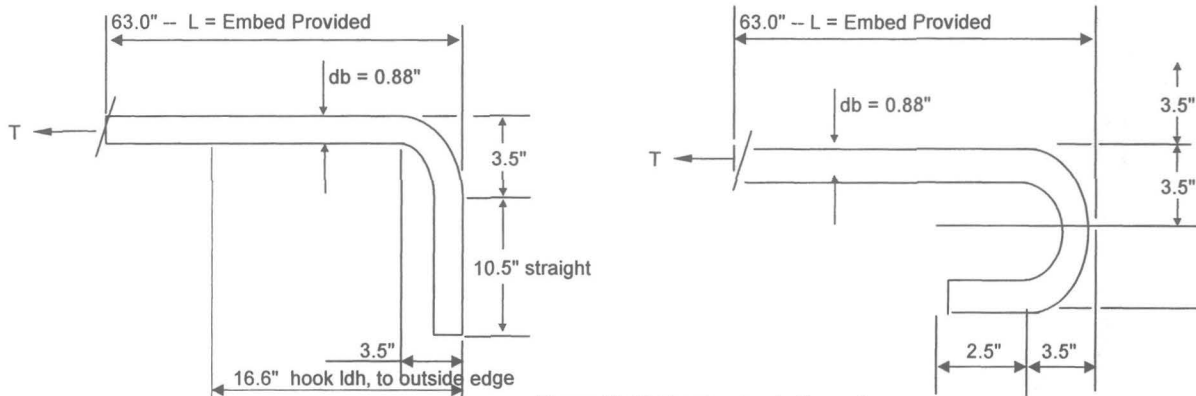
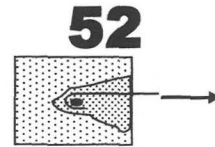


Figure 52-10 Tension hook dimensions.

For ties, #3, #4, #5 inside bend diameter = 4 db  
Tie hook extension = 6 db

**Tension hook 16.6 required < 63.0" allowed**



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**LAP SPLICE in TENSION**

# 7, fy 60 ksi, f'c 4

**Class A lap splice**

Factor	1.0 unit	
Lap	31.3 in	factor * $l_d$
	1 logic	

99 ACI 12.15.1

Use Class B splices, factor of  $1.3 l_d$ , for:  
Lap splices of deformed bars and deformed wire in tension.

**Class B lap splice**

Factor	1.3 unit	
Lap	61.0 in	factor * $l_d$
[Lap<=L]	1 logic	

Except,

Class A splices, factor of  $1.0 l_d$ , may be used when:

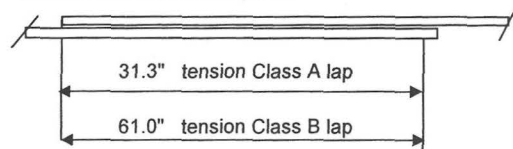
- (1) the area of reinforcement provided is at least twice that required by analysis over the entire length of the splice and,
- (2) one half or less of the total reinforcement is spliced within the required lap length.

row 259

**. Tension Class A lap splice 31.3 required < 63.00" allowed**

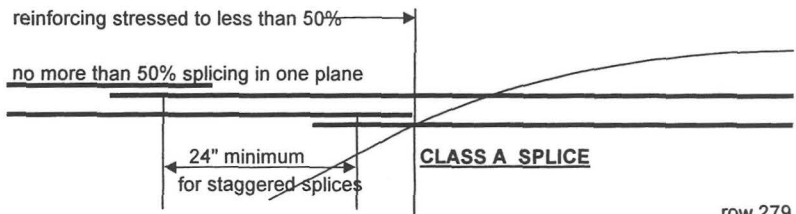
**. Tension Class B lap splice 61.0 required < 63.00" allowed**

Otherwise, use Class B splice.



row 269

	As req / As provided	
	50%	100%
Up to 50% splicing	A	B
Greater than 50% splicing	B	B



row 279

Figure 52-11 Class A and B splices.

**LAP SPLICE in COMPRESSION**

[f'c<3]	1.00 unit	$1 + (f'c < 3) * 0.333$
min_c1	26.3 unit	$0.0005 * F_y * \text{Bar\_}\# / 8$
	1 logic	$f_y \leq 60 \text{ ksi}$
min_c2	26.3 unit	$(0.0009 * F_y - 24) * \text{Bar\_}\# / 8$ for $F_y > 60$
	0 logic	$f_y \leq 60 \text{ ksi}$
Lap_c	26.25 in	
[Lap<=L]	1 logic	

99 ACI 12.16.1

Compression splices - ties throughout lap splice length with an effective area of  $0.0015 * (\text{thickness of member}) * (\text{spacing of ties})$ .

row 289

**. Compression lap splice 26.25 required < 63.00" allowed**

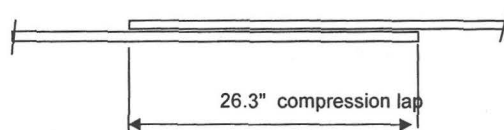
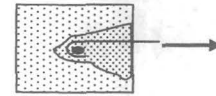


Figure 52-12 Lap splice in compression.

row 299

row 309



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**For BAR USED IN SHEAR FRICTION**

# 7,  $f_y$  60 ksi,  $f'_c$  4

Bar	6 unit	bar number 0.750" diameter	n UBC 1911.7.4.3	
$A_{vf}$	0.44 in <sup>2</sup>	area of bar in shear	1.4 monolithic concrete	
$f_y$	36 ksi		1.0 concrete placed against roughened-hardened concrete	
n	0.7 unit		0.6 against un-roughened hardened concrete	
l	1 unit		0.7 against as-rolled structural steel	
u	0.7 unit	$n * \lambda = u$		
$V_n$	11.088 k	$A_{vf} * F_y * n * l$	lambda UBC 1911.7.4.3	
$V_{u\_shear}$	9.425 k-ult	$0.85 * V_n$ allowable (11-26)	1 normal weight concrete	row 319
			0.85 sand light weight concrete	
			0.75 all-light weight concrete	

For net tension across shear plane,  
add  $A_s$ \_tension +  $A_s$ \_shear friction

UBC 1911.1.1

$T_{u\_tension}$  14.256 k-ult 0.9 \*  $f_y$  \*  $A_{bar}$  allowable

$T_{tension}$  0.5 k required tension  
 $V_{shear}$  3.32 k required shear

factor 1.43 1.43E  
 $T_{u\_required}$  0.715 k-ult  
 $V_{u\_required}$  4.748 k-ult

$T_{u\_req'd} / T_{u\_tension} + V_{u\_req'd} / V_{u\_shear}$  Unity  
0.715 / 14.256 4.748 / 9.425  
0.050 0.504 0.554 Unity.

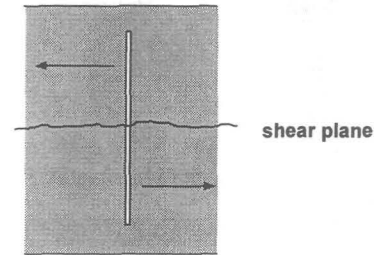
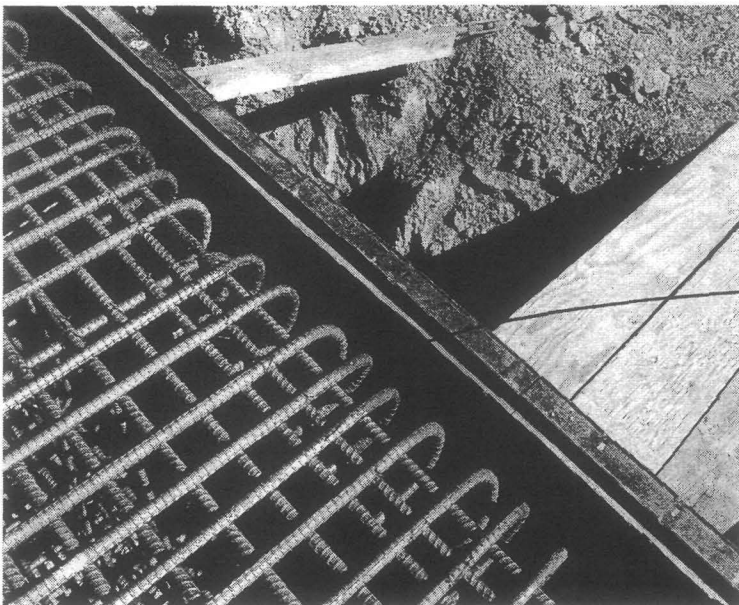


Figure 52-13 The shear friction plane.

row 339

**PHOTOGRAPH**



Because this is a pile cap, there are no vertical bars at the face. Vertical bars are usually used to limit unsightly cracks (temperature reinforcing). The appearance of cracks won't affect this buried face. row 349

**Hooked reinforcing**

The straight bar running through the hook provides "confinement." More concrete than just that used by the hook is added by the perpendicular bar.



row 359

Figure 52-14 Use hooked reinforcing where embedment of straight bars cannot be achieved in the space provided.



# REINFORCED CONCRETE BEAM TANK SUPPORT



Values from frame analysis for water test greatest moment  
24" piling, 42" Deck, 48" Pile Cap

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53 Concrete Beam.xls

A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>CONCRETE BEAM DESIGN</b>													<b>I gross 575,967 in<sup>4</sup> / I cracked 123,858 in<sup>4</sup> / I effective 575,967 in<sup>4</sup></b>

$f_y$	60 ksi	yield strength of reinforcing
$f_c$	4 ksi	compressive strength of concrete
$d'$	5 in	depth of compression reinforcing

$b_w$	84 in	width
$d$	40.0 in	depth of tension reinforcing
depth_OA	42 in	overall depth

	Bar Qty	Bar Size#	$A_s$
$A'_s$	22.00	7	13.20 in <sup>2</sup>
$A_s$	22.00	7	13.20 in <sup>2</sup>

M working	936.0 k-ft	required service level moment
$M_u$ req'd	1341.0 k-ft ult	required ultimate/factored moment

$M_u$  prov 2964.67 k-ft ultimate provided

OK Beam stressed to 45 %

OK  $A_s$  min 11.20 <  $A_s$  provided 13.20

OK x balance 14.87 ≥ 4.264 required

Length	39 ft	length of joist
t	4.5 in	thickness of slab
c	78 in	spacing of joists
flange	0 logic	0 = no flanges, 1 = spandrel, 2 = T beam

$I_a$	575967 in <sup>4</sup>	
$I_{cracked}$	123858 in <sup>4</sup>	
$I_e$	575967 in <sup>4</sup>	
$\epsilon_t$	0.00507 unitless	allowable tension reinforcing strain 0.00400 minimum strain allowed

**$\rho_{min}$  -- Minimum Reinforcement in Flexural Members**

$A_s$ min 1	10.63 in <sup>2</sup>	$3 \sqrt{f_c} / f_y b_w d$ 02 ACI 10.5.1 (10-3) $3 * \sqrt{4 * 1000} * 84.0 * 40.0 / 60 / 1000$
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$A_s$ min 2	11.20 in <sup>2</sup>	$200 * w * d / f_y / 1000$ 02 ACI 10.5.1 $200 * 84.0 * 40.0 / 60 / 1000$
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$A_s$ logic	1 logic	$MAX(11.20, 10.63) \leq 13.20$
-------------	---------	--------------------------------

When the area of tension reinforcing steel is less than  $+A_s$  minimum, the amount of reinforcing provided must be increased by 1/3 beyond that needed for tensile reinforcement. 02 ACI 10.5.3

When the beam is stressed to 75% and  $+A_s = 1.33 x A_s$  provided, the minimum requirements of reinforcement have been met.

**For Seismic Resistance**

$A_s$ min	11.20 in <sup>2</sup>	$200 * b_w * d / f_y$ ACI 21.3.2 $200 * 84 * 40.0 / 60 / 1000$
-----------	-----------------------	---

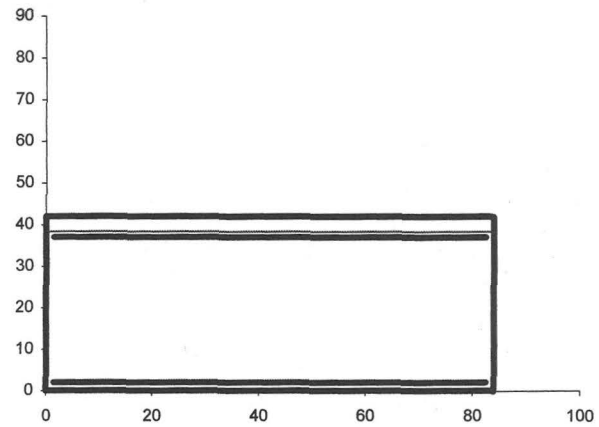


Figure 53-1 Beam cross-section with Whitney's stress block and reinforcing.

row 30

Bar Size # in American nomenclature, bar size is given as a number which equates to 8 th's of an inch hence, a #6 bar is 6/8 inch = 3/4"

$f_y$  ultimate tensile strength of reinforcing, k/in<sup>2</sup>  
 $f_c$  ultimate compression strength of concrete, k/in<sup>2</sup>

row 40

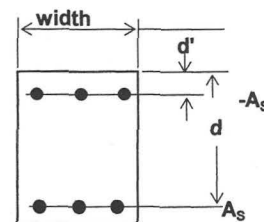


Figure 53-2 Beam cross-section.

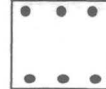
row 50

$-A_s, A'_s$  negative reinforcing - usually the top steel, in<sup>2</sup>  
 $+A_s$  positive reinforcing - usually the bottom steel, in<sup>2</sup>

row 60

row 70

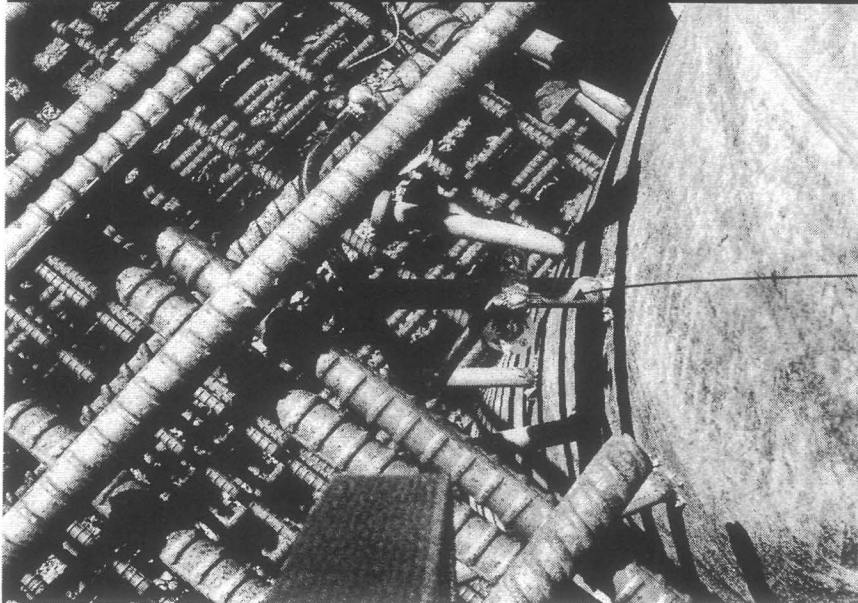
Values from frame analysis for water test greatest moment  
24" piling, 42" Deck, 48" Pile Cap



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53 Concrete Beam.xls

PHOTOGRAPHS



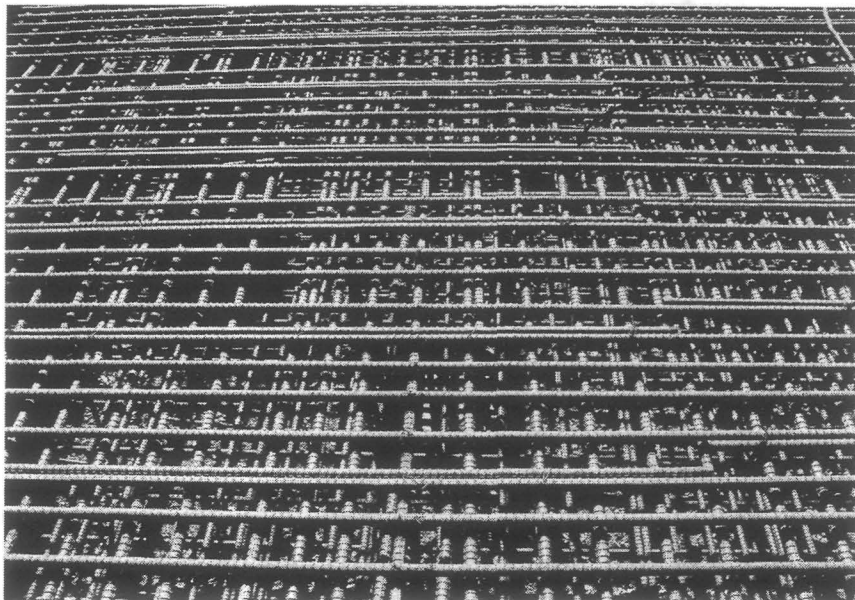
row 80

Positive gounding of the reinforcing mat to the pile column.

row 90

Figure 53-3 Looking down at a forrest of rebar and studs.

row 97



Splicing

Splicing adds to the congestion. 1" spacing is generally required to allow the 3/4" aggregate to pass down through the upper and lower mats.

This mat is made up of #7's @ 4" each way. Because the cross-section of reinforcing bar is oblong and with lugs, about 1" to 1 1/8" of space is required to accomodate the bar.

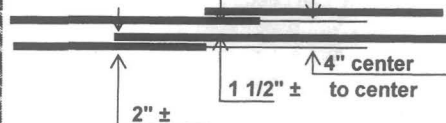


Figure 53-4 #7's @ 4."  
For some serious reinforcing, try #8's @ 4."

The contractor did specify a specialized mix to make sure that the concrete would place easily.



# LN<sub>2</sub> BULK STORAGE TANK TEST MEASUREMENTS

Christy  
November 5, 2003

54 Tank Test Measurements.xls

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### Summary of Tank Test Measurements

Please refer to the D sized drawing for measurement recordings.

The soils engineer predicted less than **1/4"** settlement under working loads for individual piles. It appears that our greatest settlement is on the order of **1/8"**.

Targets were glued to foundation columns on Friday, October 24, 2003. The water fill process began on Thursday the 29th and was finished on Sunday, November 2nd.

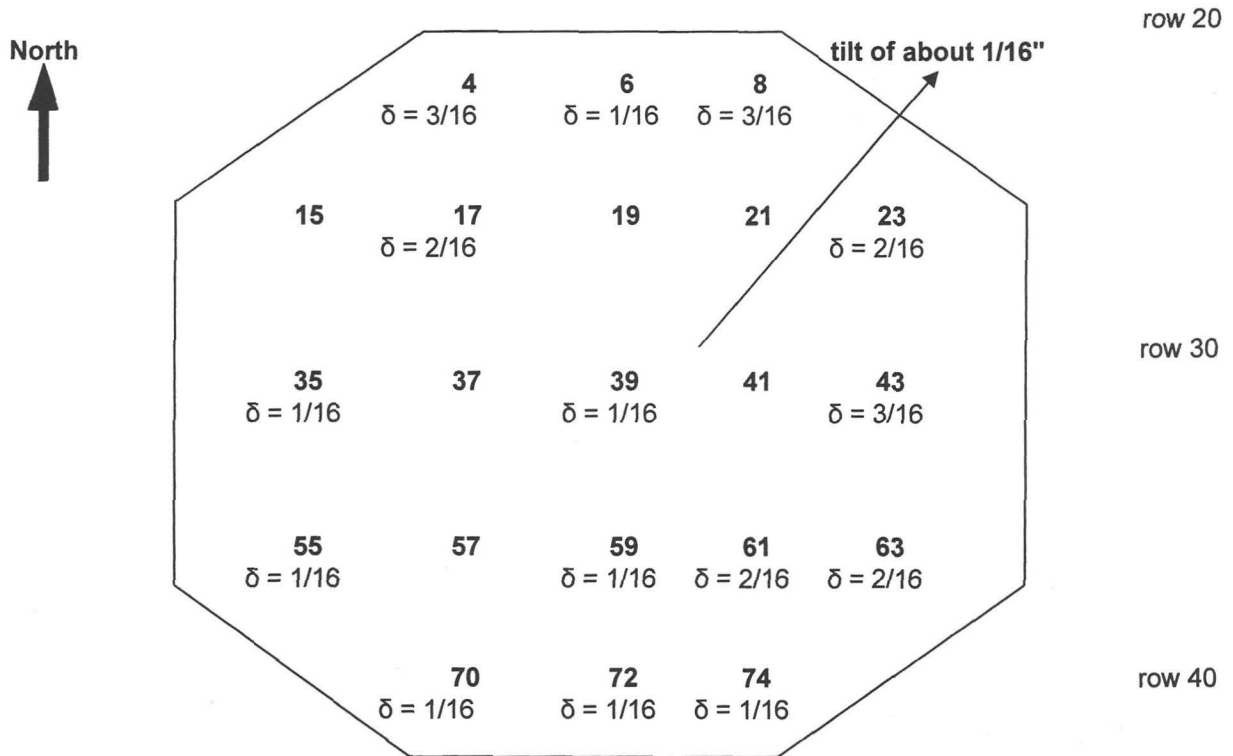
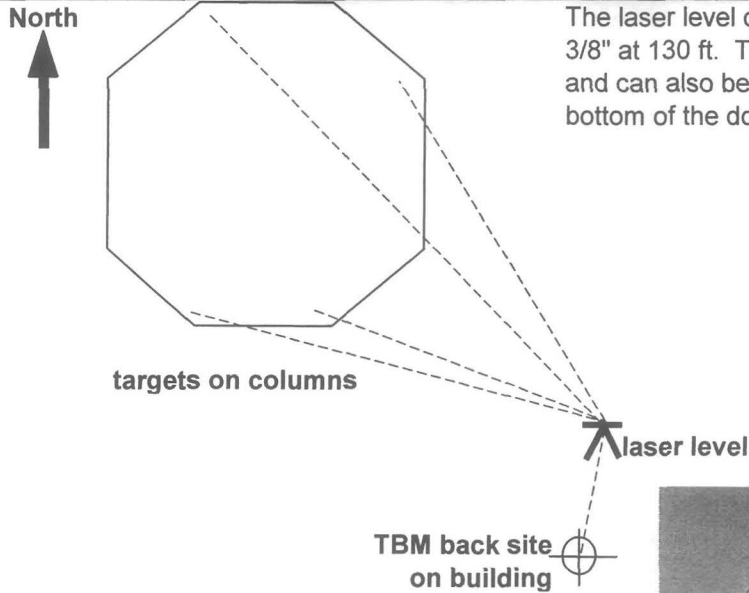


Figure 54-1. Laser Level Measurements of Column Settlements

row 50

### THE LASER LEVEL SETUP



The laser level dot is about 1/8" at 80 ft and 3/8" at 130 ft. The dot can be split in half by eye and can also be split by marking the top and bottom of the dot and calculating the middle.

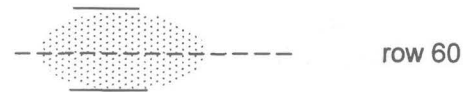


Figure 54-2 Laser Level Plan View



red and white reflective tape on targets

Figure 54-3 Enlargement of Targets on Columns

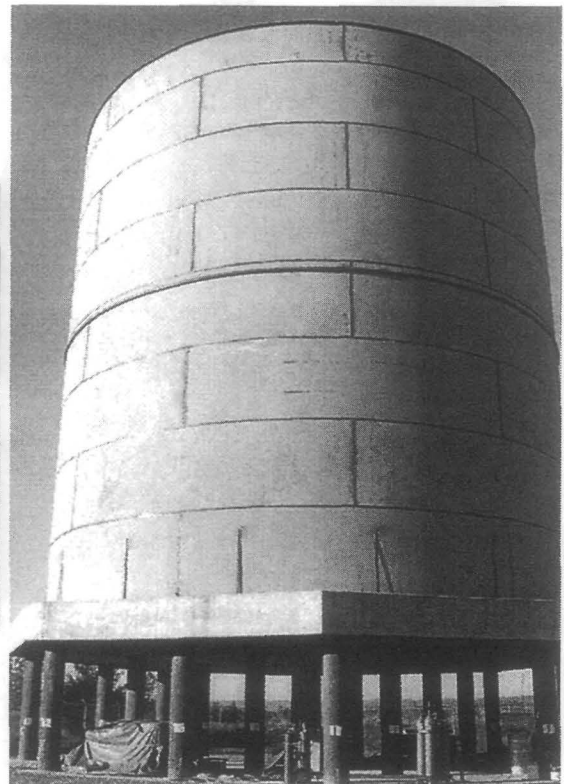


Figure 54-4 Tank Elevation Looking Northwest



# LN<sub>2</sub> BULK STORAGE TANK TEST MEASUREMENTS

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## COLUMN SHORTENING

5 and 3 Lb. lead weights were hung on monel line from the bottom of the deck.

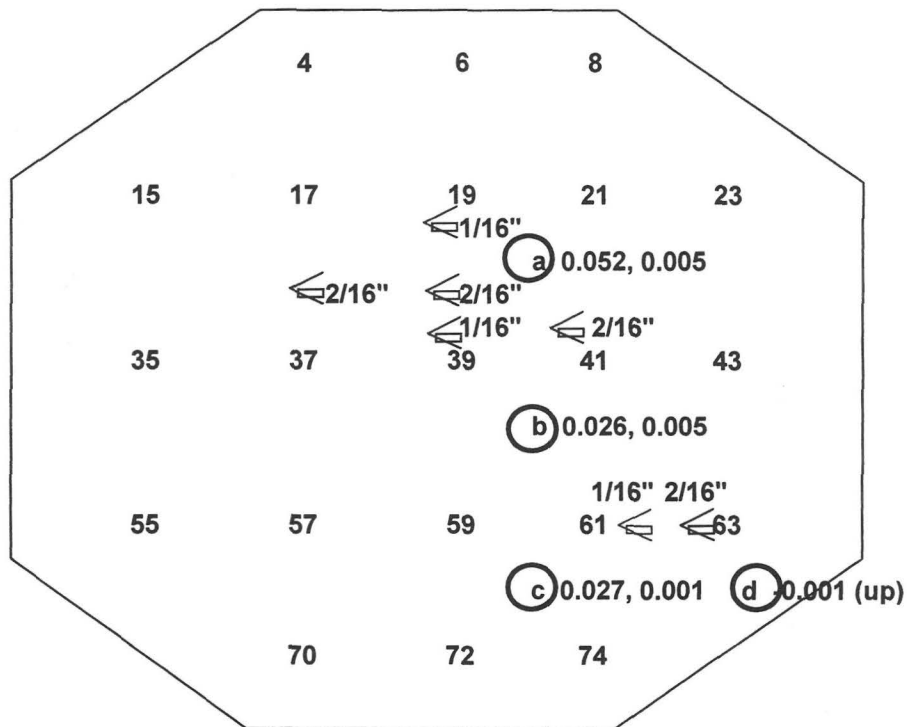
monel 0.000778 /100° F /100 ft coefficient of expansion  
Temperatures varied from 43° F on Sunday to 57° F on Monday and

row 100

results in about a  $132'' / 1200 * 14° F * 0.000778 \text{ in/in} = 0.0012''$  of lengthening.  
Temperature lengthening is a nominal issue in these measurements.

- 3 mechanical dial gages during the water loading test.  
The electronic dial gage was used only on the day of the air overpressure test.

- ◁ laser tape measure from pile cap to deck underside



row 110

row 120

row 130

Figure 54-5 Dial Gage Telltales and Laser Measurements

Note: The ◁ symbol indicates a < painted on the concrete and the laser's position on that <. Laser measurements were made with a Hilti PD25.

### COLUMN SHORTENING -- Continued

For reference: 1/16" = 0.0625"

0.007" calculated deflection down

shortening say 0.026 - 0.007 - 0.0035 = **0.016"**

0.0035" estimated deflection up

Estimate (measured) column load(s) from telltale information  
Convert column reinforcing to an equivalent area of concrete and add to the gross area of the column.

$A_s$	52.96 in <sup>2</sup>	
$A_{concrete}$	399 in <sup>2</sup>	
$n$	8.04 unitless	
$A_{effective}$	825 in <sup>2</sup>	$8.04 * 52.96 + 399$

For stress in the column(s)

$E \epsilon = \sigma$		
$E$	3605 k/in <sup>2</sup>	
$\epsilon$	1.159E-04 in/in	0.016 in / 138 in
$\sigma$	0.418 k/in <sup>2</sup>	$3605 \text{ k/in}^2 * 1.159E-04$
$P_{measured}$	<b>345 k</b>	$0.418 \text{ k/in}^2 * 825 \text{ in}^2$

The average design values for columns 39 to 139 and 41 to 141 is **470k**.

Tank	741 k	empty weight
Deck	1839 k	concrete deck weight
$P_{DL \text{ Avg}}$	123 k /column	$(741 + 1839) / 21 \text{ columns}$
$P_{calculated}$	<b>347 k</b>	$470 - 123$

The  $P_{measured}$  value of **345 k** compares favorably with  $P_{calculated}$  water test weight of **345 k**.

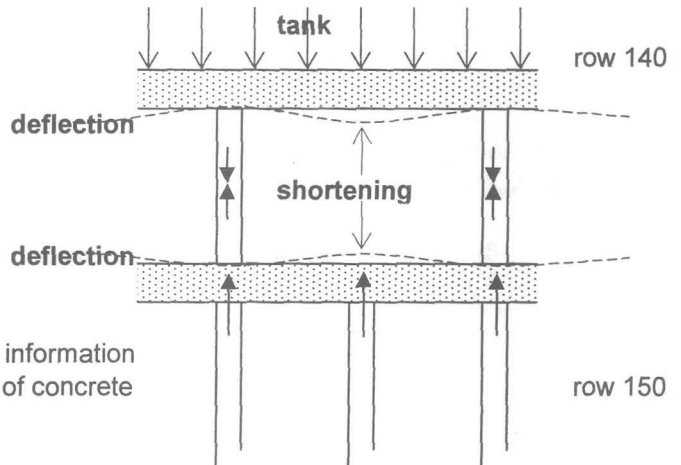


Figure 54-6 Foundation Partial Elevation

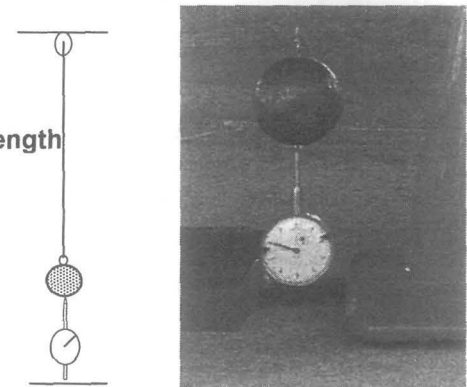


Figure 54-7. Mechanical Dial Gage Telltale with 5-pound Lead Weight

$E$	concrete modulus of elasticity
$\epsilon$	strain
	row 170
$\sigma$	stress
$P$	force



# LN<sub>2</sub> BULK STORAGE TANK TEST MEASUREMENTS

Christy  
November 5, 2003

54 Tank Test Measurements.xls

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### COLUMN SHORTENING -- Continued

For deflections during the 3.75 psi overpressure

Calculate the change in column force using the change in the distance between the bottom of the deck and the top of the pile cap.

$\delta$	0.005 in	measured during the test
$\epsilon$	3.62E-05 in/in	0.005/138
$\sigma$	0.130616 k/in <sup>2</sup>	3.62E-05 * 3605

$P_{\text{measured}}$	<b>108 k</b>	$0.130616 \text{ k/in}^2 * 825 \text{ in}^2$
-----------------------	--------------	--

$P_{\text{calculated}}$	<b>106 k</b>	$0.00375 \text{ k/in}^2 * 144 \text{ in}^2/\text{ft}^2 * 14\text{ft} * 14\text{ft}$
-------------------------	--------------	---

The  $P_{\text{measured}}$  of **108 k** compares favorably to the  $P_{\text{calculated}}$  of **106 k**.



**54-8 Electronic Dial Gage Telltale with 3-Pound Lead Weight**

Note that electronic dial gage d indicates **-0.001"** (up). This amounts to about **22k** reduction in force in column force because the shell and anchor bolts of the inner tank are pulling up against the deck.

The mechanical dial gage c indicates **+0.001"** (down) is also in keeping with the inner tank shell uplift.

row 200

The foundation appears to have performed as designed.

Sincerely,

Craig T. Christy, P.E.

row 210



**PART 5:**

**REFERENCE  
MATERIALS**





# LRFD COMPARED TO WORKING STRENGTH LOADS INTRODUCTION

# 55 LRFD

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15:41  
12/20/05

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## ALLOWABLE STRESS DESIGN versus LOAD RESISTANCE FACTOR DESIGN

Following these comments are examples for a liquid nitrogen tank in a zone 4 environment. The examples compare LRFD factoring on the left side of the page versus working strength design on the right side of the page.

For trapezoidal loading where all of the soil below the footing is loaded in compression, the ratio of LRFD to working strength is 1.41. However, where working strength calculations show +0.015 ksf, LRFD calculations show -0.053 ksf which should not be ignored.

In the example on the next page, the footing size has been decreased to take advantage of the soil's load bearing capacity and a triangular loading where some of the footing does not bear on the soil. The working strength triangular calculations indicate 1.860 ksf of bearing during the event while the LRFD calculations show 5.150 ksf in ultimate bearing which is unrealistic.

row 20

When load factoring first appeared about 25 years ago, it was declared as "the way" to save on concrete reinforcing. At the time the codes were re-written to take "advantage" of load factoring, reinforcing for shear was substantially increased because of the many failures that had occurred.

In truth, the savings in tension reinforcing was due to the Whitney's stress block which reflected the way in which real-life concrete behaves. The savings are not due to load factoring.

row 30

There are actually two issues in the debate over LRFD:

1. Factoring loads for a better probabilistic estimate of load risk
2. Better methods of calculating beams, columns, footings, and etcetera.

The same issues apply to LRFD steel design. In Section 2 of the AMERICAN INSTITUTE of STEEL CONSTRUCTION's ASD manual, "Allowable Moments in Beams" graphs show an arbitrary drop from 24 ksi to 21.6 ksi in most beams which often effects a beam over a substantial portion of its length. This drop is equal to a 9% reduction in stress and is simply an issue of how beams are modeled in our calculations. Smooth this drop into a curve and you may possibly save on steel just as the Whitney's stress block saves tension reinforcing in concrete.

row 40

LRFD may reflect a more accurate estimate of load risk but it is an estimate that does not vary much from the straight forward estimates. In building missiles, 5% counts for a lot but, in civil and structural engineering, the safety factor for beams and columns starts at about 1.9 and the safety factor for connections is usually taken as 4 or 5.

LRFD adds complication to an uncertain world. It takes away your ability to estimate a design in your head which is important both in the field and when using a computer. And, as can be seen in the following examples, it leads us to bogus answers in our more complicated calculations.

row 50

We have known for decades that a residential bedroom floor should be designed for a 40 psf live load and a live load deflection not to exceed L/360. Usually, for quality construction, we increase the joist size to the next size up for greater comfort. When designing cold formed steel joists, limit live load deflection to L/500 for comfort -- all of the load factoring in the world will not make up for an irate owner who has a bouncy floor.

row 60



# LRFD COMPARED TO WORKING STRENGTH LOADS INTRODUCTION

**55**  
**LRFD**  
 Christy  
 14:22  
 09/24/07

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**ALLOWABLE STRESS DESIGN versus LOAD RESISTANCE FACTOR DESIGN -- Continued**

The old ASD loads have the required factors built-in -- in wood design, be careful to check deflection on longer spans.

When you use LRFD, check deflection, drift, and vibration for all materials.

The following examples yield these results:

ITEM	LRFD Factor / unfactored loads
floors	1.59
foundation DL + LL	1.44
Foundation trapezoidal	4.41 $e_x$ calculated LRFD <span style="float: right;">row 70</span>
	1.29 $e_x$ calculated unfactored loads
Foundation triangular	3.18 $e_x$ calculated LRFD
	1.27 $e_x$ calculated unfactored loads
Average factor	1.40

row 90

row 100



# LRFD COMPARED TO WORKING STRENGTH LOADS

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 12/20/05

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## LOAD FACTOR RESISTANCE DESIGN

The first factoring example compares four common load configurations for residential and storage floors. In using an average factor of 1.59, the result was from 5% heavier to 5% lighter than what the LRFD factoring would yield.

factor	1.59	generic factor	ultimate load / working load			
	lb/ft <sup>2</sup>		factor	load	ratio	
LL	40 residence	1.7	68.0			row 20
DL	15 wood framing	1.4	21.0	1.62	-1.77 %	
LL	125 storage	1.7	212.5			
DL	15 wood framing	1.4	21.0	1.67	-4.90 %	5% unconservative
LL	40 residence	1.7	68.0			
DL	75 concrete	1.4	105.0	1.50	5.39 %	5% conservative
LL	125 storage	1.7	212.5			
DL	75 concrete	1.4	105.0	1.59	0.16 %	row 30
		average ratio	1.59			

Note:  
 ft^4 is the same as ft<sup>4</sup>. Using the carrot ^ is a notation shortcut and reflects the way an exponent is written in spreadsheets.

row 40

row 50

row 60

**FOUNDATION IN OVERTURNING -- TRAPEZOIDAL LOADING**

The following examples are used to demonstrate the design of footings to resist seismic loads -- these footings are considered to be eccentric footings.

The issue is: can we mix LRFD with eccentricities derived from the working loads to get reasonable ultimate moment values with which to design concrete? Using factored loads to derive the eccentricity of a footing can yield very unreasonable results.

Length	29 ft	length along the X axis
Width	29 ft	width along the Y axis
Ixx	58940 ft^4	moment of inertia of footing area about YY
Area	841 ft^2	area of footing
Depth	1.5 ft	depth (thickness) of footing
DL_ftg	189.2 k	weight of footing at 0.150 k/ft^2
Height	33.17 ft	height of tank
DL_v	33 k	tare (empty) weight of tank
LL_c	39.81 k	contents of tank
DL_surr	222 k	vessel + footing
LL_sum	33 k	contents
DL_M	3222 k-ft	dead load -- max DL righting moment
LL_M	479 k-ft	live load -- max LL righting moment used in seismic

Mot\_W 106.79 k-ft wind overturning to bottom of slab for ultimate strength

Zone	0.4	seismic zone factor
soil	0.44	stiff soil
Na	1.5	near source factor
R	2.2	structure response factor
I	1.25	importance factor structure at grade -- oxygen

Seismic 0.938 g ult Factor used in ultimate strength seismic calculations equation (30-5)

Mot\_E 1643 k-ft ult seismic overturning to bottom of slab for ultimate strength  
 $(\text{Depth} / 2 * \text{DL\_ftg} + \text{Height} * 2/3 * (\text{DL\_v} + \text{LL\_c})) * \text{Seismic}$   
 $1.50\text{ft} / 2 * 189.2\text{k} + 33.17\text{ft} * 2/3 * (33.00\text{k} + 39.81\text{k}) * 0.938 \text{ g}$

M\_ult 5325 k-ft ult 1.4 D + 1.7 L righting moment  
 $1.4 * 3,222 + 1.7 * 479$  M\_work 3701 k-ft DL + LL righting moment  
 1.44 ratio q ultimate / q working

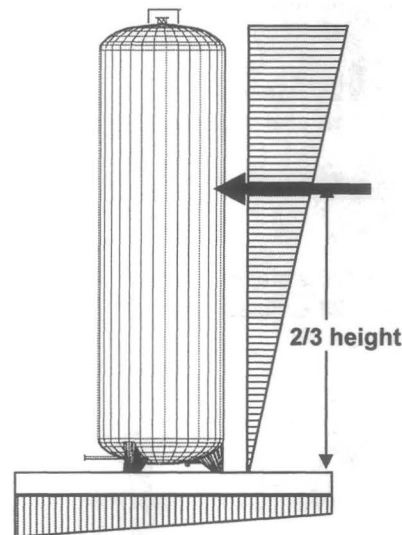


Figure 56-1 Elevation of tank and foundation in overturning.

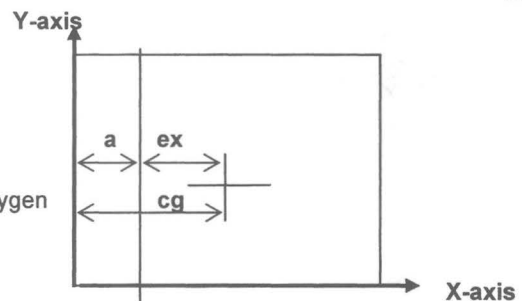


Figure 56-2 Plan view of foundation.

row 70

row 80

row 90

row 110



# LRFD COMPARED TO WORKING STRENGTH LOADS

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**FOUNDATION IN OVERTURNING -- TRAPEZOIDAL LOADING -- Continued**

Ultimate load at loaded edge  
 $1.1 * (1.2D + 1.0E + (f_1 LL_ + f_2 S))$   
 '97UBC 1612.2.1 12-5a

Mot\_E 1808 k-ft ult 1.1 \* 1,643  
 MrtD+L 4780 k-ft ult 1.1 \* (1.2 \* 3,222 + 479)

a 9.02 ft  $(Mrt\_D\_L - Mot\_E) / (1.1 * 1.2 * DL\_sum + 1.1 * LL\_sum)$   
 $(4,780 - 1,808) / (1.1 * 1.2 * 222 + 1.1 * 33)$  row 120

cg\_x 14.50 ft 29.00 /2 from loaded edge along x  
 ex 5.48 ft ult (14.50 - 9.02) CG - a LRFD loads

P DL&LL /A	+/-	P * ex * cx /lxx	+/-	P * ey* cy /lyy	=	sum	
				0.000	=	0.392 + 0.445 + 0.000	
		$1.1 * (1.2 * 222 + 33) * 5.48 * 14.50 /58,940$					
		$1.1 * (1.2 * 222 + 33) /841$					
0.392	+	0.445	+	0.000	=	0.837 ksf ult	row 130
0.392	-	-0.445	+	0.000	=	-0.053 ksf ult	
						negative loading not possible	

**ALTERNATIVELY -- Use ex calculated with unfactored DL + LL**

Mot\_E 1174 k-ft M\_ot ult / 1.4  
 MrtD&L 3701 k-ft Mrt\_D&L rotation about XX

a 9.90 ft  $(Mrt\_D\_L - Mot\_E) / (DL\_sum + LL\_sum)$   
 $(3,701 - 1,174) / (222 + 33)$  row 140

cg\_x 14.50 ft from loaded edge along x  
 ex 4.60 ft CG - a

P DL&LL /A	+/-	P * ex * cx /lxx	+/-	P * ey* cy /lyy	=	sum	
				0.000	=	0.392 + 0.373 + 0.000	
		$1.1 * (1.2 * 222 + 33) * 4.60 * 14.50 /58,940$					
		$1.1 * (1.2 * 222 + 33) /841$					
0.392	+	0.373	+	0.000	=	0.765 ksf ult	row 150
0.392	-	-0.373	+	0.000	=	0.019 ksf ult	

row 160



# LRFD COMPARED TO WORKING STRENGTH LOADS

## 56 LRFD

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A B C D E F G H I J K L M N  
**FOUNDATION IN OVERTURNING -- TRAPEZOIDAL LOADING -- Continued**

**Working load at loaded edge**

Mot\_E 1174 k-ft M\_ot ult / 1.4  
MrtD&L 3701 k-ft Mrt\_D&L rotation about XX  
  
a 9.90 ft (Mrt\_D\_L - Mot\_E) / (DL\_sum + LL\_sum)  
(3,701 - 1,174) / (222 + 33)

cg\_x 14.50 ft from loaded edge along x  
ex 4.60 ft CG - a

row 170

P DL&LL /A	+/-	P * ex * cx /lxx	+/-	P * ey * cy /lyy	=	sum
				0.000	=	0.303 + 0.289 + 0.000
		(222 + 33) * 4.60 * 14.50 /58,940				
(222 + 33) /841						
0.303	+	0.289	+	0.000	=	0.592 ksf asd
0.303	-	-0.289	+	0.000	=	0.015 ksf asd

row 180

0.837 /0.592 = 1.41 ratio q ultimate / q working  
0.765 /0.592 = 1.29 ratio q ultimate / q working

row 190

row 200

row 210



# LRFD COMPARED TO WORKING STRENGTH LOADS

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## FOUNDATION IN OVERTURNING -- TRIANGULAR SOIL LOADING

Length.	20.00 ft	length along the X axis
Width.	20.00 ft	width along the Y axis
lxx.	13333 ft <sup>4</sup>	moment of inertia of footing area about YY
Area.	400 ft <sup>2</sup>	area of footing
Depth.	1.5 ft	depth (thickness) of footing
DL_ftg.	90.0 k	weight of footing at 0.150 k/ft <sup>2</sup>
Height.	33.17 ft	height of tank
DL_v.	33 k	tare (empty) weight of tank
LL_c.	39.81 k	contents of tank
DL_surr	123 k	vessel + footing
LL_sum	33 k	contents
DL_M.	1230 k-ft	dead load -- max DL righting moment
LL_M.	330 k-ft	live load -- max LL righting moment used in seismic

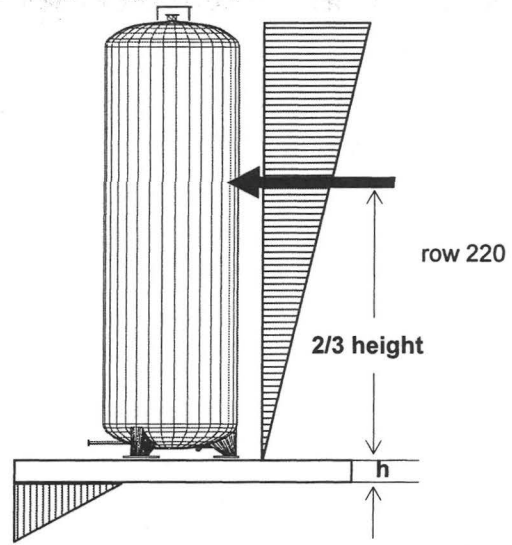


Figure 56-3 Elevation of tank and foundation in overturning.

Mot\_W. 106.79 k-ft wind overturning to bottom of slab for ultimate strength

Seismic Zone	0.4	zone factor
soil	0.44	stiff soil
Na	1.50	near source factor
R	2.2	structure response factor
I	1.25	importance factor structure at grade -- oxygen

Seismic 0.938 g ult Factor used in ultimate strength seismic calculations equation (30-5)

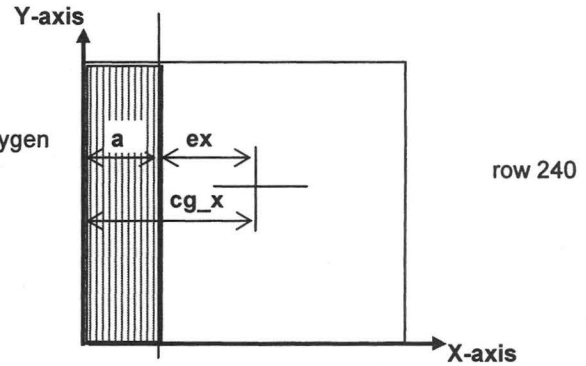


Figure 56-4 Plan view of foundation.

Mot\_E 1574 k-ft seismic overturning to bottom of slab for ultimate strength  
 $(\text{Depth} / 2 * \text{DL\_ftg} + \text{Height} * 2/3 * (\text{DL\_v} + \text{LL\_c})) * \text{Seismic}$   
 $1.50\text{ft} / 2 * 90.0\text{k} + 33.17\text{ft} * 2/3 * (33.00\text{k} + 39.81\text{k}) * 0.938\text{g}$

row 260



# LRFD COMPARED TO WORKING STRENGTH LOADS

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**FOUNDATION IN OVERTURNING -- TRIANGULAR SOIL LOADING -- Continued**

$$q = 2 * P / (3 * \text{width} * (B \text{ cross section of footing} / 2 - e))$$

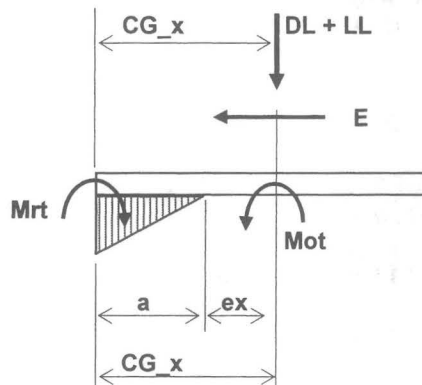


Figure 56-5 Elevation view of triangular soil loading.

**Ultimate Loads**

1.1 \* (1.2D + 1.0E + (f<sub>1</sub> LL<sub>1</sub> + f<sub>2</sub> S))  
 '97UBC 1612.2.1 12-5a  
 Mot\_E 1731 k-ft<sub>ult</sub> 1.1 \* 1,643 k-ft<sub>ult</sub>  
 Mrt 1987 k-ft<sub>ult</sub> 1.1 \* (1.2 \* 1,230 + 330)  
 DL + LL 199 k<sub>ult</sub> 1.1 \* (1.2 \* 123 + 33) k<sub>ult</sub>  
 ex 8.71 ft<sub>ult</sub> 20.00 / 2 - (1,987 - 1,731) / 199

q <sub>x ult</sub>	5.145	ksf <sub>ult</sub>
--------------------	-------	--------------------

$$2 * 198.66 / (3 * 20.00 * (20.00 / 2 - 8.71))$$

a 3.86 ft  
 Safety factor in seismic overturning = 1.39 > 1.00 required

**Working load at loaded edge**

row 280  
 q about yy = 3 \* EDGE\_Y \* (EDGE\_X / 2 - e) where  
 e = CG\_x - (M<sub>rt</sub> - M<sub>ot</sub>) / SUM(LL + DL)  
 Mot\_E 1124 k-ft M<sub>ot ult</sub> / 1.4  
 Mrt 1560 k-ft  
 DL + LL 156 k  
 ex 7.20 ft 20.00 / 2 - (1,560 - 1,124) / 156

q <sub>x asd</sub>	1.860	ksf <sub>asd</sub>
--------------------	-------	--------------------

$$2 * 156.00 / (3 * 20.00 * (20.00 / 2 - 7.20))$$

row 290

a 8.39 ft

$$5.145 / 1.860 = 2.77 \text{ ratio } q \text{ ultimate} / q \text{ working}$$

**ALTERNATIVELY -- Use ex calculated with unfactored DL + LL**

DL + LL 199 k<sub>ult</sub> row 300  
 ex 7.20 ft 20.00 / 2 - (1,560 - 1,124) / 156  

q <sub>x</sub>	2.369	ksf <sub>ult</sub>
----------------	-------	--------------------

$$2 * 198.66 / (3 * 20.00 * (20.00 / 2 - 7.20))$$

a 8.39 ft  

$$2.369 / 1.860 = 1.27 \text{ ratio } q \text{ ultimate} / q \text{ working}$$

row 310



# LRFD COMPARED TO WORKING STRENGTH LOADS

**56** Christy  
18:39  
**LRFD** 12/20/05

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56 LRFD Compared.xls

A B C D E F G H I J K L M N  
**LRFD FACTORING '97 UBC**

**1612.2.1 Basic load combinations with exception 2 -- multiply loads by 1.1 for loads including seismic forces**

D	0.0	dead load -- max DL righting moment	
L	0	live load or earth pressure -- max LL righting moment used in seismic	
L <sub>r</sub>	0	roof live load	
S	0	snow	
W	0	wind	
E	70.0	seismic -- when derived from the UBC, use E/1.4 for working (service level) values	
T	0	differential settlement	
H	0	earth pressure	row 320
F	0	fluid pressure, load factor = 1.4	
max	70.0		
f 1	1.0	1.0 floors in public assembly, LL >100 psf, garage 0.5 of other live loads	
f 2	0.2	0.7 roofs that can't shed snow, 0.2 other	

**97 UBC 1612.2.1**

E <sub>1</sub>	1.1	multiple use 1.1 for concrete and masonry subjected to seismic forces	
12-1	0	1.1 * (1.4 D + 1.3F)	1.54D + 1.43F
12-2	0	1.1 * (1.2D + 1.6*L + 0.5* (L or S))	
12-3	0	1.1 * (1.2D + 1.6(L <sub>r</sub> or S) + (f <sub>1</sub> L or 0.8W))	row 330
12-4	0	1.1 * (1.2D + 1.3W + f <sub>1</sub> L + 0.5(L <sub>r</sub> or S))	
12-5a	77	1.1 * (1.2D + 1.0E + (f <sub>1</sub> LL <sub>-</sub> + f <sub>2</sub> S) + 1.3F)	1.32 D + 1.1 E + 1.1 (f <sub>1</sub> L or 0.88 W) + 1.43F
12-6a	77	1.1 * (0.9D + 1.0E or 1.3W)	0.99 D + 1.1 E or 1.43 W
12-6b	-77	1.1 * (0.9D - 1.0E or 1.3W)	0.99 D - 1.1 E or 1.43 W
max	77	ratio 1.100	

row 340

**97 UBC 1909.2 for Concrete**

Where E is included in the design, use UBC 1612.2.1 per UBC 1909.2.3

9-1	0	1.4D + 1.7L + 1.4F	
9-2a	0	0.75 (1.4D + 1.7L + 1.7W)	1.05 D + 1.275 L + 1.275 W
9-3a	0	0.9D + 1.3W	
9-4a	0	1.4D + 1.7L + 1.7H	
9-4b	0	0.9D + 0L + 1.7H	row 350
9-5	0	0.75 (1.4D + 1.4T + 1.7L + 1.4F)	1.05 D + 1.05 L + 1.275 L + 1.05 F
9-6	0	1.4 (D + T)	1.4 D + 1.4 T
max	0	ratio 0.000	

row 360



# LRFD COMPARED TO WORKING STRENGTH LOADS

**56**  
**LRFD**  
Christy  
18:39  
12/20/05

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56 LRFD Compared.xls

A B C D E F G H I J K L M N  
LRFD FACTORING '99 ACI

99 ACI Values		Where E = UBC seismic value / 1.4
E UBC	50	UBC E / 1.4
9-1a	0	1.4 D + 1.7 L
9-1b	0	1.4 D + 1.7 L + 1.4 F
9-2a	0	1.2 D + 1.6 L + 1.7 W
9-2b	70	1.05 D + 1.28 L + 1.4 E
9-3a	72	0.9 D + 1.43 E
9-3b	0	0.9 D + 1.7 H
9-4a	0	1.4 D + 1.7 L + 1.7 H
9-4b	0	0.9 D + 1.7 H
9-5	0	1.05 D + 1.4 T + 1.275 L
9-6	0	1.4 D + 1.4 T
max	72	ratio 1.021

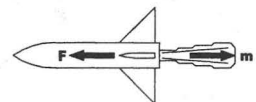
row 370

row 380

row 390

row 400

row 410



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A	B	C	D	E	F	G	H
<b>INTRODUCTION</b>							

This is part of a demonstration for students at Robert Gray Middle School, Portland, Oregon.

x	distance	feet					quantity
t	time	seconds					quantity
v	velocity (speed)	$\frac{dx}{dt}$	$\frac{\text{change in distance}}{\text{change in time}}$	$\frac{\text{feet}}{\text{second}}$			steady state
a	acceleration	$\frac{dv}{dt}$	$\frac{\text{change in velocity}}{\text{change in time}}$	$\frac{\text{feet}}{\text{second} / \text{second}}$			change in state
m	mass		$\frac{\text{weight}}{\text{acceleration of gravity}}$	$\frac{\text{pounds} - \text{second}^2}{\text{feet}}$			quantity
F = ma	force = mass times acceleration				pounds		quantity

In other words, every action has an opposite and equal reaction.

This concept was discovered by Isaac Newton who, as the story goes, was sitting under an apple tree watching the apples fall. This story is fairly close to the truth in that Newton had been attending university in London when a severe plague occurred and all of the students were sent home. Newton had time on his hands and was able to develop  $F = ma$  and the beginnings of calculus.

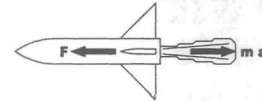
$F = ma$  is Newton's way of describing the effect of gravity. In Imperial units gravity is described as:

$$32.17 \text{ feet / second}^2$$

A few relationships:

$$x = vt = at^2 / 2 = v^2 / 2a$$

$$v = at = (2ax)^{1/2}$$



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A B C D E F G H  
**JUMPING**

Not considering the effects of air friction, if you jump from a 10' height, your speed when you hit the ground will be:

$$v = (2 \times 32.17 \text{ feet/second}^2 \times 10 \text{ feet})^{1/2}$$

$$= 25.37 \text{ feet/second} \qquad 17.3 \text{ miles / hour}$$

The time it takes to make this trip is:

$$t = \frac{25.37 \text{ feet/second}}{32.17 \text{ feet/second}^2} = 0.788 \text{ second}$$

Say that your footprints in the ground are 3" deep. You weigh 100 pounds. The force that you strike the ground with is:

$$v^2 = 2ax$$

$$a = v^2 / 2x$$

$$x = \frac{3 \text{ inches}}{12 \text{ inches / foot}} = 0.25 \text{ feet}$$

$$a = \frac{(25.37 \text{ feet/second})^2}{2 \times 0.25 \text{ feet}} = 1286.8 \text{ feet/second}^2$$

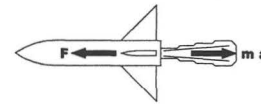
$$m = \frac{100 \text{ pounds}}{32.17 \text{ feet/second}^2} = 3.11 \frac{\text{pound-second}^2}{\text{feet}}$$

$$F = \frac{3.11 \text{ pound-second}^2}{\text{feet}} \times \frac{1286.8 \text{ feet}}{\text{second}^2}$$

$$= 4000 \text{ pounds}$$

This is what your feet and ankles see when you hit the ground and may cause injury.

Concrete paving has very little give. Jumping 10' onto pavement will cause injury.



A B C D E F G H

**GRAVITY and THRUST**

Gravity is acceleration. When you hold a ball in your hand, the force to keep that ball up is the mass of the ball times gravity.

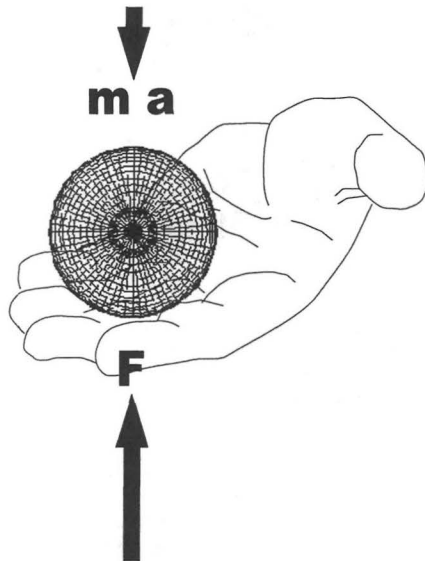


Figure 57-1 Gravity versus the force of holding an object.

Another version of  $F = ma$  is the rocket engine. Fuel inside the rocket is relatively at rest -- fuel inside the rocket moves at the same speed as the rocket. When the fuel is burned, it expands and is forced away from the rocket. The change in speed of the fuel molecules from 0 to moving away from the rocket is acceleration. The mass of the fuel times the acceleration away from the rocket equals force.

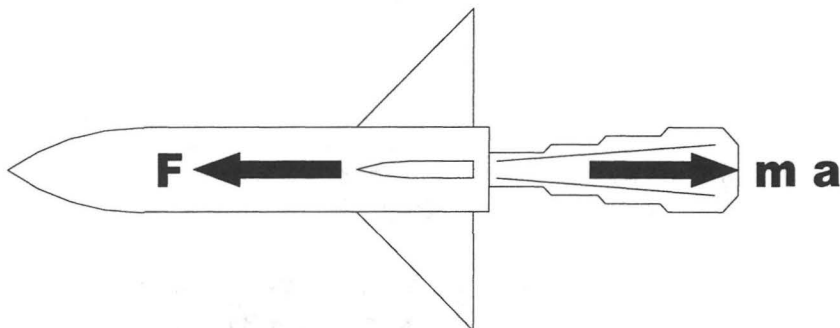
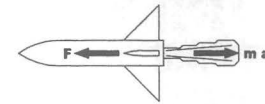


Figure 57-2 The thrust of expanding gasses accelerates the mass of the rocket.

The power of rocket and jet engines is measured in **Lbs. thrust** which is the same as saying **Lbs. force**.

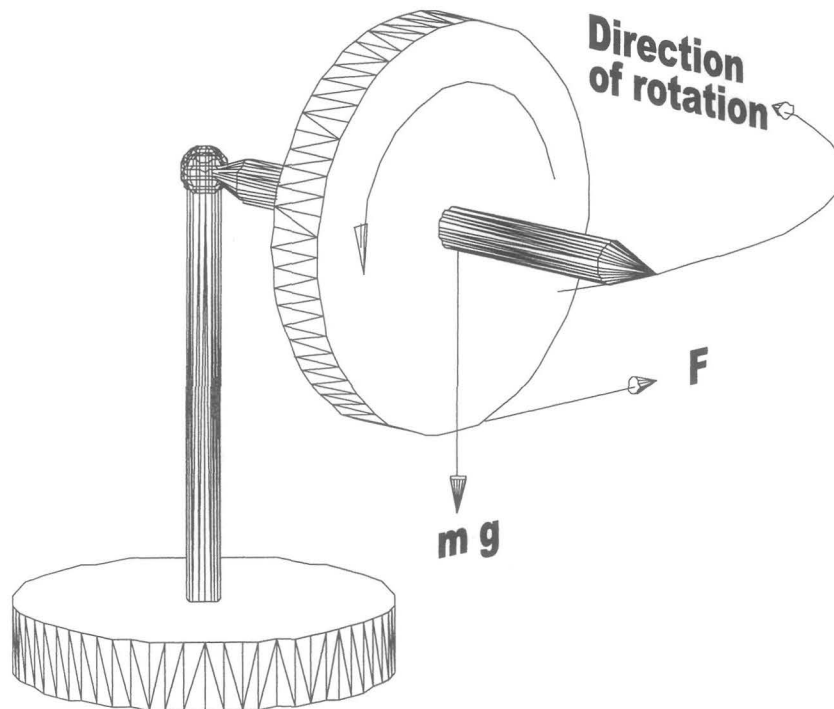


A B C D E F G H

**GYROSCOPIC PRECESSION**

Gyroscopes serve as another example of  $F = ma$ . The "ma" is the weight of the spinning wheel and the resulting force "F" rotates the gyroscope as shown in the diagram.

Try this with a bicycle wheel. This effect helps the bike rider balance the bicycle and helps in the turn. With propeller driven aircraft, gyroscopic precession is important in the handling characteristics of the plane.



**Figure 57-3 Gyroscopic precession.**

The airplane propeller turns in clockwise direction as you look at it from inside the plane. When the airplane turns to the right, the nose lifts up. When the plane turns to the left, the nose dips down.

This effect is especially important for powerful tail-dragger airplanes during takeoff. As the plane rolls down the runway, the increasing air speed allows the pilot to lift the tail so that the wings cut through the air at the right angle for take off. If the pilot uses too much power during this maneuver, the plane will veer to the left and off of the runway. This can be dangerous. It was particularly a problem for the P51 Mustang which earned it the name "Flying Coffin."

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58 Quadratic and Cubic Equations.xls

A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>Y = mX + b</b>													
y_1	= m	*	x_1	+ b	x	y							
					5	2							
					2	3							
y_2	= m	*	x_2	+ b	3	2.6666667							
m	-0.333		$\frac{y_1 - y_2}{x_1 - x_2}$										
b	3.667		$y_1 - m * x_1$										
x	3												
y	2.667		$mX + b$										
<b>Condensed solution</b>													
c	2.667												
<b>Solution to be copied</b>													
x_1	2.5												
y_1	2												
x_2	5												
y_2	6												
x	3												
y	2.800												
<b>Simplified solution to be copied</b>													
	line 1		line 2		X	Y							
x_1	0		3.5		0	3.689							
y_1	3.689		0		10	7.02							
x_2	10		6.5										
y_2	7.02		6.5										
m	0.3331		1										
b	3.689		-3.5		3.5	0							
formal					10	6.5							
x	10.78		10.78		10.780	7.280							
	7.28		7.28										
<b>Condensed</b>													
x	4		10.78										
y	5.02		7.28										

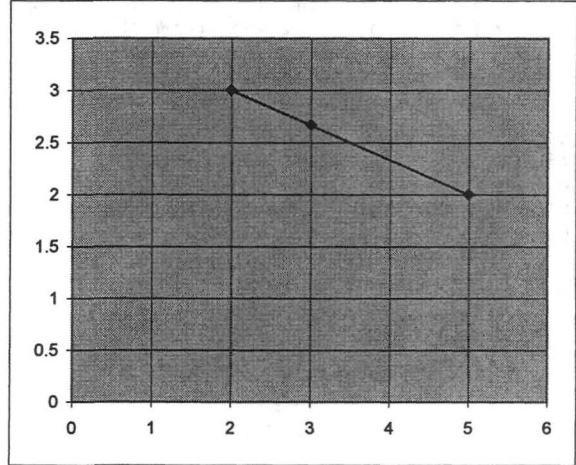


Figure 58-1 A simple straight line.

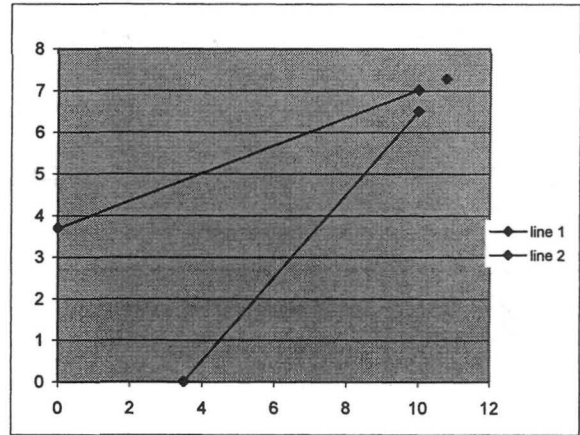


Figure 58-2 The intersection of two straight lines using  $y = mx + b$ .

Solve for the intersection of two lines

Algebra	line 1	line 2	
y	1	1	
mx	0.333	-mx	1.000
b	3.689	-b	-3.500

Matrix  
 $y = mx + b$   
 $y - mx = b$

	y	-mx	= b
line 1	1.000	-0.333	3.689
line 2	1.000	-1.000	-3.500

subtract		
	0	
-0.667	x solution	10.780
7.189	y solution	7.280

minverse			mmult intersection
1.499	-0.499		7.280 = y
1.499	-1.499		10.780 = x

row 60

row 70

row 80

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58 Quadratic and Cubic Equations.xls

### QUADRATIC EQUATION

The quadratic equation shown below is a straight forward example of spread sheet math that makes a somewhat difficult calculation more accurate. The **ERR** flag indicates imaginary (i) root(s).

$ax^2$	$bx$	$c$
2	-12	9

$$[-b + (b^2 - 4ac)^{0.5}] / 2a = 0$$

$x_1$	5.12 first root
$x_2$	0.88 second root

Assign range names of A, B, and C to the input values to make the equations more readable.

For a straight line  $y = mx + b$

m	1
b	100 this is the y intercept at $x = 0$

Note: as a convention, capitalized X and Y are data plots and lower case x and y are distances from the plot to a fitted line or curve. #NUM! is not plotted, text is plotted as 0.

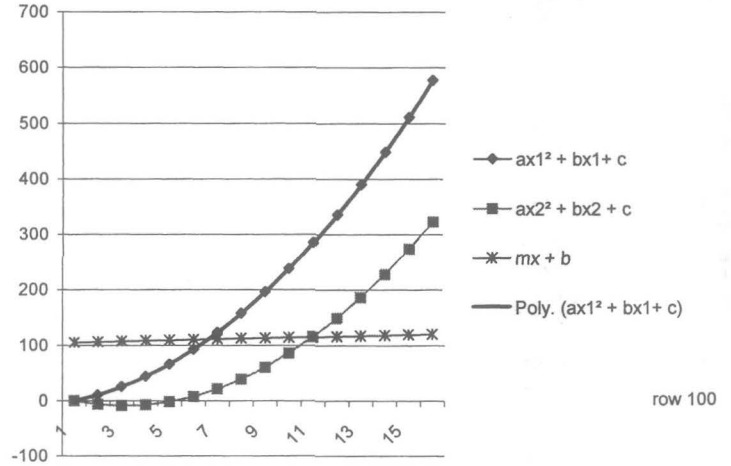


Figure 58-3 Solutions to the quadratic equation.

Test	$x_1$	5.12132034	6.1213203	7.1213203	8.1213203	9.1213203	10.12132	11.12132	12.1213	13.1213	14.12	15.12
a	$x_2$	0.87867966	1.8786797	2.8786797	3.8786797	4.8786797	5.8786797	6.8786797	7.87868	8.87868	9.88	10.88
b	$mx+b$	105.12132	106.12132	107.12132	108.12132	109.12132	110.12132	111.12132	112.121	113.121	114.12	115.121
c	$ax_1^2 + bx_1 + c$	0	10.485281	24.970563	43.455844	65.941125	92.426407	122.91169	157.397	195.882	238.37	284.853
d	$ax_2^2 + bx_2 + c$	0	-6.485281	-8.970563	-7.455844	-1.941125	7.5735931	21.088312	38.603	60.1177	85.632	115.147

### Linest Fit to the Quadratic Equation

x increment	0.6				
X	$aX^2$	bX	c	Y	Y linest
0.32	0.2	-3.9	9	5.4	5.4
0.92	1.7	-11.1	9	-0.4	-0.4
1.52	4.6	-18.3	9	-4.6	-4.6
2.12	9.0	-25.5	9	-7.5	-7.5
2.72	14.8	-32.7	9	-8.8	-8.8
3.32	22.1	-39.9	9	-8.8	-8.8
3.92	30.8	-47.1	9	-7.3	-7.3
4.52	40.9	-54.3	9	-4.4	-4.4
5.12	52.5	-61.5	9	0.0	0.0
5.72	65.5	-68.7	9	5.8	5.8
6.32	79.9	-75.9	9	13.1	13.1
6.92	95.8	-83.1	9	21.8	21.8
7.52	113.1	-90.3	9	31.9	31.9
8.12	131.9	-97.5	9	43.5	43.5
8.72	152.1	-104.7	9	56.5	56.5
9.32	173.8	-111.9	9	70.9	70.9
9.92	196.9	-119.1	9	86.8	86.8
10.52	221.4	-126.3	9	104.1	104.1
11.12	247.4	-133.5	9	122.9	122.9
11.72	274.8	-140.7	9	143.1	143.1
12.32	303.6	-147.9	9	164.8	164.8
12.92	333.9	-155.1	9	187.9	187.9
13.52	365.7	-162.3	9	212.4	212.4
14.12	398.8	-169.5	9	238.4	238.4
14.72	433.4	-176.7	9	265.8	265.8
15.32	469.5	-183.9	9	294.6	294.6
15.92	507.0	-191.1	9	324.9	324.9

linest	m1	m2	b	
m	1.00	1.00	9.00	#N/A
se	0.00	0	0	#N/A
$r^2$	1.0000	1.7E-14	#N/A	#N/A
F	5.024E+32	24	#N/A	#N/A
$SS_{reg}$	288499.03	6.9E-27	#N/A	#N/A

`=LINEST(E44:E70,B44:C70,TRUE,TRUE)`

describe the linest range, enter the equation, and then press [Ctrl] [Shift] [Enter] simultaneously to get this equation throughout the range

`=(=LINEST(E48:E74,B48:C74,TRUE,TRUE))`

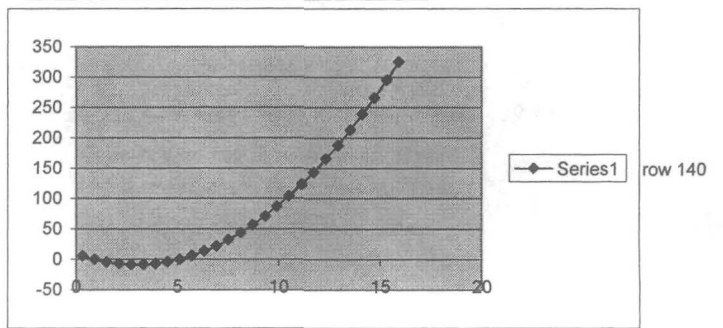


Figure 58-4 The cubic equation.

**CUBIC EQUATION ALGEBRAIC and TRIGONOMETRIC SOLUTION**

Typically, if the algebraic solution can provide an answer, the trigonometric solution will return #NUM's and vice versa.

**Algebraic Solution**

i represents imaginary numbers

	p	q	r	sum = y		
	3	2	-1	0		
$x^3$	$px^2$	$qx$	$r$	$= Y$		
0.034	0.316	0.649	-1.000	0.000	$x_1$	0.325 OK
-11.010	14.847	-4.449	-1.000	-1.612	$x_2$	-2.225 !!! i
-1.331	3.631	-2.200	-1.000	-0.901	$x_3$	-1.100 !!! i
a	-1.000	$1/3 * (3 * q - p^2)$ $1/3 * (3 * 2.0 - 3.0^2)$				
b	-1.000	$1/27 * (2 * p^3 - 9 * p * q + 27 * r)$ $1/27 * (2 * 3.0^3 - 9 * 3.0 * 2.0 + 27 * -1.0)$				
flag 1	1 logic	$b^2/4 + a^3/27 > 0$		1 real root and 2 imaginary roots		
flag 2	0 logic	$b^2/4 + a^3/27 = 0$		3 real roots of which 2 at least are equal		
flag 3	0 logic	$b^2/4 + a^3/27 < 0$		3 real and unequal roots		
[A]	0.987	$\sqrt[3]{-b/2 + \sqrt{b^2/4 + a^3/27}}$ $(-1.000/2 + \text{SQRT}(-1.000^2/4 + -1.000^3/27))^{1/3}$				
logic	1	$\sqrt[3]{-b/2 - \sqrt{b^2/4 + a^3/27}}$ $(-1.000/2 - \text{SQRT}(-1.000^2/4 + -1.000^3/27))^{1/3}$				
B_eq	0.338	$\text{ABS}(-b/2 - \text{SQRT}(b^2/4 + a^3/27))^{1/3}$ $\text{ABS}(-1.000/2 - \text{SQRT}(-1.000^2/4 + -1.000^3/27))^{1/3}$				row 180
[B]	0.338	$\text{IF}(\text{logic}, B\_eq, -B\_eq)$ $\text{IF}(1, 0.338, -0.338)$				
$X_1$	0.325	$[A] + [B] - p/3$ $0.987 + 0.338 - 3.000/3$				
$X_2$	-2.225	$-( [A] + [B] ) / 2 + ( [A] - [B] ) / 2 * -3 \sqrt[3]{-p/3}$ $-(0.987 + 0.338) / 2 + (0.987 - 0.338) / 2 * (-3^{0.5}) - 3.000 / 3$				
$X_3$	-1.100	$-( [A] + [B] ) / 2 - ( [A] - [B] ) / 2 * -3 \sqrt[3]{-p/3}$ $-(0.987 + 0.338) / 2 - (0.987 - 0.338) / 2 * (-3^{0.5}) - 3.000 / 3$				

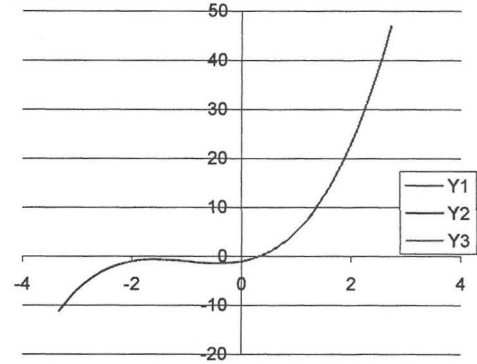


Figure 58-5 The cubic equation algebraic solution.

row 170

**Trigonometric Solution**

i represents imaginary numbers

	p	q	r	sum = y		
	3	1	-2	0		
$x^3$	$px^2$	$qx$	$r$	$= Y$		
0.236	1.146	1.236	-1.000	1.618	$x_1$	0.618 !!! i
-8.000	12.000	-4.000	-1.000	-1.000	$x_2$	-2.000 !!! i
-4.236	7.854	-3.236	-1.000	-0.618	$x_3$	-1.618 !!! i
a	-2.000	$1/3 * (3 * q - p^2)$ $1/3 * (3 * 1.0 - 3.0^2)$				
b	-1.000	$1/27 * (2 * p^3 - 9 * p * q + 27 * r)$ $1/27 * (2 * 3.0^3 - 9 * 3.0 * 1.0 + 27 * -2.0)$				
cos $\Phi$	0.919	$-b/2 / \sqrt{-a^3/27}$ $-1.000/2 / \text{SQRT}(-1.000^3/27)$				
arcs $\Phi$	0.406					
$X_1$	0.618	$2 * \sqrt{-a/3} * \cos(\Phi/3) - p/3$ $2 * (-1.000/3)^{0.5} * \text{COS}(0.406/3) - 3.000/3$				
$X_2$	-2.000	$-2 * \sqrt{-a/3} * \cos(\Phi/3 - p/3) - p/3$ $-2 * (-1.000/3)^{0.5} * \text{COS}(0.406/3 - \text{PI}/3) - 3.000/3$				
$X_3$	-1.618	$-2 * \sqrt{-a/3} * \cos(\Phi/3 + p/3 * 2/3) - p/3$ $2 * (-1.000/3)^{0.5} * \text{COS}(0.406/3 + 2 * \text{PI} * 2/3) - 3.000/3$				

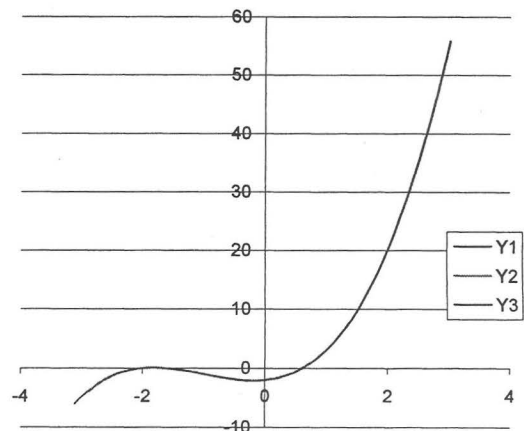
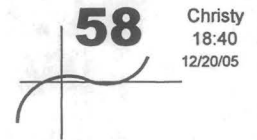


Figure 58-6 The cubic equation trigonometric solution.

row 220



# QUADRATIC and CUBIC EQUATIONS



Christy  
18:40  
12/20/05

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**CUBIC EQUATION GRAPHING**

For the equation  $x^3 + px^2 + qx + r = 0$ , the value of  $x$  crosses the  $Y$ -axis at  $y = 0$ .  
The graph  $X$ -axis is calculated around the  $y = 0$  value. Each  $X$ -axis and its corresponding  $y$  values are a separate series in the same graph.

Left click on the graph and right click on the **Source Data...** in the pop-up menu.  
Left click on the **Series** tab to view the source data for each  $xy$  series.

**Algebraic Solution**

increment 0.1

X axis	Y	X axis	Y	X axis	Y
-0.775	-1.213	-3.325	-11.238	-2.200	-1.528
-0.675	-1.290	-3.225	-9.785	-2.100	-1.231
-0.575	-1.348	-3.125	-8.466	-2.000	-1.000
-0.475	-1.380	-3.025	-7.275	-1.900	-0.829
-0.375	-1.381	-2.925	-6.205	-1.800	-0.712
-0.275	-1.344	-2.825	-5.250	-1.700	-0.643
-0.175	-1.264	-2.725	-4.405	-1.600	-0.616
-0.075	-1.134	-2.625	-3.664	-1.500	-0.625
0.025	-0.949	-2.525	-3.019	-1.400	-0.664
0.125	-0.702	-2.425	-2.467	-1.300	-0.727
0.225	-0.388	-2.325	-2.000	-1.200	-0.808
0.325	0.000	-2.225	-1.612	-1.100	-0.901 where $y = 0$
0.425	0.467	-2.125	-1.298	-1.000	-1.000
0.525	1.020	-2.025	-1.051	-0.900	-1.099
0.625	1.664	-1.925	-0.866	-0.800	-1.192
0.725	2.406	-1.825	-0.736	-0.700	-1.273
0.825	3.251	-1.725	-0.656	-0.600	-1.336
0.925	4.205	-1.625	-0.619	-0.500	-1.375
1.025	5.276	-1.525	-0.620	-0.400	-1.384
1.125	6.467	-1.425	-0.652	-0.300	-1.357
1.225	7.786	-1.325	-0.710	-0.200	-1.288
1.325	9.239	-1.225	-0.787	-0.100	-1.171
1.425	10.831	-1.125	-0.877	0.000	-1.000
1.525	12.568	-1.025	-0.975	0.100	-0.769
1.625	14.457	-0.925	-1.075	0.200	-0.472
1.725	16.504	-0.825	-1.170	0.300	-0.103
1.825	18.714	-0.725	-1.254	0.400	0.344
1.925	21.093	-0.625	-1.322	0.500	0.875
2.025	23.648	-0.525	-1.368	0.600	1.495
2.125	26.385	-0.425	-1.385	0.700	2.212
2.225	29.308	-0.325	-1.367	0.800	3.031
2.325	32.426	-0.225	-1.309	0.900	3.958
2.425	35.743	-0.125	-1.205	1.000	4.999
2.525	39.265	-0.025	-1.047	1.100	6.160
2.625	42.999	0.075	-0.832	1.200	7.447
2.725	46.950	0.175	-0.552	1.300	8.866

**Trigonometric Solution**

row 230

0.1 0.1 0.1

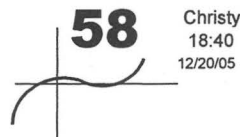
X axis	Y	X axis	Y	X axis	Y
-0.482	-1.897	-3.100	-6.061	-2.718	-2.635
-0.382	-2.000	-3.000	-5.000	-2.618	-2.000
-0.282	-2.066	-2.900	-4.059	-2.518	-1.462
-0.182	-2.089	-2.800	-3.232	-2.418	-1.015
-0.082	-2.062	-2.700	-2.513	-2.318	-0.654
0.018	-1.981	-2.600	-1.896	-2.218	-0.371
0.118	-1.839	-2.500	-1.375	-2.118	-0.161
0.218	-1.629	-2.400	-0.944	-2.018	-0.019
0.318	-1.346	-2.300	-0.597	-1.918	0.062
0.418	-0.985	-2.200	-0.328	-1.818	0.089
0.518	-0.538	-2.100	-0.131	-1.718	0.066
0.618	0.000	-2.000	0.000	-1.618	0.000
0.718	0.635	-1.900	0.071	-1.518	-0.103
0.818	1.373	-1.800	0.088	-1.418	-0.237
0.918	2.220	-1.700	0.057	-1.318	-0.396
1.018	3.182	-1.600	-0.016	-1.218	-0.574
1.118	4.266	-1.500	-0.125	-1.118	-0.766
1.218	5.476	-1.400	-0.264	-1.018	-0.964
1.318	6.819	-1.300	-0.427	-0.918	-1.163
1.418	8.302	-1.200	-0.608	-0.818	-1.358
1.518	9.930	-1.100	-0.801	-0.718	-1.542
1.618	11.708	-1.000	-1.000	-0.618	-1.708
1.718	13.644	-0.900	-1.199	-0.518	-1.852
1.818	15.743	-0.800	-1.392	-0.418	-1.967
1.918	18.011	-0.700	-1.573	-0.318	-2.047
2.018	20.454	-0.600	-1.736	-0.218	-2.086
2.118	23.078	-0.500	-1.875	-0.118	-2.078
2.218	25.889	-0.400	-1.984	-0.018	-2.017
2.318	28.893	-0.300	-2.057	0.082	-1.897
2.418	32.097	-0.200	-2.088	0.182	-1.713
2.518	35.505	-0.100	-2.071	0.282	-1.457
2.618	39.125	0.000	-2.000	0.382	-1.125
2.718	42.961	0.100	-1.869	0.482	-0.709
2.818	47.021	0.200	-1.672	0.582	-0.205
2.918	51.310	0.300	-1.403	0.682	0.394
3.018	55.833	0.400	-1.056	0.782	1.095

row 280

row 290



# QUADRATIC and CUBIC EQUATIONS



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## THE SHOOTING METHOD

Algebraic Solution i represents imaginary numbers

	p	q	r	sum = y		
	4	2	-1			
$x^3$	$px^2$	$qx$	$r$	$= Y$		
#NUM!	#NUM!	#NUM!	-1.000	#NUM!	#NUM!	
#NUM!	#NUM!	#NUM!	-1.000	#NUM!	#NUM!	
#NUM!	#NUM!	#NUM!	-1.000	#NUM!	#NUM!	

3	2	-1	1 real root, 2 imaginary
3	12	-6	1 real root, 2 imaginary
4	2	-1	3 real and unequal roots
-3	3	-1	3 real w/ atleast 2 equal
1	-1	-1	3 real w/ atleast 2 equal

a.  $-3.333$   $1/3 * (3 * 2.0 - 4.0^2)$   
 b.  $1.074$   $1/27 * (2 * 4.0^3 - 9 * 4.0 * 2.0 + 27 * -1.0)$

flag 1 0 logic  $b^2/4 + a^3/27 > 0$  1 real root and 2 imaginary roots  
 flag 2 0 logic  $b^2/4 + a^3/27 = 0$  3 real roots of which 2 at least are equal  
 flag 3 3 logic  $b^2/4 + a^3/27 < 0$  3 real and unequal roots

[A.] #NUM!  $(-1.074/2 + \text{SQRT}(1.074^2/4 + -3.333^3/27))^{1/3}$

logic #NUM!  $(-1.074/2 - \text{SQRT}(1.074^2/4 + -3.333^3/27)) \geq 0$

B\_eq #NUM!  $\text{ABS}(-1.074/2 - \text{SQRT}(1.074^2/4 + -3.333^3/27))^{1/3}$

[B.] #NUM! #VALUE!

ISNUMBER

X <sub>1</sub>	#NUM!	0	#VALUE!
X <sub>2</sub>	#NUM!	0	#VALUE!
X <sub>3</sub>	#NUM!	0	#VALUE!

increment

X <sub>1</sub>	Y <sub>1</sub>	X <sub>2</sub>	Y <sub>2</sub>	X <sub>3</sub>	Y <sub>3</sub>
0.3		0.3		0.3	
-2.997	2.014	-6.603	-127.678	-4.300	-15.147
-2.697	3.083	-6.303	-105.083	-4.000	-9.000
-2.397	3.416	-6.003	-85.172	-3.700	-4.293
-2.097	3.175	-5.703	-67.783	-3.400	-0.864
-1.797	2.521	-5.403	-52.753	-3.100	1.449
-1.497	1.616	-5.103	-39.920	-2.800	2.808
-1.197	0.623	-4.803	-29.123	-2.500	3.375
-0.897	-0.297	-4.503	-20.199	-2.200	3.312
-0.597	-0.981	-4.203	-12.987	-1.900	2.781
-0.297	-1.267	-3.903	-7.325	-1.600	1.944
0.003	-0.994	-3.603	-3.050	-1.300	0.963
0.303	0.000	-3.303	0.000	-1.000	0.000
0.603	1.878	-3.003	1.986	-0.700	-0.783
0.903	4.801	-2.703	3.071	-0.400	-1.224
1.203	8.932	-2.403	3.416	-0.100	-1.161
1.503	14.433	-2.103	3.183	0.200	-0.432
1.803	21.465	-1.803	2.535	0.500	1.125
2.103	30.190	-1.503	1.634	0.800	3.672
2.403	40.771	-1.203	0.641	1.100	7.371
2.703	53.369	-0.903	-0.281	1.400	12.384
3.003	68.147	-0.603	-0.971	1.700	18.873
3.303	85.267	-0.303	-1.267	2.000	27.000
3.603	104.890	-0.003	-1.006	2.300	36.927
3.903	127.178	0.297	-0.026	2.600	48.816
4.203	152.294	0.597	1.834	2.900	62.829
4.503	180.399	0.897	4.737	3.200	79.128
4.803	211.656	1.197	8.844	3.500	97.875
5.103	246.227	1.497	14.317	3.800	119.232
5.403	284.272	1.797	21.320	4.100	143.361
5.703	325.956	2.097	30.012	4.400	170.424
6.003	371.439	2.397	40.557	4.700	200.583
6.303	420.883	2.697	53.117	5.000	234.000
6.603	474.451	2.997	67.853	5.300	270.837
6.903	532.304	3.297	84.928	5.600	311.256
7.203	594.605	3.597	104.503	5.900	355.419
7.503	661.516	3.897	126.740	6.200	403.488

where y = 0

convergence OK OK OK

### Trigonometric Solution

	p	q	r	sum = y	
	4	2	-1	0	daisy chained from algebraic
$x^3$	$px^2$	$qx$	$r$		inputs above
0.0277564	0.3666923	0.6055513	-1	-1.44E-15	OK
-36.02776	43.633308	-6.605551	-1	-8.88E-16	OK
-1	4	-2	-1	0	OK

a  $-3.333$   $1/3 * (3 * 2.0 - 4.0^2)$   
 b  $1.074$   $1/27 * (2 * 4.0^3 - 9 * 4.0 * 2.0 + 27 * -1.0)$

cos F  $-0.459$   $-0.000/2 / \text{SQRT}(- (0.000^3)/27)$   
 arcsin F  $2.047$

ISNUMBER

X <sub>1</sub>	0.303	0.3027756	$2 * (-0.000/3)^{0.5} * \text{COS}(2.047/3) - 4.000/3$
X <sub>2</sub>	-3.303	-3.302776	$-2 * (-0.000/3)^{0.5} * \text{COS}(2.047/3 - \text{PI}/3) - 4.000/3$
X <sub>3</sub>	-1.000	-1.2	$(-0.000/3)^{0.5} * \text{COS}(2.047/3 + 2 * \text{PI} * 2/3) - 4.000/3$

The value of X is determined by where the line crosses the X-axis at Y = 0  
 The trigonometric solution is used for 3 real and unequal roots.

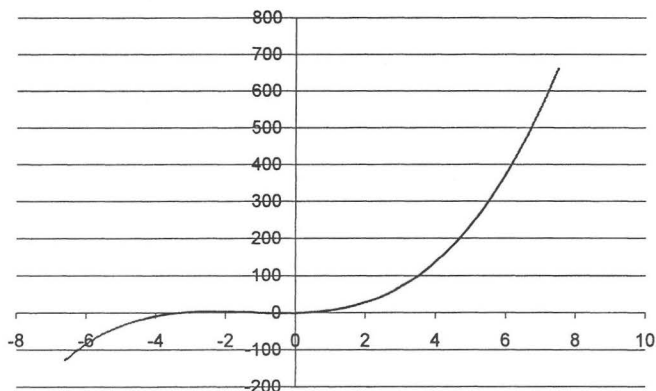


Figure 58-7 The shooting method solution.



# QUADRATIC and CUBIC EQUATIONS

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58 Quadratic and Cubic Equations.xls

A B C D E F G H I J K L M N  
CURVE FITTING with EXCEL TRENDLINE

	x		p	q	r		
	0.562		4	1	-2		
increment	0.03	x <sup>3</sup>	px <sup>2</sup>	qx	r	y graph	y calculated
	0.232	0.012	0.215	0.232	-2	-1.540	-1.540
	0.262	0.018	0.275	0.262	-2	-1.445	-1.445
	0.292	0.025	0.341	0.292	-2	-1.342	-1.342
	0.322	0.033	0.415	0.322	-2	-1.230	-1.230
	0.352	0.044	0.496	0.352	-2	-1.109	-1.109
	0.382	0.056	0.584	0.382	-2	-0.979	-0.979
	0.412	0.070	0.679	0.412	-2	-0.839	-0.839
	0.442	0.086	0.781	0.442	-2	-0.690	-0.690
	0.472	0.105	0.891	0.472	-2	-0.532	-0.532
	0.502	0.127	1.008	0.502	-2	-0.363	-0.363
	0.532	0.151	1.132	0.532	-2	-0.185	-0.185
Y intercept	0.562	0.178	1.263	0.562	-2	0.003	0.003
	0.592	0.207	1.402	0.592	-2	0.201	0.201
	0.622	0.241	1.548	0.622	-2	0.410	0.410
	0.652	0.277	1.700	0.652	-2	0.630	0.630
	0.682	0.317	1.860	0.682	-2	0.860	0.860
	0.712	0.361	2.028	0.712	-2	1.101	1.101
	0.742	0.409	2.202	0.742	-2	1.353	1.353
	0.772	0.460	2.384	0.772	-2	1.616	1.616
	0.802	0.516	2.573	0.802	-2	1.891	1.891
	0.832	0.576	2.769	0.832	-2	2.177	2.177
	0.862	0.641	2.972	0.862	-2	2.475	2.475
	0.892	0.710	3.183	0.892	-2	2.784	2.784
	0.922	0.784	3.400	0.922	-2	3.106	3.106
	0.952	0.863	3.625	0.952	-2	3.440	3.440
	0.982	0.947	3.857	0.982	-2	3.786	3.786
	1.012	1.036	4.097	1.012	-2	4.145	4.145
	1.042	1.131	4.343	1.042	-2	4.516	4.516
	1.072	1.232	4.597	1.072	-2	4.901	4.901
	1.102	1.338	4.858	1.102	-2	5.298	5.298
	1.132	1.451	5.126	1.132	-2	5.708	5.708
	1.162	1.569	5.401	1.162	-2	6.132	6.132
	1.192	1.694	5.683	1.192	-2	6.569	6.569
	1.222	1.825	5.973	1.222	-2	7.020	7.020
	1.252	1.963	6.270	1.252	-2	7.485	7.485
	1.282	2.107	6.574	1.282	-2	7.963	7.963

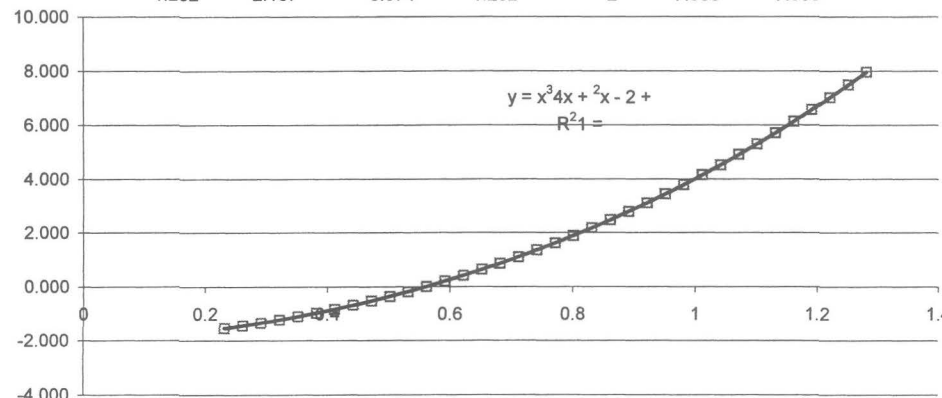


Figure 58-8 Using the Excel add trend function to solve the equation This solution used the 3rd power.

linest	m <sub>1</sub>	m <sub>2</sub>	m <sub>3</sub>	b
m	1.00	1.00	1.00	-2.00
se	3.269E-15	1.168E-15	2.0423E-15	6.825E-16
r <sup>2</sup>	1.0000	2.901E-16	#N/A	#N/A
F	1.151E+33	32	#N/A	#N/A
ss <sub>reg</sub>	290.74466	2.694E-30	#N/A	#N/A



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59 LISP.xls

**CREATING AN ASCII FILE**

ASCII files are basic text files that can be read by most spreadsheets and word processing programs.

ASCII files can also be printed from the DOS prompt.

D threads 0.9729 in

	Sine	Cosine	X	Y	Z	
0	0.0000	1.0000	0.9729	0.0000	0.0000	cat
1	0.1736	0.9848	0.9582	0.1689	0.0069	dog
2	0.3420	0.9397	0.9143	0.3328	0.0139	horse
3	0.5000	0.8660	0.8426	0.4865	0.0208	
4	0.6428	0.7660	0.7453	0.6254	0.0278	
5	0.7660	0.6428	0.6254	0.7453	0.0347	
6	0.8660	0.5000	0.4865	0.8426	0.0417	
7	0.9397	0.3420	0.3328	0.9143	0.0486	
8	0.9848	0.1736	0.1689	0.9582	0.0556	
9	1.0000	0.0000	0.0000	0.9729	0.0625	

First, make calculations in the spreadsheet

row 20

Header for reference.

row 30

It is easiest to copy the values and paste-special-values into a separate, blank spreadsheet. Set column widths to 10 or edit the LISP routine to read 9 character width columns.

Save the file as a \*.prn file.

row 40

row 50

row 60

Be sure that (\*.prn) type file is selected. This creates a space delimited file which the LISP routine can read.

The file can be reviewed with Microsoft Notepad.

Figure 59-1 Saving information as a .prn file.

row 70



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59 LISP.xls

A B C D E F G H I J K L M N  
**READING WITH THE LISP ROUTINE**

```
; 3DPLine.lsp
;
; Craig T. Christy
; INDUSTRY CONSULTING ENGINEERS
; 4334 S.W. Washouga Avenue
; Portland, Oregon 97202
; 503 246 9222
```

```
; Data can be generated in Excel, then copy clipped and pasted for values
; into a plane spreadsheet. Save as "name".prn.
; Plot the line in its own, blank window. Make sure that the window is
; large enough to plot the line. Trim the plotted line as required.
; Record your data as follows:
```

```
; 123456789012345678901234567890
; 0.8466 0 0
; 0.8338 0.147 0.0069
; 0.7956 0.2896 0.0139
```

The 3DSpiral routine reads each row of the ASCII.prn file and edit the vertex of a dummy 3DPolyline.

```
(defun C:3DPLine (/ FILE EOF OldPD COUNT RFILE vertex
                 X Y Z DATA BLANK_LINE) ; define function variables
```

```
; Get the Scale Factor
(setq SF ; scale factor
 (getreal "\nScale factor.....< 1.0 > ? : ") )
(if (or (= SF "") (= SF nil))(setq SF 1.0) ) ; set scale to 1 if nil end if
; Get the data file with extension
(setq RFILE ; variable name, use FindFile for current directory
 (FindFile (getstring "\n.....INPUT File with EXTension: ")))
```

```
(setq FILE (open RFILE "r") ; open file to read
 EOF "NO" ; set end of file to no
 OldPD (getvar "PDMode") ; save Pdmode point display style
 COUNT 0 ; set counter to 0
 BLANK_LINE 1) ; set blank line & end setq
```

Be sure that the window is big enough to plot the entire object or plotting errors will occur.

```
(setvar "BlipMode" 1)
(setvar "CMDEcho" 0)
(setvar "PDMode" 0) ; set pdmode
```

This command creates the dummy 3DPolyline

This plot has been trimmed with the Acad Trim command

```
(command "3DPOLY" 0.001 1 "") ; create 3D polyline to be edited
(read-line FILE) ; dummy line read
(setq DATA (read-line FILE)) ; read in first line of data
  (setq X (atof (substr DATA 1 10)) ; get x value
        Y (atof (substr DATA 10 20)) ; get y value
        Z (atof (substr DATA 20 30)) ; get z value
        vertex (list X Y Z) ; x y z value & end setq
  )
(command "pedit" 0.001 "edit" "insert" vertex "") ; edit 3D polyline vertex
```

These values describe the start and end of each column.

This command edits the 3DPolyline described as 0.001

row 130

**READING WITH THE LISP ROUTINE -- Continued**

```

;; Enter while loop to start processing point
(while (= EOF "NO")
  (setq COUNT (+ COUNT 1))
  (if (= DATA nil)
    (setq EOF "YES")
    (progn
      (setq X (atof (substr DATA 1 10))
            Y (atof (substr DATA 10 20))
            Z (atof (substr DATA 20 30))
            vertex (list X Y Z))
      (command "insert" vertex "")
      (setq DATA (read-line FILE))
      (if (= DATA "")
        (setq COUNT 0)
        (DATA (read-line FILE)))
      )
    )
  )
)
(command "exit" "exit")
(close FILE)
(command "PDMODE" OldPD)
; Exiting message
(princ "\nFinished plotting 3D polyline.....")
(princ)
) ; end defun
  
```

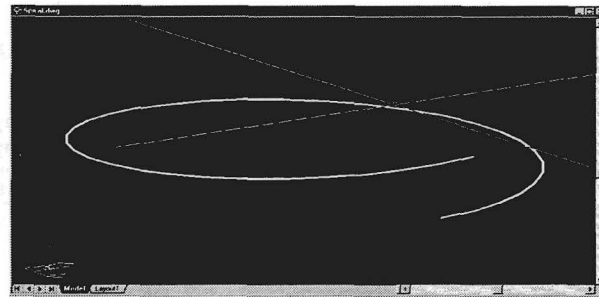
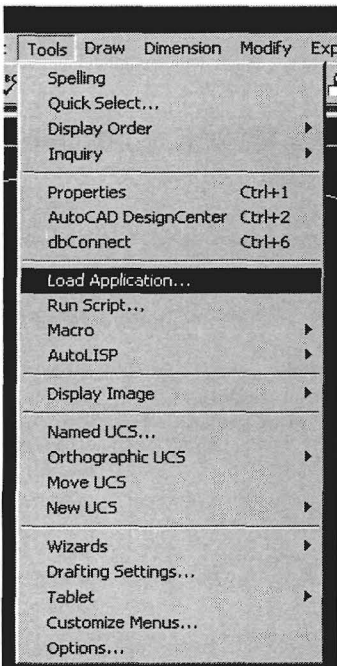
```

; while
; setq Increment counter
; if data is nil
; declare end of file
; else
; get x value
; get y value
; get z value
; x y z value & end setq
; edit 3D polyline
; read next line of data & end setq
; if data is <Alt-168>
; start next line set count to 0
; read next line of data & end setq
; end IF
; end progn
; end IF
; end while
; exit 3D polyline editing
; restore the original PDMODE
  
```

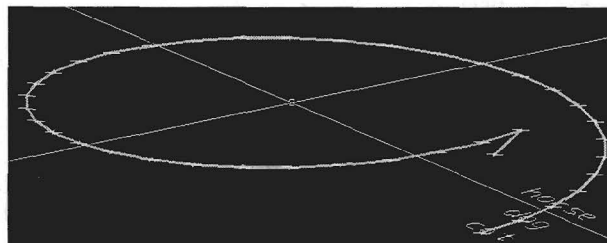
Edit the X, Y, and Z values to change the column widths

row 140  
row 150

row 160



row 170



row 180

Figure 59-2 The 3D spiral generated from calculations in the spreadsheet and plotted by the LISP routine.

Figure 59-3 Load the LISP routine in AutoCAD with the Tools Load Application menu.

row 190



# UNITS CONVERSION

**60**

Christy  
18:41  
12/20/05



60 Units.xls

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A B C D E F G H I J K L M N

**UNITS CONVERSION**

gravity 9.80621 m/sec<sup>2</sup> meters / second = m/sec<sup>2</sup> at 45 degrees latitude  
second

gravity 32.1725 ft/sec<sup>2</sup>

Distance 1 inch 25.4 mm exact conversion  
1 foot 304.80 mm 12 in \* 25.4 mm/inch  
1 yard 91.44 mm 3 ft \* 12 in/ft \* 25.4 mm/inch row 20

1 mm 0.03937 in 1000 μ 1000000 n 10,000,000 ångstrom  
1.0E+00 mm 1.0E+03 μ 1.0E+06 n 1.0E+07 ångstrom

1 meter 3.28084 ft 0.91440 yard  
1 kilometer 0.62137 mile  
1 mm

1 μ 0.001 mm 1000 n 10000 ångstrom  
1.0E-03 mm 1.0E+03 n 1.0E+04 ångstrom row 30

Area 1 m<sup>2</sup> 1.19599 yard<sup>2</sup> 10.7639 ft<sup>2</sup> 1550.0 in<sup>2</sup>  
1 Km<sup>2</sup> 2.59000 Mile<sup>2</sup>

1 ft<sup>2</sup> 0.09290 m<sup>2</sup>  
1 yard<sup>2</sup> 0.83613 m<sup>2</sup>  
1 in<sup>2</sup> 645.160 mm<sup>2</sup>

row 40

Weight 1 lb av 0.4536 kilogram 14.5833 oz troy  
1 oz av 28.3495 gram 1.09714 oz troy 437.5 grains  
1 lb av 453.592 gram 16 oz av 1.21527 lb troy 4739.7 grains  
1 oz troy 31.1035 gram 0.91146 oz av 0.08333 lb troy 24 grains 7.78 carats  
1 lb troy 373.242 gram 12 oz troy 0.82286 lb av 5760 grains

1 ton 907.185 kg 2000 lbs

row 50

1 gram 0.001 kg 0.03527 oz av 15.43236 grains  
1 kg 1000 g 2.20462 lb  
1 metric ton 1000 kg 2205 lbs

mass 1 kg 9.80621 kg-m/sec<sup>2</sup> 70.9284 lb-sec<sup>2</sup> /ft  
1 lb 4.44801 kg-m/sec<sup>2</sup> 0.03108 lb-sec<sup>2</sup> /ft

row 60

row 70





# UNITS CONVERSION

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A	B	C	D	E	F	G	H	I	J	K	L	M	N
<b>NOTATION</b>													
Imperial	feet-pounds-seconds		mks		meters-kilograms-seconds a rational metric system				SI		System Internationale		
ft	foot		m		meter				KPa		Kilopascal		
in	inch		mm		millimeter				MPa		MegaPascal		
			cm		centimeter = 10 millimeters				N		Newton		
ft^2	square foot, f <sup>2</sup>		mm		millimeter				Nm		Newton Meter		
ft^3	cubic foot, ft <sup>3</sup>		A		ångstrom								row 140
in^2	square inch, in <sup>2</sup>			m^2	square meter, m <sup>2</sup>								
in^3	cubic inch, in <sup>3</sup>			m^3	cubic meter, m <sup>3</sup>								
oz av	avoirdupois ounce			gr	gram								
oz troy	apothecary ounce			kg	kilogram								
				tonne	metric ton								
				kfg	kilograms force (Japanese)								
psf	pounds per square foot, lb /ft <sup>2</sup>												row 150
psi	pounds per square inch, lb /in <sup>2</sup>												
F	Fahrenheit degrees		C		Centigrade degrees								
R	Rankine degrees		K		Kelvin degrees								
cal	calorie												
Btu	British thermal unit												
kW-h	kilowatt hour												
<b>Prefix Summary</b>													
p	10 <sup>-12</sup>	pico		0.000 000 000 001									row 160
n	10 <sup>-9</sup>	nano		0.000 000 001									
μ	10 <sup>-6</sup>	micro		0.000 001									
m	10 <sup>-3</sup>	milli		0.001									
k	10 <sup>3</sup>	kilo		1 000									
M	10 <sup>6</sup>	mega		1 000 000									
G	10 <sup>9</sup>	giga		1 000 000 000									
T	10 <sup>12</sup>	tera		1 000 000 000 000									
<b>Density</b>													
1 Litre of water = 1 cubic decimeter = 1 kilogram													
density	1	kg/m <sup>3</sup>	0.06246	lb/ft <sup>3</sup>									
water	999.36	kg/m <sup>3</sup>	62.42	lb /ft <sup>3</sup>	at 39.2°F, 3.98°C								
steel	7850	kg/m <sup>3</sup>	490.35	lb/ft <sup>3</sup>									
concrete	2400	kg/m <sup>3</sup>	149.92	lb/ft <sup>3</sup>									
<b>Speed of Sound</b>													
dry air 0°C	331	m/sec	1192896	m/hr	1087	ft/sec	741	miles/hr					row 180
mild steel	5960	m/sec	21456000	m/hr	19554	ft/sec	13332	miles/hr					
pyrex glass	5640	m/sec	20304000	m/hr	18504	ft/sec	12616	miles/hr					
kerosene	1324	m/sec	4766400	m/hr	4344	ft/sec	2962	miles/hr	at 25°C				
water	1498	m/sec	5392800	m/hr	4915	ft/sec	3351	miles/hr	at 25°C, distilled				
<b>row 190</b>													





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A	B	C	D	E	F	G	H	I	J	K	L	M	N
---	---	---	---	---	---	---	---	---	---	---	---	---	---

**Convert Hp to Work**

F	9.60 k	cyclical load applied											
delta	0.50 in	1/2 of stroke								0.020 * 96"	max drift		
T	1.50 sec/cycle	time for complete cycle + and - deflections											

energy	2.40 in-k	$P * \text{delta} / 2$	for 1/2 of stroke	force applied one direction only
power	0.900 in-k / sec			
Hp	0.550 ft-k/sec	constant		
Hp	0.046 in-k/sec	constant		

Hp_req	19.6 hp	in straight line
rpm_req	40 rpm	
motor	3.0 Hp	motor

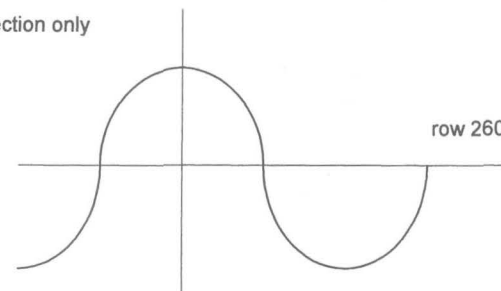


Figure 60-2 Rotation represented as a sine wave.

**As Impact -- Spring compressed by piston**

P_stroke	9.60
arm	0.50
V_init	1.00 in/sec

V_final	0
time	0.375 sec
k_spring	19.2 k/in

Theta	90 deg	
cos_t	0.000	$\text{COS}(\text{Theta} / 180 * \text{PI}())$
sin_t	1.000	$\text{SIN}(\text{Theta} / 180 * \text{PI}())$
v	1.000 in/sec x	$V_{\text{init}} * \text{sin}_t$
F	0.00	$P_{\text{stroke}} * \text{cos}_t$
Torque	0.00 k-in	$F * \text{arm} * \text{sin}_t$

Theta	135 deg
cos_t	-0.707
sin_t	0.707
v	0.707 in/sec x
F	-6.79
Torque	-2.40 k-in

Theta	180 deg
cos_t	-1.000
sin_t	0.000
v	0.000 in/sec x
F	-9.60
Torque	0.00 k-in

TEST	140 deg
cos_t	-0.766
sin_t	0.643
v	0.643 in/sec x
F	-7.35
Torque	-2.36 k-in



Figure 60-3 Convert torque to linear force.

**As Function of Motor Torque**

throw	0.25 in
F	9.6 k
Torq	2.40 k-in

rpm	40.00 rpm
	0.67 hz
Hp	1.5 hp
V_top	0.523441 in/sec



# NOTATION

# 61

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A	B	C
<b>GENERAL</b>		
#NUM	a problem occurs with a number in a formula or a function	
\$	cell row and/or column absolute reference	
&	ampersand used in string concatenation	
.mpr	ASCII file extension used in AutoCAD	
[Ctrl] [Shift] [Enter]	table entry command	
[F2]	edit key	
[F4]	absolute reference key	
[F5]	moving around the spreadsheet	
absolute reference	how a cell is referenced by a formula, \$	row 20
Ad <sup>2</sup>	area * (distance from an axis) <sup>2</sup> . moment of inertia . in <sup>4</sup>	
ampersand	& used in concatenating/combining text and equations	
AND	Boolean logical operator	
ASD	allowable stress design	
atan	arctangent, radians	
b	the Y intercept in a graph	
bd <sup>3</sup> /12	moment of inertia for a rectangle, in <sup>4</sup>	row 30
c	speed of pressure wave, celerity, ft/sec	
c	actual damping, lb-sec/in	
c	distance of centroid to the extreme fiber in tension or compression, inches	
c <sub>c</sub>	critical damping, lb-sec/in	
celerity	movement of the pressure wave in a pipe	
CG	center of gravity	
CG X →	CG located in the X direction from the Y axis.	
d, d <sub>x</sub>	distance, distance from the x-axis	
E	Young's modulus of elasticity, 29,000 ksi for steel, first yield, ksi, k/in <sup>2</sup>	row 40
e	2.71828 base of natural logarithms	
Ek	kinetic energy	
Ep	potential energy	
f	1/T, Hz, cycles per second	
F	force as in F = ma, F = m z", lbs	
FEM	fixed end moment as opposed to pinned end with no moment resistance	
FEM	fixed end moment	
f <sub>n</sub>	natural frequency, cycles per second, Hertz ω <sub>n</sub> /2π, 1/T	row 50
g	gravity, 32.17 ft/sec/sec, 386.04 in/sec <sup>2</sup> , 9.80621 m/sec <sup>2</sup>	
Greek C	font	
Greek S	font	
Hz	Hertz, cycles/sec	
i	complex conjugate, imaginary number	
I	moment of inertia, in <sup>4</sup>	
iterative solution	the shooting method -- converging two equations to within a degree of accuracy	
I <sub>xx</sub> , I <sub>yy</sub>	moments of inertia about x-axis and y-axis respectively, in <sup>4</sup>	



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A B C

**GENERAL -- Continued**

k	number of constants in an equation	
k	stiffness factor, k/in	
K	liquid bulk modulus of elasticity for water this is usually 300 ksi unless the water contains a significant air bubbles as in papermill stock lines. Air bubbles are compressible and the value of K must be reduced.	
K.E.	kinetic energy	
L	length of beam or column, in	
LRFD	load resistance factor design	
LVDT	linear voltage displacement transducer	
m	the slope of straight line in a graph	row 70
m	mass, lb-ft/sec <sup>2</sup> , kg-m/sec <sup>2</sup>	
M	moment	
m, mass	weight / gravity, k-sec <sup>2</sup> /in, kg-sec <sup>2</sup> /m	
moment distribution	a method of solving multi-span beam-column moments and reactions created by Mr. Hardy Cross, hence, also referred to as the Hardy Cross method	
n	number of bolt threads	
n	Poisson's ratio 0.27 to 0.3 for steel	
NOT	Boolean logical operator	row 80
OR	Boolean logical operator	
P.E.	potential energy	
p-delta, pd, PΔ	an effect that takes place in columns and slender walls where a column is already bent and an axial load is applied to it, it will bend more.	
pline	AutoCAD contiguous line	
q	soil pressure, k/ft <sup>2</sup>	
Q	flowrate in pipe, ft <sup>3</sup> /sec	
Re	Reynolds number, unitless factor for air flow	
right hand rule	mathematical rule -- an arrow going away from you rotates in a clockwise direction	
r <sub>o</sub>	soil modulus of compressibility, lbs/in <sup>2</sup> /in, lbs/in <sup>3</sup>	row 90
S	section modulus, I/c, in <sup>3</sup>	
s, σ	stress, psi, lb/in <sup>2</sup> , ksi, k/in <sup>2</sup> , kg/cm <sup>2</sup> , kPa	
Script S	font	
seismic	earthquake, E, fraction of gravity, force	
shooting method	converging two equations to within a degree of accuracy	
Symap	font	
Symath	font	
Symbol	font	
SymbolSH	font	row 100
Symeteo	font	



# NOTATION

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A B C

**GENERAL -- Continued**

T	period, seconds	
t	time at which z' is calculated, second	
tabs		
TLA	three letter acronym	
V	shear	
v	velocity, in/sec	row 110
w	uniform load, k/ft	
w	uniform load, lbs/inch	
X <sub>mm</sub>	overall mean denoted in text books as X with double bars on top	
z'	velocity, in/sec	
z''	acceleration, in/sec <sup>2</sup>	
z <sub>c</sub>	known as x <sub>0</sub> in some references, resulting displacement, inch	
ZIP	ZIP files (WinZip®) are condensed files for storage and transmission	
δ	deflection, inches	
ζ, ξ	damping factor, unitless	row 120
π	PI() in Excel nomenclature, 3.142, unitless	
ρ	density of the liquid, lb/ft <sup>3</sup> , where water = 62.4 lb/ft <sup>3</sup>	
σ	stress, k/in <sup>2</sup>	
τ	duration of applied force, second	

**BOLTS**

F/thread	F <sub>v</sub> * area of thread in shear	
F <sub>t</sub>	tension, kips/in <sup>2</sup>	
F <sub>v</sub>	shear through threads in plane, kips/in <sup>2</sup>	
H	0.866 P	row 130
head	bolt head	
K root	least diameter of a bolt at the threads	
n	number of threads/inch	
pitch	spacing of threads, inch	
w thread	actual width of thread pitch - pitch/4	

**CELERITY -- WAVE ACTION**

b, circ	shell circumference, ft	
C <sub>1</sub>	arbitrary factor, unitless	
C <sub>2</sub>	lateral seismic force coefficient, unitless	row 140
D	tank diameter, ft	
density	density of stored product, k/ft <sup>3</sup>	
d <sub>wave</sub>	wave height, ft	
F <sub>a</sub>	minimum yield strength in compression, k/in <sup>2</sup>	
F <sub>by</sub>	minimum yield strength in bending, k/in <sup>2</sup>	
G	specific gravity of stored product, unitless	
H	maximum design liquid height, ft	
H <sub>t</sub>	total height of tank shell, ft	
I	wind or seismic importance factor, unitless	row 150
k	factor for D/H	



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A B C

**CELERITY -- WAVE ACTION -- Continued**

$M_{ot}$	tank overturning moment, k-ft	
$M_{rt}$	righting moment, k-ft	
S	site amplification factor from API Table L-2	
T	period of first mode sloshing, sec	
tank_full	weight of full tank, k	
$t_b$	thickness of bottom of tank, in	
$t_s$	shell thickness, in	
V	volume of tank, ft <sup>3</sup>	row 160
W arm	vertical arm to lateral forces, ft	
W sum	for lateral forces, k	
$W_{tank}$	tank shell per foot of circumference, k/ft	
$W_r$	total weight of tank roof and insulation, 0 when included in Ws, k	
$W_{s tare}$	weight of empty tank, tare, k	
$W_T$	weight of liquid, k	
$X_s$	height to the CG of the shell usually taken as 2/3 Ht for flexible structures, ft	
Z	seismic zone coefficient, unitless	
$\sigma$	longitudinal stress at bottom of the shell, lbs/in <sup>2</sup>	row 170

**CONCRETE PULLOUT**

$\mu$	concrete roughness factor	
$A_b$	net cross-section area of bolt	
$A_c$	shear area $A_c$ (base plate or shear plane)	
$A_p$	effective area of projected cone onto the surface of the slab	
$d_e$	edge distance <b>toward</b> loaded edge	
Edge 2	edge distance <b>away</b> from loaded edge	
$f_c$	compression strength of concrete	
$f_{ut}$	bolt ultimate tensile strength	row 180
$f_y$	specified yield strength = $F_u$ tensile for bolt material	
$\lambda$	concrete weight factor	
$\Phi$	concrete strength reduction factor	

**CONCRETE FOUNDATION DESIGN**

$a_x$	the 1/3 point of the triangular soil loading profile, ft	
$CG_x$	center of gravity from the x-axis, ft	
$d_{20}$	deflection indexed to soil modulus, inch	
$e_x$	eccentricity of all loads including dead and live loads, the slab, and moment due to seismic or wind forces located from the geographical center of gravity $CG_x$ , ft	row 190
$I_{xx}$	moment of inertia about the x-axis or an axis parallel to the x-axis, ft <sup>4</sup>	
$Mot_x$	overturning moment about the x-axis, k-ft	
$Mrt_x$	righting moment about the x-axis from loads	
$M_u$	ultimate moment for LRFD design	
$M_x$	moment about the x-axis or an axis parallel to the x-axis, k-ft	
$q_x$	soil pressure along the loaded top or bottom edge, ksf, working in the opposite direction of $Mot_x$ , k-ft	





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A	B	C
<b>STATISTICS</b>		
b	the Y-axis intercept the point at which the line starts for a given value of X and Y along the slope m	
CM	correction for the mean	
df	degrees of freedom $n - k$	row 230
F statistic	MST / MSE the chance relation between data groups and within a group the F statistic determines whether the observed relationship between dependent and independent variables occurs by chance. Always positive	
k	number of constants in the equation	
m	the slope of a straight line in $y = mx + b$	
MSE	mean square for error	
MST	mean squares for treatment	
$n_1$	factor for the groups in the F statistic	
$n_2$	factor for the number of observations within a number of groups	
R Square, $r^2$	the correlation of estimated and actual y values. A measure correlation varies from 0 to 1 with 1 being the best correlation	
s, s coefficient	standard deviation, standard measure of dispersion	
SS Residual, SSE	sum of squares for error = $S(Y - Y_m)^2$	row 240
ssreg	the sum of the squared differences for the actual values and the average y values for each point	
standard error se	the standard error values for the coefficients $m_1, m_2, etc.$	
Syx	Standard Error of Estimate of the dependent variable Y regressed against the independent variable(s) X	
t	Student's t -- describes the sampling distribution of a deviation from the population mean divided by the standard error	
two tail	excluded areas of a Gaussian curve in statistics	
V	lateral force, * W	
$X_m Y_m$	the mean value(s) of X and Y	
$X_{mm}$	overall mean denoted in text books as X with double bars on top	
$Y = mX + b$	straight line graph	
y intercept	where a straight or curved line crosses the y-axis, sometimes set to 0	row 250
$Y_c$	the computed/expected value of y	
$\beta$	a pure number representing the net regression coefficient expressed in units of its own standard deviation.	
$\beta$	a pure number representing the net regression coefficient expressed in units of its own standard deviation.	
$\Sigma x^2$	$\Sigma x^2$ represents standard error of regression coefficient: the dispersion of X values around their mean.	



# NOTATION

# 61

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VORTEX	A	B	C
$C_D$		coefficient of drag	
$C_L$		coefficient of lift	
D		max stack diameter at CL of plate	
d		diameter of cylinder perpendicular to wind flow, ft	row 260
d		logarithmic decrement for damping	
$D_{cantilever}$		amplified deflection	
d_mean		diameter of cylinder to middle of plate, ft	
$D_r$		average diameter of stack for DPE calculations	
$D_s$		static deflection for DPE calculations	
E		Young's modulus of elasticity, ksi	
E heat		modulus of elasticity at operating temperature, ksi	
$E_{ASD}$		$g_{working} = \text{Code Seismic} / 1.4$	
$f_n$		natural frequency, $1 / T_n$ frequency, cycles/second	
$f_v$		shedding frequency of vortices, Hz	
Fy		first yield strength, ksi	
g		gravity, 386 in/sec <sup>2</sup> , 32.2 ft/sec <sup>2</sup>	row 272
$H_r$		spacing between stiffener rings	
k		spring constant, lb/in	
$K_1'$		ratio of force to structure weight	
$K_1''$		ratio of force to structure weight and modulus	
L		height of stack/structure from TANK inputs	
$L_{vortex}$		force on stack at critical wind velocity	
M.F.		magnification factor, conservatively $p / d$	
M.F.		foundation magnification factor	
m_air		viscosity of air, lb-sec/ft <sup>2</sup>	row 282
mass		$W / g$ , lb-sec <sup>2</sup> /in	
$q_{critical}$		pressure at critical wind velocity, psf, lb/ft <sup>2</sup>	
$q_{wind}$		$0.00257 * (V \text{ mph})^2$ generic wind pressure calculation	
$R_e$		Reynolds number, unitless	
s		stress, ksi, k/in <sup>2</sup>	
S		dimensionless parameter, Strouhal number	
$S_m$		required section modulus at ring	
t		temperature, degrees Fahrenheit	
t, t'		corroded plate thickness	
$T_n$		natural, resonant frequency of structure	row 292
V		wind velocity, ft/sec	
$V_1$		first critical velocity at which vortex shedding frequency equals the natural frequency of the structure	
$V_{wind}$		possible vortex shedding wind speed where $R_e < 50,000$	
$V_{wind}$		vortex shedding per resonant frequency of structure	
W		weight, lbs	
$\beta$		type of construction factor	
$\epsilon$		coefficient of expansion, unitless	
$\epsilon_{damping}$		damping factor for type of structure	
$\Theta$		angle used in calculating a partially loaded ring, radians	
$\rho_{air}$		air mass density, lb-sec <sup>2</sup> /ft <sup>4</sup>	row 302



# NOTATION

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	A	B	C
<b>WIND</b>			
C <sub>e</sub>		Gust Factor Coefficient	
C <sub>q</sub>		pressure coefficient	
Exposure		Exposure and gust factor coefficient B, C, or D	
I		importance factor	
P wind		pressure of wind, lbs/ft <sup>2</sup>	
q <sub>s</sub>		wind pressure at a designated height, lbs/ft <sup>2</sup>	
Q <sub>s</sub>		wind stagnation pressure at standard height	
V wind		velocity of wind, miles/hour	
V <sub>basic</sub>		basic wind speed, miles/hour	

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## REFERENCES

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