Includes required cassette.

HEWLETT-PACKARD

HP-41

USERS' LIBRARY SOLUTIONS
Structural Design

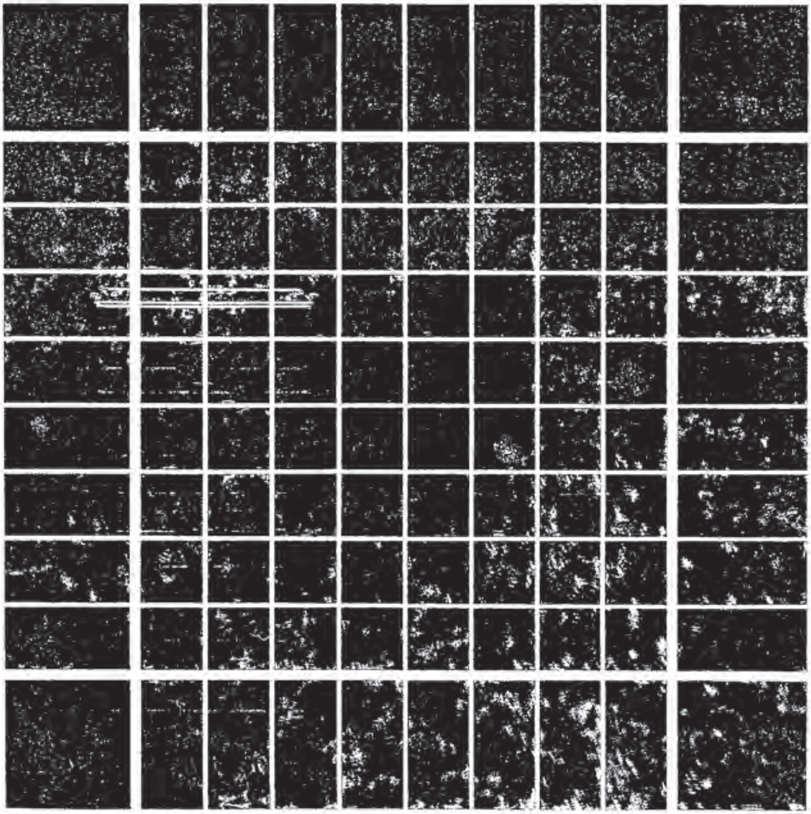


TABLE OF CONTENTS

This Solutions Book was developed and coded by Charles I. Dinsmore.

INTRODUCTION

This HP-41C Solutions book was written to help you get the most from your calculator. The programs were chosen to provide useful calculations for many of the common problems encountered.

They will provide you with immediate capabilities in your everyday calculations and you will find them useful as guides to programming techniques for writing your own customized software. The comments on each program listing describe the approach used to reach the solution and help you follow the programmer's logic as you become and expert on your HP calculator.

KEYING A PROGRAM INTO THE HP-41C

There are several things that you should keep in mind while you are keying in programs from the program listings provided in this book. The output from the HP 82143A printer provides a convenient way of listing and an easily understood method of keying in programs without showing every keystroke. This type of output is what appears in this handbook. Once you understand the procedure for keying programs in from the printed listings, you will find this method simple and fast. Here is the procedure:

1. At the end of each program listing is a listing of status information required to properly execute that program. Included is the SIZE allocation required. Before you begin keying in the program, press [XEQ] [ALPHA] SIZE [ALPHA] and specify the allocation (three digits; e.g., 10 should be specified as 010).

   Also included in the status information is the display format and status of flags important to the program. To ensure proper execution, check to see that the display status of the HP-41C is set as specified and check to see that all applicable flags are set or clear as specified.

2. Set the HP-41C to PRGM mode (press the [PRGM] key) and press ■ [GTO] [.] [.] to prepare the calculator for the new program.

3. Begin keying in the program. Following is a list of hints that will help you when you key in your programs from the program listings in this handbook.

   a. When you see " (quote marks) around a character or group of characters in the program listing, those characters are ALPHA. To key them in, simply press [ALPHA], key in the characters, then press [ALPHA] again. So "SAMPLE" would be keyed in as [ALPHA] "SAMPLE" [ALPHA].

   b. The diamond in front of each LBL instruction is only a visual aid to help you locate labels in the program listings. When you key in a program, ignore the diamond.

   c. The printer indication of divide sign is /. When you see / in the program listing, press [÷].

   d. The printer indication of the multiply sign is *. When you see * in the program listing, press [×].

   e. The ├ character in the program listing is an indication of the [APPEND] function. When you see ├, press ■ [APPEND] in ALPHA mode (press ■ and the K key).

   f. All operations requiring register addresses accept those addresses in these forms:

      nn (a two-digit number)
      IND nn (INDIRECT: ■ , followed fy a two-digit number)
      X, Y, Z, T, or L (a STACK address: [.] followed by X, Y, Z, T, or L)
      IND X, Y, Z, T or L (INDIRECT stack: ■ [.] followed by X, Y, Z, T, or L)

      Indirect addresses are specified by pressing ■ and then the indirect address. Stack addresses are specified by pressing [.] followed by X, Y, Z, T, or L. Indirect stack addresses are specified by pressing ■ [.] and X, Y, Z, T, or L.

Printer Listing	Keystrokes	Display
01♦LBL "SAMPLE"	■ [LBL] [ALPHA] SAMPLE [ALPHA]	01 LBL^{T}SAMPLE
02 "THIS IS A "	[ALPHA] *THIS IS A* [ALPHA]	02^{T}THIS IS A
03 "├SAMPLE"	[ALPHA] ■ [APPEND] SAMPLE	03^{T} ├ SAMPLE
04 AVIEW	■ AVIEW [ALPHA]	04 AVIEW
05 6	6	05 6
06 ENTER↑	[ENTER↑]	06 ENTER ↑
07 -2	2 [CHS]	07 -2
08 /	[÷]	08 /
09 ABS	[XEQ] [ALPHA] ABS [ALPHA]	09 ABS
10 STO IND L	[STO] ■ [.] L	10 STO IND L
11 "R3="	[ALPHA] R3= ■ [ARCL] 03	11^{T}R3=
12 ARCL 03	■ [AVIEW]	12 ARCL 03
13 AVIEW	[ALPHA]	13 AVIEW
14 RTN	■ [RTN]	14 RTN

STRUCTURAL DESIGN

"Structural Design" provides a group of programs that can be used to solve problems frequently encountered by structural designers and engineers. Problems involving steel, reinforced concrete, and some miscellaneous areas are addressed.

The devices required to use the group of programs consist of an HP-41CV or a calculator/memory ROM configuration with equivalent memory and an HP 82161A Digital Cassette Drive. A printer is highly recommended, but not required. In addition, the programs may be used in conjunction with the HP 00041-15021 "Structural Analysis Pac".

The programs are written to allow the user to move easily from one to another. At the end of each program, the user is asked if another program is desired. If so, the specified program is loaded into the calculator and begins execution. If the current program is to be used again, it is begun by pressing [R/S].

In order to create an easy-to-use package, all of the programs use the same type of prompting response techniques that can be characterized by the user's response. For numeric data input, the user must input a value. For a choice between numeric input and a program provided default value, the user either inputs a value or presses [R/S] to instruct the program to use the default value. The final type of prompt requires a yes/no response. All "yes" responses are made by pressing "Y [R/S]" and a "no" response is indicated by pressing only "[R/S]", though "N [R/S]" will work also.

Program Overviews

Steel

The program "STLSOL" (Steel Solver) analyzes steel columns and beams based on the A.I.S.C. (American Institute of Steel Construction) 1980 specifications for steel construction. "STLSOL" utilizes a file based steel section table containing 226 sections, each of which contains 10 properties required for the analysis of a beam or column. For a description of the recorded properties, refer to page 2. All of the W, S, and M shapes are represented. Each file is accessed using the section name, e.g. "W12X120". A routine is provided to create data files for other sections that must be used to complete an analysis.

Concrete

Five programs, "MAG", "UL2CON", "CIRCON", "CONBM", and "REBAR", are provided for concrete beams and columns. All follow the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

"MAG" calculates the Moment Magnification Factor for the case of slender columns. It is based on the approximation procedure given in section 10.11 of "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

"UL2CON" computes the ultimate capacity using the ultimate strength design method for a rectangular concrete section subject to a given axial compression load and moments about two perpendicular axes. The concrete section may be square or rectangular with up to 43 reinforcing bars. "CIRCON" computes the ultimate capacity using the ultimate strength design method for a circular concrete section subject to a given axial compression load and moments about two perpendicular axes. The section may have up to 124 reinforcing bars placed in either a circular or square pattern.

The beam solution program, "CONBM", consists of two modes, design and analysis. The design mode allows the user to calculate the required reinforcing steel area for tension and, if necessary, for compression. Analysis mode determines the ultimate moment capacity. The section being analyzed may contain tension and compression reinforcing. The strain on the compression reinforcing is checked to determine if the reinforcing has yielded, and the appropriate steel stress is used to compute the ultimate moment contributed by the compression reinforcing.

"REBAR" computes the development length for reinforcing steel in concrete elements according to the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

Miscellaneous Routines

"MWALL" is used to design masonry shear wall subjected to axial loading and lateral forces.

"TILTUP" uses the ultimate strength design method to analyze cast-in-place or precast concrete tilt-up walls.

"RIGID" computes the coefficients for the deflection and rigidity of masonry or concrete walls and piers for distribution of lateral forces cantilevered as determined by the user.

"TRUSS" is a design aid to a user familiar with structural design methods and engineering mechanics. The program calculates up to two unknown forces in a joint. Known forces are input as vector quantities. For output forces, negative and positive values indicate compression and tension respectively.

Media Protection

To avoid any problems that could arise due to destruction or loss of media, we suggest that you make a backup of the cassette tape. Also, you may want to make a cassette tape containing a subset of the section properties files for daily use to increase the life of the "Structural Design" tape.

STLSOL

Using the 1980 A.I.S.C. "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings", "STLSOL" provides a ready solution for the analysis of structural steel beams and columns of W, I, H, S, and M shaped cross sections. I and H sections must be keyed in as special sections, though the information may be saved if desired. The program calculates the following information.

For columns:

1. The actual axial stress.
2. Allowable bending stress according to A.I.S.C. 1980 requirements considering compactness and the limiting values of unsupported length between bracing, about the x-axis F_{bx}.
3. Allowable bending stress according to A.I.S.C. 1980 requirements considering compactness and the limiting values of unsupported length about the y-axis, F_{by}
4. Actual bending stress f_{bx} and f_{by}
5. Solution of the interaction equations for combined stresses of compression and bending about 1 or 2 (x,y) axes

For axial case only:

6. Allowable axial stress F_a
7. Allowable concentric load P_a. Computed using F_a

For beams:

1. Allowable bending stress according to A.I.S.C. 1980 requirements considering compactness and the limiting values of unsupported length about the x-axis, F_{bx}.
2. Allowable bending stress according to A.I.S.C. 1980 requirements considering compactness and the limiting values of unsupported length about the y-axis, F_{by}
3. Actual bending stress f_{bx} and f_{by}
4. Percent of stress under or over expressed in terms of unity for uniaxial or biaxial bending. For biaxial bending the A.I.S.C. equation for interaction is used.

Included in this documentation are tables for determining the values K_x, K_y, C_{mx}, and C_{my}. The value K is a coefficient which determines the effective column length. The value C_m is a moment reduction factor as explained in the A.I.S.C. specification. The value C_b is a coefficient used in determining the allowable bending stress.

Determination of C_{mx} and C_{my}

1. For compression members in frames subject to joint translation (sidesway) $C_m = 0.85$.
2. For compression members in frames braced against joint translation and not subject to transverse loading between their supports in the plane of bending, $C_m = 0.6 - 0.4\ M1/M2$ but not less than 0.4. Where M1/M2 is the ratio of the smaller to larger moments at the ends of that portion of the member unbraced in the plane of bending under consideration. M1/M2 is positive when the member is bent in reverse curvature, negative when bent in single curvature.
3. For compression members in frames braced against joint translation in the plane of loading and subjected to transverse loading between their supports, the value of C_m may be determined by rational analysis. However, in lieu of such analysis, the following values may be used:
   a. For members with restrained ends $C_m = 0.85$
   b. For members with unrestrained ends $C_m = 1.0$

Determination of C_b (for allowable bending stress)

$C_b = 1.75 + 1.05\,(M1/M2) + 0.3\,(M1/M2)^2$ but not more than 2.3 (C_b can conservatively be taken as unity ... 1.0)

where M1 is the smaller and M2 is the larger bending moment at the ends of the unbraced length, taken about the strong axis of the member where M1/M2, the ratio of end moments is positive when M1 and M2 have the same sign (reverse curvature) and negative when they are of the opposite sign (single curvature). When the bending moment at any point within the unbraced length is larger than that at both ends of this length the value of C_b shall be taken as unity. For frames braced against joint translation, $C_b = 1.0$

Section Properties Files

Section properties for 226 steel sections are contained on the tape storage medium. Properties exist for all of the W, S, and M sections, as listed in the A.I.S.C. Steel Manual. The program also allows the user to create additional files for sections that are not already represented. If desired, the properties may be saved as a file on the mass storage medium.

Due to the 7 character limit for data file names, eight files use a truncated form of the actual cross section they represent. The correspondence is:

FILE NAME	ACTUAL CROSS SECTION
S5X14.7	S5x14.75
S6X17.2	S6x17.25
S10X25	S10x25.4
S12X31	S12x31.8
S12X40	S12x40.8
S15X42	S15x42.9
S18X54	S18x54.7
M12X11	M12x11.8

Note that if the entire cross section name is keyed in, only the first 7 characters will be used; hence the correct file will be read in.

The following properties are stored in each steel section file:

A = Area in inches^2
d = Depth of section
b_f = Width of flange
t_f = Flange thickness
t_w = Thickness of web
S_x = Section modulus, x-axis
r_x = Radius of gyration, x-axis
S_y = Section modulus, y-axis
r_y = Radius of gyration, y-axis
r_t = Radius of gyration of a section comprised of the compression flange plus one third of the compression web area

It should be noted that the moments of inertia of the sections are not stored in the data files. Only the properties required for the beam and column solution programs are stored. For use in other programs, the moments of inertia are easily computed from the stored properties according to the following

$$I_x = S_x(d)/2 \text{ and } I_y = S_y(b_f)/2$$

$$I_x = Ar_x^2 \text{ and } I_y = Ar_y^2$$

A directory listing of the programs and data files can be found in Appendix B. Note that the data files have been secured so that no file modification can accidentally occur.

OPERATING LIMITS AND WARNINGS

1. The user is advised to at least familiarize himself with the A.I.S.C. specifications regarding allowable stresses in beam and column design due to the complexity in conforming to the many conditions involved.
2. Program is not valid for A514 steel or box type members, angles, channels, or tees.
3. Flanges shall be continuously connected to the web.
4. Slenderness ratios $KL/r > 200$ will give an error message.
5. Section 1.10 requirements for very slender webs is not addressed by the program.
6. When width-thickness ratios exceed section 1.9, the message "APPENDIX C GOVERNS" is displayed.

DEFINITIONS

A = Cross sectional area, inches²
A_f = Area of compression flange
C_b = Bending coefficient dependent upon moment gradient
b_f = Flange width of section, inches
C_{mx}, C_{my} = Moment reduction coefficient
d = Depth of section, inches
E = Modulus of elasticity of steel at $29 \cdot 10^6$ psi
f_a = Computed axial stress
F_a = Allowable compression stress
f_{bx} = Computed bending stress "x"
F_{bx} = Allowable bending stress x-axis
f_{by} = Computed bending stress "y"
F_{by} = Allowable bending stress y-axis
$F'e_y$ = Euler stress for a prismatic member divided by a factor of safety
FY or fy = Specified minimum yield stress of the type of steel being used (kips per inch²)
K_x = Effective length factor "x"
K_y = Effective length factor "y"
L = Length
L_b = Unbraced length, compression flange
L_c = Maximum unbraced length of compression flange at which allowable bending stress may be taken at $0.66F_y$
L_x = Unbraced length "x"
L_y = Unbraced length "y"
M_x = Moment about x-axis corrseponding to y direction
M_y = Moment about y-axis corresponding to x direction
P = Design axial load
r_t = Radius of gyration of a section comprising the compression flange plus one third of the compression web area, taken about an axis in the plane of the web
r_x = Radius of gyration about x-axis, inches
r_y = Radius of gyration about y-axis, inches
S_x = Section modulus about x-axis, inches³
S_y = Section modulus about y-axis, inches³
t_f = Flange thickness, inches
T_w = Web thickness, inches

EQUATIONS AND FORMULAS

Compression

$$C_c = \sqrt{\frac{2\pi^2E}{FY}}$$

$$\frac{d}{t_w} \leq \frac{253}{\sqrt{FY}} \quad (1.9.2.2.)$$

$$F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right] FY}{\frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}} \quad (1.5\text{-}1)$$

$$F_a = \frac{12\pi^2E}{23(KL/r)^2} \quad (1.5\text{-}2)$$

Bending, allowable stresses

$$\frac{b_f}{2t_f} > \frac{65}{\sqrt{FY}} \quad (1.5.1.4.1.2)$$

$$\frac{b}{t_f} > \frac{190}{\sqrt{FY}} \quad (\text{Section } 1.9)$$

$$\frac{d}{t} = \frac{257}{\sqrt{FY}} \quad (1.5\text{-}4b)$$

$$\frac{640\left(1 - 3.74\frac{f_a}{FY}\right)}{\sqrt{FY}} = \frac{d}{t} \quad (1.5\text{-}4a)$$

$$L_c = L_b > \frac{76b_f}{\sqrt{FY}} \quad (1.5.1.4.1.5.)$$

$$L_a = L_b > \frac{20000}{\left(\frac{d}{A_f}\right) FY} \quad (1.5.1.4.1.5.)$$

$$F_{bx} = \frac{2}{3} FY$$

$$F_{bx} = .6FY$$

$F_{by} = .75FY$

$$F'e = \frac{12\pi^2}{23(KL_b/r_b)^2}E$$

$$F_{bx} = FY\left[.79 - .002\left(\frac{b_f}{2t_f}\right)\sqrt{FY}\right] \quad (1.5\text{-}5a)$$

$F_{by} = .6FY$

$$F_{bx} = \left[\frac{2}{3} - \frac{FY(L/r_t)^2}{1.53 \cdot 10^6 C_b}\right]FY \quad (1.5\text{-}6a)$$

$$F_{bx} = \frac{1.7 \cdot 10^5 C_b}{(L_b/r_t)^2} \quad (1.5\text{-}6b)$$

$$F_{by} = FY\left[1.075 - .005\left(\frac{b_f}{2t_f}\right)\sqrt{FY}\right] \quad (1.5\text{-}5b)$$

$$F_{bx} = \frac{1.2 \cdot 10^4 C_b}{L_d/A_f} \quad (1.5\text{-}7)$$

Interaction Equations (Combined Stresses)

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'e_x}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'e_x} F_{by}\right)} \leq 1.0 \quad (1.6\text{-}1b)$$

$$\frac{f_a}{.6FY} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \quad (1.6\text{-}1b)$$

$$\text{when } \frac{f_a}{F_a} \leq .15 \quad \frac{f_a}{F_a} + \frac{f_b}{F_b} + \frac{f_{by}}{F_{by}} \leq 1.0$$

REFERENCES

Johnston, Jen-Lin, Galambos, "Basic Steel Design", 2nd Edition, Prentice-Hall, 1980.

Crawley, Dillon, "Steel Building Analysis and Design", John Wiley and Sons, 1977.

"A.I.S.C. Specifications for the Design, Fabrication, and Erection of Steel for Buildings", 1980.

PROGRAM USE NOTES

If a printer is attached, much of the information will be printed. The section properties, design data, and output will be listed.

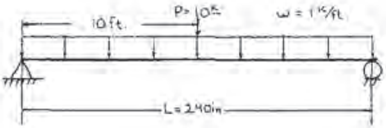
If a file of section properties is created in step 6a and a "DUPLICATE FILE" error occurs, key in a new file name and press [R/S].

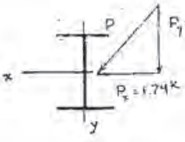
If the message "KL/R>200" appears, pressing [R/S] will allow the program to restart at step 4 of the instructions.

If L_c is exceeded, the display "Lc EXCEEDED" will momentarily appear and if a printer is attached, will be printed out.

If an exisiting section does not satisfy A.I.S.C. compact requirements (i.e., it is not partially compact) of section 1.5.1.4.1, the display "PART COMPACT" will momentarily appear, and if a printer is attached, be printed out.

SAMPLE PROBLEM #1:





A simply supported beam with a span of 20 ft. carries a uniform load of 1K/ft. including its own weight. A concentrated oblique load at midspan acts through the centroid as shown. Use A36 steel with no intermediate supports (try a W12x53).

Use the Structural Analysis Pac (HP 00041-15021) interactively to solve the moments.

Design Data
FYLD = 36 ksi
l_{bx} = 240 in
l_{by} = 240 in

SOLUTION:

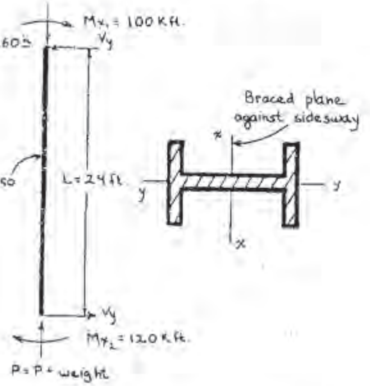
Input	Function	Display	Comments
Load "STLSOL"			
Begin	[XEQ] "SIMPLE"	L=?	Find moments
20	[R/S]	RDY A-I	
1	[ENTER↑]	1.00	
1	[XEQ] "a"	1.00	
1	[XEQ] "b"	0.00	
10	[ENTER↑]	10.00	
9.85	[XEQ] "c"	0.00	
10	[XEQ] "C"	MX=99.25	
12	[×]	1191	Mx = 1191 K-in.
	[XEQ] "SIMPLE"	L=?	
20	[R/S]	RDY A-I	
1	[ENTER↑]	1.00	
1	[XEQ] "a"	1.00	
10	[ENTER↑]	10.00	
1.74	[XEQ] "c"	0.00	
10	[XEQ] "C"	MX=8.70	
12	[×]	104.4	Mx = 104.4 K-in.
	[XEQ] "STLSOL"	COLUMN?	If the message "SIZE>=30" is displayed, set size ≥ 30 and press [R/S]
N*	[R/S]	BMSOL	"BMSOL" prints out if printer in use.
		NEW SHAPE?	
Y	[R/S]	DESIGNATION?	
W12X53	[R/S]	NEW DESIGN?	Properties are read from tape into the calculator. If a printer is in use, they are printed out.
Y	[R/S]	DESIGN DATA FYLD=	
36	[R/S]	L=	
240	[R/S]	Lb=	
240	[R/S]	MX=	
1191	[R/S]	MY=	For 1 way bending about the x-axis input My as 0.00
104.4	[R/S]	Lc EXCEEDED	
	[R/S]**	FbX=22.00	Allowable bending stresses
	[R/S]**	FbY=27.00	
	[R/S]**	FbX=16.87	Actual bending stresses
	[R/S]**	FbY=5.44	
	[R/S]**	0.97<=1.00	Beam okay, stresses 97% of capacity.
		CHANGES?	Answer "Y" to rerun problem with change in values.
N	[R/S]	NEW PRGM?	
N	[R/S]	0.00	
			To begin example 2, press [R/S]. The display "COLUMN?" will appear.

---

*Pressing only [R/S] also indicates a "no" response.

**If printer is in use, you need not perform this keystroke

SAMPLE PROBLEM #2:



Analyze the column, W14x90 as shown with the following design data.

Designation = W14x90
FYLD = 36 ksi (A36 steel)
$K_x = 1.2$
$K_y = 1.0$
$L_x = 288$ in
$L_y = 288$ in
$L_b = 288$ in

$M_x = 120 \times 12 = 1{,}440$ K in
$M_y = 0.0$
$P = 260 \div 2 = 262$ K in.

$$C_{m_x} = 0.6 - 0.4\left(\frac{100}{120}\right) = 0.27$$

(use 0.4)

$C_{my} = 0.0$
$C_b = 1.0$ (C_b should be known in case asked for)

SOLUTION:

Input	Function	Display	Comments
Load "STLSOL"			Load "STLSOL" if it is not in the calculator.
Begin	[XEQ] "STLSOL"	COLUMN?	If the message "SIZE>=30" appears, set size ≥ 30 and press [R/S].
Y	[R/S]	COLSOL	"COLSOL" printed out if printer in use.
		NEW SHAPE?	
Y	[R/S]	DESIGNATION?	
W14X90	[R/S]	NEW DESIGN?	Properties are read from tape into the calculator. If a printer is in use, they are printed out.
Y	[R/S]	DESIGN DATA FYLD=	
36	[R/S]	KX=	
1.2	[R/S]	LX=	
288	[R/S]	KY=	
1	[R/S]	LY=	
288	[R/S]	COMBINED?	
Y	[R/S]	MX=	
1440	[R/S]	MY=	
0	[R/S]	P=	
262	[R/S]	CMX=	
.4	[R/S]	CMY=	

Input	Function	Display	Comments
0	[R/S]	Lb=	
288	[R/S]	Lc EXCEEDED	
		Fa=15.59	F_a, the allowable compression stress
	[R/S]*	Pa=413.25	
	[R/S]*	Fa=9.89	f_a, the computed axial stress
	[R/S]*	FbX=22.00	F_{bx}, allowable bending stresses
	[R/S]*	FbY=27.00	F_{by}
	[R/S]*	FBX=10.07	f_{bx}, computed bending stresses
	[R/S]*	FBY=0.00	f_{by}
	[R/S]*	0.91<=1.00	Column stress okay
	[R/S]*	CHANGES?	
N	[R/S]	NEW PRGM?	
N	[R/S]	0.00	

*If printer is in use, you need not perform this keystroke

USER INSTRUCTIONS

SIZE: 30

Step	Instructions	Input	Function	Display
1	Load "STLSOL"			
2	Begin		[XEQ] "STLSOL"	COLUMN?*
3a	If column solution desired	Y	[R/S]	COLSOL
3b	If beam solution desired	N**	[R/S]	BMSOL NEW SHAPE?
4a	If new shape or first run	Y	[R/S]	DESIGNATION?
4b	If not, press then go to step 7.	N	[R/S]	
5a	If desired section properties file exists, key in name	file name	[R/S]	If a printer is attached properties are output.
	Go to step 7.			
5b	For a special section press only		[R/S]	A=?
	Then key in properties: cross sectional area (in^2)	A	[R/S]	d=
	depth of section (in)	d	[R/S]	BF=
	width of flange (in)	b_f	[R/S]	TF=
	thickness of flange (in)	t_f	[R/S]	TW=
	thickness of web (in)	t_w	[R/S]	SX=
	section modulus, x-axis x-axis (in^3)	S_x	[R/S]	RX=
	radius of gyration, x-axis (in)	r_x	[R/S]	SY=
	section modulus, y-axis (in^3)	S_y	[R/S]	RY=
	radius of gyration, y-axis (in)	r_y	[R/S]	RT=
	radius of gyration for compression flange plus 1/3 of compression web	r_t	[R/S]	REVIEW?
5c	To review		[R/S]	A=nn?
	If the value is correct, press only		[R/S]	d=nn?
	If the value is in error, key in	new value	[R/S]	BF=nn?
	All properties will be displayed in this manner. The review will start over after last value.			REVIEW?
5d.	To skip review	N	[R/S]	MAKE FILE?
6.	To make a data file on the cassette, press	Y	[R/S]	FILE NAME?
	Then key in desired name.	file name	[R/S]	NEW DESIGN?
7.	For beam solution go to step 11. COLUMN SOLUTION			
8.	If new design or 1st run, press	Y	[R/S]	DESIGN DATA
	else press and go to step 12	N***	[R/S]	
9.	Key in design data			FYLD=
	Input yield strength (ksi)	FYLD	[R/S]	KX=
	Input effective length factor, x	K_x	[R/S]	LX=
	Input unbraced length, x (in)	L_x	[R/S]	KY=
	Input effective length factor, y	K_y	[R/S]	LY=
	Input unbraced length, y (in)	L_y	[R/S]	COMBINED?
10a.	If combined axial load and bending press		[R/S]	MX=
	Input moment about x (K-in)	M_x	[R/S]	MY=
	Input moment about y (K-in)	M_y	[R/S]	P=
	Input design axial load (kips)	P	[R/S]	CMX=
	Input moment reduction coefficient, x	C_{mx}	[R/S]	CMY=
	Input moment reduction coefficient, y	C_{my}	[R/S]	Lb=****
	Input unbraced compression flange length (in)	L_b	[R/S]	
	Go to step 12			
10b.	If axial load only	N	[R/S]	
	Only F_a, P_a will be output Go to step 12			
	BEAM SOLUTION			NEW DESIGN?
11a.	If new design or 1st run, press	Y	[R/S]	FYLD=
	and key in design data Input yield strength (ksi)	FYLD	[R/S]	L=
	Input length (in)	L	[R/S]	Lb=
	Input unbraced length of compression flange (in)	L_b	[R/S]	MX=
	Input moment about x (K-in)	M_x	[R/S]	MY=
	Input moment about y (K-in)	M_y	[R/S]	
11b.	Else press	N	[R/S]	
12.	F_a, P_a are the only outputs for the uniaxial column case. F_{bx}, F_{by}, f_{bx}, f_{by} are the only ouptuts for beam solution allowable axial stress (ksi)			Fa=nn
	maximum axial load (kips)		[R/S]*****	Pa=nn
	actual axial stress (ksi)		[R/S]*****	fa=nn
	allowable bending stress, x (ksi)		[R/S]*****	FbX=nn

Step	Instructions	Input	Function	Display
	allowable bending stress, y (ksi)		[R/S]*****	FbY=nn
	actual bending stress, x (ksi)		[R/S]*****	FBX=nn
	actual bending stress, y (ksi)		[R/S]*****	FBY=nn
	interaction equation		[R/S]*****	N.nn(< or >) =1.00
			[R/S]*****	CHANGES?
13a	If you desire to rerun the same problem with a different section or set of design parameters, press and go to step 4a	Y	[R/S]	NEW SHAPE?
13b	Else press	N	[R/S]	NEW PRGM?
14a	If a new program recorded on the cassette is desired, press	Y	[R/S]	PRGM NAME?
	then key in the program name	file name	[R/S]	
14b	Else press	N	[R/S]	0.00
15	To begin a new problem requiring STLSOL press and go to step 3		[R/S]	COLUMN?

*If the display "SIZE>=30" appears, set size to at least 30 and press [R/S].

**Pressing only [R/S] also indicates a "no" response.

***If a "no" response is given at steps 4a and 8, the program loops back to 4a.

****If L_u is exceeded, C_b will be prompted for.

*****If printer is in use, you need not perform this keystroke.

REGISTERS, STATUS, FLAGS

Data Registers Status

00 A	SIZE 030	TOT. REG 267
01 d	ENG	FIX 2 SCI
02 b_f	DEG	RAD GRAD
03 t_f		
04 t_w		
05 S_x		
06 r_x		
07 S_y		
08 r_y		
09 r_t		
10 FY		
11 K_x		
12 L_x,L		
13 K_y		
14 L_y,L_b		
15 M_x		
16 M_y		
17 P		
18 C_{mx}		
19 C_{my}		
20 F_a		
21 P_a		
22 f_a		
23 F_{bx}		
24 F_{by}		
25 f_{bx}		
26 f_{by}		
27 C_b		
28 Counter		
29 Miscellaneous intermediate values		

Flags

# SET INDICATES	CLEAR INDICATES
00 New section or design	
01 Non compact section	Compact section
02 L_x or L_c exceeded	$L_{x,y} < L_c$ and L_u
03 $f_a/F_a > 0.15$	
04 $f_a/F_a < 0.15$	
05 Combined loading	Axial solution
06 Beam solution	Column solution
07 Review spec. section data	Spec. section input
12 Double-wide print	Single-wide print
13 Print lower case	Print default case
21 Printer enable	Printer disable
23 Alpha data entered	No alpha data entered
25 Error ignore on	No error ignore
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "STL
SOL"
 02 CF 21          Print outputs if printer in use
 03 FS? 55
 04 SF 21
 05 .007
 06♦LBL 32         Clear flags 0-7
 07 CF IND X
 08 ISG X
 09 GTO 32
 10 ADV
 11 "SIZE>=3       Size check
0"
 12 SF 25
 13 RCL 29
 14 FC?C 25        Display minimum size if necessary
 15 PROMPT
 16 SF 12
 17 "COLUMN?
"
 18 AON
 19 STOP
 20 XEQ 37         Places response in Y, "Y" in X
 21 X≠Y?
 22 SF 06          If beam, set flag 6
 23 "COLSOL"
```

```
 24 FS? 06
 25 "BMSOL"
 26 AVIEW          Display solution type
 27 PSE
 28 CF 12
 29 ADV
 30♦LBL 01
 31 CF 02
 32 CF 03
 33 AON            Ask if new shape
 34 CLD
 35 "NEW SHA
PE?"
 36 STOP
 37 XEQ 37         Places response in Y, "Y" in X
 38 X≠Y?
 39 GTO 02         If not, go to label 2
 40 CF 01
 41 SF 00          Clear flags here for change feature
 42 CF 23
 43 "DESIGNA       Get section file name
TION?"
 44 STOP           If unspecified
 45 FC? 23         go to special input
 46 GTO 33
 47 FS? 21
```

```
 48 AVIEW
 49 READR              Read in file from tape
 50♦LBL 35
 51 FC? 55             Properties printout, skip if no printer
 52 GTO 02
 53 9 E-3
 54 STO 28
 55 "PROPERT           Print out properties
IES"
 56 PRA
 57 FIX 2
 58 " A="
 59 XEQ 01
 60 " d="
 61 XEQ 01
 62 SF 13
 63 "BF="
 64 XEQ 01
 65 SF 13
 66 "TF="
 67 XEQ 01
 68 SF 13
 69 "TW="
 70 XEQ 01
 71 "SX="
 72 XEQ 01
 73 SF 13
 74 "RX="
 75 XEQ 01
 76 "SY="
 77 XEQ 01
 78 SF 13
 79 "RY="
 80 XEQ 01
 81 SF 13
 82 "RT="
 83♦LBL 01             Control subroutine for
 84 ARCL IND             properties print out
 28
 85 PRA
 86 CF 13
 87 ISG 28
 88 RTN
 89♦LBL 02
 90 CLD
 91 "NEW DES           Ask if new design.
IGN?"                    Response in Y, "Y" in X
 92 STOP
 93 XEQ 37
 94 AOFF
 95 X≠Y?
 96 GTO 03             If not, skip design input
 97 CF 05
 98 SF 00
 99 ADV
100 10.014             Prepare for design input
101 STO 28
102 "DESIGN            Input design data.
DATA"                    If beam solution, go to 25
103 AVIEW
104 PSE
```

```
105 FS? 06
106 GTO 25
107 "FYLD="
108 XEQ 00
109 "KX="
110 XEQ 00
111 "LX="
112 XEQ 00
113 "KY="
114 XEQ 00
115 "LY="
116 GTO 00             00 is a control subroutine for
                         prompts, see step 184
117♦LBL 33             Input for special sections file
118 AOFF
119 9 E-3
120 STO 28
121 "A="
122 XEQ 31
123 "d="
124 XEQ 31
125 "BF="
126 XEQ 31
127 "TF="
128 XEQ 31
129 "TW="
130 XEQ 31
131 "SX="
132 XEQ 31
133 "RX="
134 XEQ 31
135 "SY="
136 XEQ 31
137 "RY="
138 XEQ 31
139 "RT="
140♦LBL 31             Control subroutine for
141 RCL IND              special sections file
28
142 FS? 07
143 ARCL X
144 FS? 07
145 "├?"               Append "?" if reviewing data
146 PROMPT
147 STO IND
28
148 ISG 28
149 RTN
150 "REVIEW?           Review input if desired
"
151 AON
152 STOP
153 AOFF
154 XEQ 37             Response in Y, "Y" in X
155 X≠Y?               If not, continue at 34.
156 GTO 34               Show correct value
157 SF 07
158 GTO 33
159♦LBL 34
160 "MAKE FI           Create a file if desired
LE?"
```

```
161 AON
162 STOP
163 XEQ 37          Response in Y, "Y" in X
164 X≠Y?
165 GTO 35          If file unnecessary, continue
166 AON
167 "FILE NA        else get file name
ME?"
168 STOP
169 10              Create a 10 register data file
170 CREATE
171 0               Store registers 0-9 in file
172 SEEKR
173 9 E-3
174 WRTRX
175 GTO 35
176♦LBL 25          Design input for beam solution
177 "FYLD="
178 XEQ 00
179 ISG 28
180 " L="
181 XEQ 00
182 ISG 28
183 "Lb="
184♦LBL 00          Control subroutine for
185 PROMPT            design data input
186 ARCL X
187 STO IND
28
188 FS? 21
189 AVIEW
190 ISG 28
191 RTN
192 CLD
193♦LBL 03          New shape check:
194 FC?C 00           If not, return to 01
195 GTO 01
196 FS? 06          If beam, continue at 26
197 GTO 26
198 "COMBINE        Combined loading?
D?"
199 AON
200 STOP
201 XEQ 37          Response in Y, "Y" in X
202 AOFF
203 X≠Y?            If not, continue at 04
204 GTO 04
205 SF 05           Indicate combined loading
206 15.019
207 STO 28
208 "MX="           Input combined loading data
209 XEQ 05
210 "MY="
211 XEQ 05
212 " P="
213 XEQ 05
214 "CMX="
215 XEQ 05
216 "CMY="
217♦LBL 05          Control subroutine for
218 PROMPT            combined loading, data input
```

```
219 ARCL X
220 STO IND
28
221 FS? 21
222 AVIEW
223 ISG 28
224 RTN
225 GTO 04
226♦LBL 26          Input beam loading data
227 "MX="
228 PROMPT
229 ARCL X
230 STO 15
231 FS? 21
232 AVIEW
233 "MY="
234 PROMPT
235 ARCL X
236 STO 16
237 FS? 21
238 AVIEW
239 GTO 27          LBL 27 at line 340
240♦LBL 04          Compute allowable axial stress
241 CLD
242 FS? 05
243 GTO 04
244 253
245 RCL 10
246 SQRT
247 /
248 RCL 01
249 RCL 04
250 /
251 X>Y?            d/la > 253/√Fy?
252 GTO 99          Display "APPENDIX C GOVERNS"
253♦LBL 04
254 RCL 11          KxLx/rx
255 RCL 12
256 *
257 RCL 06
258 /
259 RCL 13          KyLy/ry
260 RCL 14
261 *
262 RCL 08
263 /
264 X<=Y?           Use largest slenderness ratio
265 X<>Y
266 2 E2
267 X<Y?
268 GTO 21          Call error if KL/r ≥ 200
269 X<>Y
270 STO 21          Compute buckling limitation
271 PI
272 X↑2
273 2
274 *
275 29 E3
276 *
277 RCL 10
278 /
```

```
279 SQRT
280 X>Y?                $C_c > KL/r$?
281 GTO 06
282 X<>Y
283 X↑2                 $F_a = \frac{12\pi^2E}{23(KL/r)^2}$
284 1/X
285 PI
286 X↑2
287 *
288 12
289 *
290 29 E3
291 *
292 23
293 /
294 STO 20              Allowable axial stress $F_a$
295 GTO 07
296♦LBL 06               Calculate $F_a$ by equation 1.5-1
297 STO 20              Where factor of safety
298 X↑2                   equals denominator
299 2
300 *
301 RCL 21
302 X↑2
303 X<>Y
304 /
305 1
306 X<>Y
307 -
308 RCL 10
309 *
310 5
311 ENTER↑
312 3
313 /
314 RCL 21
315 .375
316 *
317 RCL 20
318 /
319 +
320 RCL 21
321 X↑2
322 LASTX
323 *
324 8
325 /
326 RCL 20
327 X↑2
328 /
329 LASTX
330 SQRT
331 /
332 -
333 /
334 STO 20
335♦LBL 07               Allowable axial stress
336 RCL 00                for alternate formula
337 *
338 STO 21
339 FC? 05              Exit if not combined
```

```
340 GTO 22
341♦LBL 27               Compute allowable bending stress
342 65
343 RCL 10
344 SQRT
345 /
346 RCL 02
347 RCL 03
348 2
349 *
350 /
351 X>Y?                $b_f/2t_f > 65/\sqrt{FY}$ ?
352 SF 01
353 "PART CO
MPACT"
354 FS? 01              Display "Partial Compactness"
355 AVIEW                 if needed
356 190
357 RCL 10
358 SQRT
359 /
360 X<>Y
361 2
362 *
363 X>Y?                $b/t_f > 190/\sqrt{FY}$ ?
364 GTO 99              Display "APPENDIX C GOVERNS"
365 257
366 RCL 10
367 SQRT
368 /
369 RCL 17
370 RCL 00
371 /
372 RCL 10
373 /
374 3.74
375 *
376 1
377 X<>Y
378 -
379 640
380 *
381 RCL 10
382 SQRT
383 /
384 X<=Y?
385 X<>Y                $640\left(1 - 3.74\frac{f_a}{F_a}\right)/\sqrt{FY} \leq 257/\sqrt{FY}$ ?
386 RCL 01
387 RCL 04
388 /
389 X>Y?                $d/t_w >$ value in Y ? If so, set flag 2.
390 SF 02
391 RCL 02
392 76                  $76b_f/\sqrt{FY}$
393 *
394 RCL 10
395 SQRT
396 /
397 FS? 06              Beam solution?
398 GTO 08
399 "Lb="
```

```
400 PROMPT
401◆LLL 08
402 FS? 06
403 RCL 14
404 STO 28
405 X>Y?          $l_b > 76b_f/\sqrt{FY}$ ?
406 SF 02
407 "Lc EXCE
EDED"
408 FS? 02
409 AVIEW
410 RCL 01
411 RCL 02
412 /
413 RCL 03
414 /
415 RCL 10        $\frac{20 \cdot 10^3}{(d/A_f)FY}$
416 *
417 2 E4
418 X<>Y
419 /
420 X<>Y
421 X>Y?          $l_b = \frac{20 \cdot 10^3}{(d/a_f)FY}$ ?
422 GTO 10
423 FS? 02
424 GTO 11        $F_{bx} = .6FY$
425 FS? 01
426 GTO 12        $F_{bx} = FY\left[.79 - .002\left(\frac{b_f}{2t_f}\sqrt{FY}\right)\right]$
427 RCL 10
428 2             $F_{bx} = \frac{2}{3}FY$
429 *
430 3
431 /
432 GTO 13
433◆LBL 99        "APPENDIX C GOVERNS" message
434 ADV
435 SF 12
436 "APPENDI
X-C"
437 AVIEW
438 PSE
439 "GOVERNS
"
440 AVIEW
441 PSE
442 CF 12
443 GTO 24        Go to exit routine
444◆LBL 12        $F_{bx} = FY\left[.79 - .002\left(\frac{b_f}{2t_f}\sqrt{FY}\right)\right]$
445 RCL 02
446 RCL 03
447 /
448 2
449 /
450 RCL 10
451 SQRT
452 *
453 2 E-3
454 *
455 .79
456 X<>Y
457 -
```

```
458 RCL 10
459 *
460 LASTX
461 1.5
462 /
463 X>Y?
464 X<>Y
465 GTO 13
466◆LBL 10        $l_b/r_t$
467 RCL 28
468 RCL 09
469 /
470 STO 25
471 102 E3
472 "Cb="         $\sqrt{\frac{1.02 \cdot 10^5 C_b}{FY}}$
473 PROMPT
474 ARCL X
475 FS? 21
476 AVIEW
477 CLD
478 STO 27
479 *
480 RCL 10
481 /
482 SQRT          $\sqrt{\frac{1.02 \cdot 10^5 C_b}{FY}} \leq l_b/r_t$?
483 X<=Y?
484 GTO 10
485◆LBL 11        $F_{bx} = .6FY$
486 .6
487 RCL 10
488 *
489 FIX 0
490 RND
491 FIX 2
492 GTO 13        $\sqrt{\frac{5.1 \cdot 10^5 C_b}{FY}}$
493◆LBL 10
494 51 E4
495 RCL 27
496 *
497 RCL 10
498 /
499 SQRT
500 RCL 25        $l_b/r_t$
501 X<=Y?
502 GTO 10
503 17 E4         $F_{bx} = \frac{17 \cdot 10^5 C_b}{(L_b/r_t)^2}$ (1.5-6b)
504 RCL 25
505 X↑2
506 /
507 GTO 14
508◆LBL 10        $F_{bx} = \left[\frac{2}{3} - \frac{FY(L/r_t)^2}{1.53 \cdot 10^6 C_b}\right]FY$ (1.5-6a)
509 X↑2
510 RCL 10
511 *
512 153 E4
513 /
514 RCL 27
515 /
516 2
517 ENTER↑
518 3
```

```
519 /
520 X<>Y
521 -
522 RCL 10
523 *
524+LBL 14
525 12 E3
526 RCL 27
527 *
528 RCL 28        F_bx = 1.2 · 10^6 C_b / (L_d/A_f)   (1.5-7)
529 /
530 RCL 01
531 /
532 RCL 02
533 *
534 RCL 03
535 *
536 X<=Y?
537 X<>Y
538 RCL 10        .6FY
539 .6
540 *
541 FIX 0         Use largest of two values,
542 RND            but not greater than .6FY
543 FIX 2
544 X>Y?
545 X<>Y
546+LBL 13
547 STO 23        Store F_bx
548 FS? 01        F_by calculation compact?
549 GTO 15
550 RCL 10
551 .75
552 *
553 STO 24        F_by = .75FY
554 FS? 06
555 GTO 28
556 GTO 16
557+LBL 15        b_f/2t_f
558 RCL 02
559 RCL 03
560 /
561 2
562 /
563 RCL 10
564 SQRT          95/√FY
565 95
566 X<>Y
567 /
568 X<>Y
569 X>Y?          b_f/2t_f > 95/√FY ?
570 GTO 17        F_by = .6FY
571 5 E-3
572 *
573 RCL 10 F_by = FY[1.075 - .005 (b_f/2t_f) √FY]
574 SQRT
575 *
576 1.075
577 X<>Y
578 -
579 RCL 10
```

```
580 *
581 LASTX
582 .75           .75FY
583 *
584 X>Y?
585 X<>Y
586 STO 24
587 FS? 06
588 GTO 28
589 GTO 16
590+LBL 17        Begin interaction equations
591 .6
592 RCL 10
593 *
594 FIX 0
595 RND
596 FIX 2
597 STO 24
598 FS? 06
599 GTO 28
600+LBL 16
601 RCL 17
602 RCL 00
603 /
604 STO 22
605 RCL 20
606 /
607 STO 28
608 .15
609 X<>Y
610 X>Y?          f_a/F_a > 0.15
611 SF 03
612+LBL 28
613 RCL 15
614 RCL 05
615 /             M_x/S_x = f_bx
616 STO 25
617 FS? 06
618 GTO 29
619 RCL 23        f_bx/F_bx
620 /
621 STO 27
622 FS? 03        f_a/F_a > 0.15 ?
623 XEQ 18
624 SF 04
625 ST+ 28
626+LBL 29
627 RCL 16
628 RCL 07
629 /
630 STO 26
631 FS? 06
632 GTO 30
633 RCL 24
634 /
635 ST+ 27
636 FS? 03
637 XEQ 18
638 ST+ 28
639 RCL 22
640 RCL 10
```

```
641 .6
642 *
643 FIX 0
644 RND
645 FIX 2
646 /
647 RCL 27
648 +
649 RCL 28
650 X<=Y?
651 X<>Y
652 STO 28
653 GTO 22
654♦LBL 18
655 XEQ 19
656 RCL 22
657 X<>Y
658 /
659 1
660 X<>Y
661 -
662 FS? 04
663 RCL 19
664 RCL 18
665 FS? 04
666 RDN
667 X<>Y
668 /
669 *
670 RTN
671♦LBL 19
672 PI
673 X↑2
674 29 E3
675 *
676 12
677 *
678 23
679 /
680 FS?C 04
681 GTO 20
682 RCL 11
683 RCL 12
684 *
685 RCL 06
686 /
687 X↑2
688 /
689 RTN
690♦LBL 20
691 RCL 13
692 RCL 14
693 *
694 RCL 08
695 /
696 X↑2
697 /
698 RTN
699♦LBL 21
700 ADV
```

```
701 "KL/R>20      KL/r > 200 display
0"
702 PROMPT
703 GTO 01        Start over
704♦LBL 22
705 ADV           Column solution output
706 20.026
707 STO 29
708 FC? 55
709 SF 21
710 "Fa="
711 XEQ 22
712 "Pa="
713 XEQ 22
714 FC? 05
715 GTO 24
716 SF 13
717 "Fa="
718 XEQ 22
719 "FbX="
720 XEQ 22
721 "FbY="
722 XEQ 22
723 SF 13
724 "FBX="
725 XEQ 22
726 SF 13
727 "FBY="
728 GTO 22
729♦LBL 30        Beam solution output
730 ADV
731 RCL 25
732 RCL 23
733 /
734 RCL 26
735 RCL 24
736 /
737 +
738 STO 28
739 23.026
740 STO 29
741 FC? 55
742 SF 21
743 "FbX="
744 XEQ 22
745 "FbY="
746 XEQ 22
747 SF 13
748 "FBX="
749 XEQ 22
750 SF 13
751 "FBY="
752♦LBL 22        Output control subroutine
753 ARCL IND
 29
754 AVIEW
755 CF 13
756 ISG 29
757 RTN
758 CLA
```

```
759 CLD
760 ARCL 28
761 1
762 RCL 28           Output for interaction
763 X<=Y?             compare to unity
764 GTO 23
765 "⊢>1.00"
766 AVIEW
767 GTO 24
768◆LBL 23
769 "⊢<=1.00
"
770 AVIEW
771◆LBL 24
772 CF 21
773 CLD
774 AON
775 "CHANGES         Start over for new design
?"                    or section if desired
776 STOP
777 XEQ 37
778 X=Y?
779 GTO 01           New program?
780 "NEW PRG
M?"
781 STOP
782 XEQ 37
783 X≠Y?             If not, clean up and quit, else
784 GTO 36
785 "PRGM NA         Get new program name
ME?"
786 STOP
787 READP            Read in new program
788◆LBL 37           Question subroutine.
789 ASTO Y            Store response in Y, "Y" in X
790 "Y"
791 ASTO X
792 RTN
793◆LBL 36
794 AOFF             Clean up display,
795 CLX               turn off alpha and stop
```

MAG

"MAG" computes Moment Magnification Factors for the case of slender columns. IT MUST BE RUN BEFORE USING THE CONCRETE PROGRAMS "UL2CON" OR "CIRCON", even if slenderness is not considered. The appropriate program will be loaded by "MAG" at its completion.

According to the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77), slenderness effects in compression members must be considered. Analysis must take into account influence of axial loads and variable moment of inertia on member stiffness and fixed end moments, effect of deflections on moments and forces, and duration of load. Section 10.10.2 states that slenderness effects may be evaluated by an approximating procedure described in section 10.11. This program is based on that procedure.

The designer must establish whether the section is a slender column by evaluating the parameter Kl_u/r. The effects of slenderness may be ignored when the section is braced against sidesway and

$$Kl_u/r < 34 - 12(M1/M2) \quad \text{(section 10.11.4.1)}$$

For members not braced against sidesway the effects of slenderness may be neglected when

$$Kl_u/r < 22.0 \quad \text{(section 10.11.4.2)}$$

For $Kl_u/r \geq 100$ the analysis must follow section 10.10.1, and is beyond the scope of this program.

The effective length of compression members is determined by the modifying member length by the factor K. When compression members are braced against sidesway, K will be taken as 1.00 unless analysis shows that a lower value may be used. For compression members not braced against sidesway, K shall be determined considering cracking and reinforcement on relative stiffness and shall be greater than 1.00. See Appendix A, page 77. The radius of gyration r may be taken as 0.30 times the overall dimensions in the direction stability is being considered for rectangular sections and 0.25 times the diameter for circular sections.

For moment magnification, compression members shall be designed using the factored load P_u from the conventional analysis, and magnified by

$$M_c = MFX(M2)$$

where $MFX, MFY = C_{m(x,y)}/[1 - (P_u/\Phi P_c)] \geq 1.0$

$$\text{and } P_c = \pi^2 EI/(Kl_u)^2$$

EI may be taken as either of the following two equations

$$EI = (E_c I_g/5) + E_s I_{se}/[1 + \beta d] \quad (10\text{-}9)$$

$$EI = E_c I_g/2.5/[1 + \beta d] \quad (10\text{-}10)$$

of which 10-10 is said to be conservative. This appears to be relative to the value of $0.1F_c'$ times Area gross. When this is compared to P_u, it provides a dividing line where

1. $P_u > 0.1F_c'A_g$ compression governs
2. $P_u < 0.1F_c'A_g$ tension governs

When 2 exists, A.C.I. provides that Φ (capacity reduction factor) may be increased from 0.7 for columns to 0.9 for beams by linear interpolation.

When Φ is modified in this way, equation 10-9 becomes the conservative equation producing extremely high magnification factors. Therefore, this program uses the largest value of EI determined by equations 10-9 and 10-10 to compute the magnification factor (see reference 1).

For members braced against sidesway without transverse loads $C_{m(x,y)}$ may be taken as

$$C_{m(x,y)} = 0.6 + 0.4(M1/M2) \quad \text{(Section 10-11)}$$

but not less than 0.4. For all other cases, C_m shall be taken as 1.0. If no moment exists at both ends of a compression member or end eccentricities are less than (0.6 + 0.03h) in. M2, $M2 = P_u(0.6 + 0.03h)$ about the x- and/or y-axes when computed and eccentricities are less than above. Computed end moments may be used to evaluate M1/M2 in section 10-11.

OPERATING LIMITS AND WARNINGS

1. $Kl_u/r > 100$ is beyond the scope of this program.

DEFINITIONS

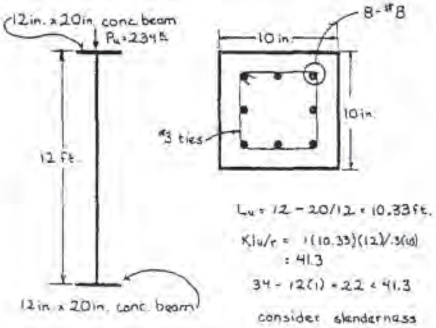
A_g = Gross concrete area
b = Width (side parallel to x-axis) inches
βd = Ratio of maximum factored dead load moment to maximum factored total load moment (always positive)
C_m = Factor related to moment diagram
E = Modulus of elasticity
E_c = Modulus of elasticity for concrete at 57,000 sqr(F_c') psi
E_s = Modulus of elasticity for steel at $29 \cdot 10^6$ psi
F_c = Concrete strength
F_c' = Ultimate concrete strength, psi
I = Moment of inertia
I_g = Gross moment of inertia of member inches^4
I_{se} = Moment of inertia of reinforcing about centroid of concrete section = Ay^2 inches^4
K = Effective length factor
l_u = Unbraced length in feet
M_c = Factored moment used for design of compression member
MFX = Moment magnification factor, x-axis
MFY = Moment magnification factor, y-axis
Mu<D.L.> = Ultimate dead load moment
Mu<al> = Ultimate applied moment (vertical and lateral being considered depending on loading considered)
M1 = Smaller computed end moment
M2 = Larger computed end moment
P_c = Critical buckling load
P_u = Factored ultimate load, kips
r = Radius of gyration
$r_{x,y}$ = Radius of gyration x-, y-axes
T = Depth (side parallel to y-axis), inches
Φ = Capacity reduction factor

REFERENCES

Wang and Salmon, "Reinforced Concrete Design", Third Edition, Harper & Row, 1979.

"Building Code Requirements for Reinforced Concrete", (A.C.I. 318-77).

SAMPLE PROBLEM:



Determine the moment magnification factor for the 10" x 10" column shown with the following data.

F_c = 3,000 psi
E_s = 29·10³ ksi
P_u = 234 kips

I_s = 2(2.37)(2.59)² = 31.796 in⁴
Mu<D.L.> = 50.4 K'
Mu<al> = 183.60 K'
K = 1.0
$C_{x,y}$ = 1.0
L_y = 10.33'
Column is subject to one way bending

SOLUTION:

Input	Function	Display	Comments
Load "MAG"			Load program "MAG"
Begin	[XEQ] "MAG"	RECTANGULAR?	If the display "SIZE>=16" is shown, set size ≥ 16, press [R/S].
Y	[R/S]	SLENDER COLUMN?	If a printer is in use copy of the inputs is made and the outputs are recorded
Y	[R/S]	MAG FACTOR X AXIS b=	
10	[R/S]	T=	
10	[R/S]	PU=	
234	[R/S]	MU<DL>=	
50.4	[R/S]	MU<aL>=	
183.6	[R/S]	IS=	
31.796	[R/S]	K=	
1	[R/S]	LU=	
10.33	[R/S]	FC=	
3000	[R/S]	CM=	
1	[R/S]	1 WAY BEND?	
Y	[R/S]	MFX=1.78	
	[R/S]*	MFY=1.00	
	[R/S]*	OKAY?	Are the magnification factors okay?
Y	[R/S]	UL2CON	Indicate a yes response

"MAG" has been replaced by "UL2CON" which would complete the solution.

*If a printer is in use, you need not perform these keystrokes.

USER INSTRUCTIONS

Step	Instructions	Input	Function	Display
1	Load "MAG"			
2	Begin		[XEQ] "MAG"	RECTANGULAR?*
3a	If rectangular, press	Y	[R/S]	SLENDER COL?
3b	If circular, press	N	[R/S]	SLENDER COL?
4a	If column is slender press	Y	[R/S]	MAG FACTOR
4b	If not, press and continue at step 8	N**	[R/S]	
5	Input for magnification factors, x-axis			b=
	Input width (side parallel to x-axis) (in)	b	[R/S]	T=
	Input depth (side parallel to y-axis) (in)	T	[R/S]	PU=
	Input factored ultimate load, (kips)	P_u	[R/S]	MU<DL>=
	Input dead load moment (kip-ft)	Mu<D.L.>	[R/S]	MU<aL>=
	Input applied moment (kip-ft)	Mu<aL>	[R/S]	IS=
	Input moment of inertia of reinforcing	I_s	[R/S]	K=
	Input effective length factor	K	[R/S]	LU=
	Input unbraced length in feet	l_u	[R/S]	FC=
	Input ultimate concrete strength, psi	F_c	[R/S]	CM=
	Input factor related to moment diagram	C_m	[R/S]	1 WAY BEND?
6a	If one way, press	Y	[R/S]	
	go to step 8b			Y AXIS
6b	If not, press	N	[R/S]	b = nn T = nn Pn = nn MU<DL> =
7	Input dead load moment, y-axis	Mu<D.L.>	[R/S]	Mu<aL> =
	Input applied moment, y-axis	Mu<aL>	[R/S]	IS=
	Input moment of inertia of reinforcing	I_s	[R/S]	K=
	Input effective length factor	K	[R/S]	LU=
	Input unbraced length in feet	l_u	[R/S]	CM=
	Input factor related to moment diag.	C_m	[R/S]	
8a	Output for nonslender columns			MFX=1.0
	go to step 9		[R/S]***	MFY=1.0

8b	Output for 1 way bending go to step 9		[R/S]***	MFX = nn MFY = 1.0
8c	Output for 2 way bending		[R/S]*** [R/S]***	MFX = nn MFY = nn OKAY?
9a	If factors are adequate press "CIRCON" or "LU2CON" will load	Y	[R/S]	
9b	If factor is too large or modification of column is desired press go to step 3	N	[R S]	RECTANGULAR?

*If the display "SIZE >= 16" appears, set size ≥ 16, press [R/S] and continue.
**Pressing only [R/S] will also indicate a "no" response.
***If a printer is in use, you need not perform these keystrokes.

REGISTERS, STATUS, FLAGS

Data Registers

00 b
01 T
02 P_u
03 Mu<D.L.>
04 Mu<al>
05 I_s
06 K
07 L_u
08 F_c
09 $E_cI_g/5+I_s$
E_s. $E_cI_g/2.5$
10 π^2EI
11 Control
12 I_g
13 MFX
14 MFY
15 Used/scratch

Status

SIZE 16 TOT. REG. 91
ENG FIX 2 SCI
DEG RAD GRAD

Flags

# SET INDICATES	CLEAR INDICATES
00 2 way bend	1 way bend
04 Rectangular	Circular
12 Double-wide print	Single-wide print
21 Printer enable	Printer disable
25 Error ignore on	No error ignore
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "MAG
"
 02 CF 21          Print outputs if printer attached
 03 FS? 55
 04 SF 21
 05 FIX 2
 06 CF 00
 07 CF 04
 08 "SIZE>=1      Check for minimum size needs
6"
 09 SF 25
 10 RCL 15
 11 FC?C 25        Display minimal size if necessary
 12 PROMPT
 13 AON
 14 "RECTANG      Ask if rectangular column.
ULAR?"               No indicates circular
 15 STOP
 16 XEQ 00         LBL 00 sets up response and
 17 X=Y?             "Y" for comparison
 18 SF 04          SF04 if rectangular
 19 1              Initialize moment magnification
 20 STO 13           coefficient registers
 21 STO 14
 22 "SLENDER
 COL?"
 23 STOP
 24 XEQ 00
 25 AOFF           If not slender column
 26 X≠Y?
 27 GTO 05         go display moments
 28 SF 12            magnification factors (= 1)
 29 "MAG FAC      else begin inputs to calculate
TOR"                 moment magnification factors for
 30 AVIEW            slender column
 31 PSE
 32 CF 12
 33 CLD
 34♦LBL 01
```

```
 35 ADV
 36 1 E3
 37 FS? 00
 38 ST/ 02
 39 "Y"            Identify axis input
 40 FC? 00
 41 "X"
 42 "⊢ AXIS"
 43 AVIEW
 44 PSE
 45 .008
 46 STO 11
 47 FS? 04
 48 GTO 01
 49 RCL IND
11
 50 "D="           Data input
 51 FC? 00
 52 PROMPT
 53 XEQ 03
 54 ISG 11
 55 GTO 02
 56♦LBL 01
 57 RCL IND
11
 58 "b="
 59 FC? 00
 60 PROMPT
 61 XEQ 03
 62 RCL IND
11
 63 "T="
 64 FC? 00
 65 PROMPT
 66 XEQ 03
 67♦LBL 02
 68 RCL IND
11
 69 "PU="
```

```
 70 FC? 00
 71 PROMPT
 72 XEQ 03
 73 "MU<DL>=
"
 74 PROMPT
 75 XEQ 03
 76 "MU<aL>=
"
 77 PROMPT
 78 XEQ 03
 79 "IS="
 80 PROMPT
 81 XEQ 03
 82 "K="
 83 PROMPT
 84 XEQ 03
 85 "LU="
 86 PROMPT
 87 XEQ 03
 88 RCL IND
11
 89 "FC="
 90 FC? 00
 91 PROMPT
 92+LBL 03            Control routine for input
 93 ARCL X
 94 FS? 55
 95 PRA
 96 STO IND
11
 97 ISG 11
 98 RTN
 99 1 E3               Change to appropriate units
100 ST* 02
101 12
102 ST* 07
103 *
104 ST* 03
105 ST* 04
106 FC? 04
107 GTO 03
108 RCL 00
109 RCL 01
110 FS? 00
111 X<>Y              Compute gross inertia rect.
112 3
113 Y↑X
114 *
115 12
116 /
117 STO 12
118 GTO 04
119+LBL 03            Computes gross I circular
120 RCL 00
121 4
122 Y↑X
123 PI
124 *
125 64
126 /
```

```
127 STO 12
128+LBL 04
129 RCL 08
130 SQRT              Compute EI
131 57 E3
132 *
133 *
134 STO 09
135 2.5
136 /
137 RCL 09
138 5
139 /
140 RCL 05
141 29 E6
142 *
143 +
144 X<=Y?
145 X<>Y
146 STO 09
147 RCL 03
148 RCL 03
149 RCL 04
150 +
151 /
152 1
153 +
154 /
155 PI
156 X↑2
157 *
158 STO 10
159 RCL 06
160 RCL 07
161 *
162 X↑2
163 /                 Pc
164 STO 15
165 XEQ 06
166 RCL 15
167 *
168 1/X
169 RCL 02
170 *
171 CHS               1 − (Pu/ΦPc)
172 1
173 +
174 "CM="             Input Cm
175 PROMPT
176 ARCL X
177 FS? 55
178 PRA
179 X<>Y
180 /
181 1
182 X<=Y?
183 X<>Y
184 FC? 00
185 STO 13
186 FS? 00
187 STO 14
```

```
188 FS? 00
189 GTO 05
190 AON
191 "1 WAY B
END?"
192 STOP
193 XEQ 00
194 X=Y?            If one way, go to output,
195 GTO 05            else go back for y-axis information
196 SF 00
197 AOFF
198 GTO 01
199•LBL 05          Output magnification factors
200 ADV
201 SF 21
202 "MFX="
203 ARCL 13
204 AVIEW
205 "MFY="
206 ARCL 14
207 AVIEW
208 "OKAY?"         Are factors acceptable?
209 AON
210 PROMPT
211 XEQ 00
212 X≠Y?            If not, start over
213 GTO "MAG
"
214 FC? 55
215 CF 21
216 CF 00
217 "MAG"           Check value in "UL2CON" and
218 ASTO X            "CIRCON" to make sure "MAG"
219 "UL2CON"          was executed.
220 FC?C 04         Load correct program name
221 "CIRCON"
222 READP           Read in program
223•LBL 00          Alpha Y/N response subroutine
224 ASTO Y
225 "Y"
```

```
226 ASTO X
227 RTN
228•LBL 06
229 FC? 04
230 GTO 07
231 RCL 00
232 RCL 01
233 *               Ag (rectangular)
234 GTO 08          Φ factor magnification
235•LBL 07
236 RCL 00          Diameter
237 X↑2
238 PI
239 4
240 /
241 *               Ag (circular)
242•LBL 08
243 RCL 08
244 *
245 .1
246 *               0.1 fc'Ag
247 RCL 02
248 X>Y?
249 GTO 09
250 RCL Y           P < 0.1 fc'Ag Modify Φ
251 X<>Y
252 -
253 X<>Y
254 /
255 5
256 /
257 .7
258 +
259 .9
260 X>Y?
261 X<>Y            ΦPu < 0.1 fc'Ag
262 RTN
263•LBL 09
264 .7
265 RTN
```

UL2CON

"UL2CON" computes the ultimate capacity for a given rectangular concrete section subject to a given axial compression load and moments about two perpendicular axes. The concrete may be square or rectangular with up to 43 reinforcing bars. The method of analysis is based on the ultimate strength design method following the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

The program generates data for an ultimate moment capacity "moment interaction diagram" at the given axial load (factored). Values are computed at specified intervals of neutral axis (N.A.) direction. The neutral axis is rotated between 0° and 90° in increments specified by the user.

The relationship between concrete compressive stress distribution and concrete strain is assumed to be rectangular. The concrete stress is taken as 0.85 f_c uniformly distributed over an equivalent compressive zone bounded by edges of the cross section and a straight line located parallel to the neutral axis of a distance $a = \beta \cdot c$ from the fiber of maximum compressive strain. The maximum concrete strain, ε, is assumed to be 0.003, with a linear relationship for strain distribution across the cross section. It is also assumed the concrete has no strength in tension and a perfect bond exists between concrete and reinforcement. Short columns only. Moment Magnification factors should be used if slender. Refer to the program "MAG" for further information about Moment Magnification factors.

Description of Input

Inputs consist of general material properties, the size of the concrete section, area of reinforcing bar used, and the quantity. The design conditions P_u, M_x, and M_y are also input. The user is prompted for all inputs which are echo printed if a printer is attached.

Description of Output

The interaction data for the section is printed as computed and represents the intersection of a horizontal plane on the three dimensional interaction diagram. The horizontal plane is the level of constant axial load. The intersection is the M_x, M_y interaction curve.

The output values of P_{ult}, $M_{x\,ult}$, and $M_{y\,ult}$ contain the capacity reduction factor Φ, which is increased linearly from 0.7 to 0.9 when $P_u < 0.1\, f_c' A_g$. A subroutine is included to check the percentage of reinforcing and will not execute if less than 1% nor greater than 8% according to the A.C.I. code.

Application of Phi factor

1. The input P_u is divided by Φ to obtain a magnified axial load P_n, according to A.C.I. 9.3. It states $P_n = P_u/\Phi$.
2. Using this magnified load, the corresponding ultimate moment capacities are computed.
3. The values of axial load and moments in (2) are then multiplied by Φ and printed out. The results represent the capacity of the member reduced by Φ.

Output units are in kips, feet, and degrees.

The solution is output in the following order:

A_s = Steel area
b = Width of section
F_c = Compressive concrete strength
F_y = Yield strength of steel
n = Empirical exponent (see reference 1 and 2)

Output at each interval:

N.A. = Angular orientation of neutral axis
P = Ultimate load computed and should be equal to the input load
ΦM_x = Ultimate load capacity
ΦM_y = Ultimate load capacity, y-axis
$S\Delta$ = Skew angle = ATAN (M_y/M_x) (Computed moments)
$B\Delta$ = Angle ATAN (M_{uy}/M_{ux}) (input moments)
T = Thickness

The user has the option to compute only uniaxial moments about each axis "x" and "y" if desired. The approximation method equation is

$$(m_x M_x)^n + (m_y M_y)^n \leq 1.0$$

See references 1 and 2.

To determine the capacity of the section from the output, the values may be interpolated between the interaction plot points which will always be conservative between points and more accurate at the point itself. The user can manually plot the interaction curve with the output.

Each point will take about 2.5 to 5 minutes to compute for average sections and rebar. The time increases as the number of rebar increase.

Method of Computation

The program mechanics rotates the position of the neutral axis in a counterclockwise direction at user-specified angles. The initial position of the neutral axis is parallel to the x-axis.

At each specified direction of the axis, the position is first located at the balance point and the balanced load capacity P_b is compared to the input P_n. If the load P_n is greater, the neutral axis must be incremented, if P_n is less, the neutral axis must be decremented. At each position of neutral axis, the axial forces on the section due to the strain in the concrete and rebar are summed and compared to the input axial load. If the summation of forces does not agree with the input load, another position of neutral axis is located using the same neutral axis angle. Finally, when the computed and input loads agree, moments are summed about the x- and y-axes and output. The angle is then incremented and the process repeated until the interaction diagram is complete.

DEFINITIONS

f_c = Concrete stress
a = Depth of concrete stress block
c = Location of neutral axis
P_u = Factored ultimate load
M_x = Ultimate load capacity about x

M_y = Ultimate load capacity about y
N.A. = Angular orientation of neutral axis.
P = Ultimate load computed and should be equal to the input load
ΦM_x = Ultimate load capacity
ΦM_y = Ultimate load capacity, y axis.
$S\Delta$ = Skew angle = ATAN (M_y/M_x) (Computed moments)
$B\Delta$ = Angle ATAN (M_{uy}/M_{ux}) (input moments)
t = Thickness
Φ = Capacity reduction factor
f_c' = Ultimate concrete strength
A_g = Gross concrete area
P_n = Magnified axial load
P_b = Balanced ultimate load
m_x = Actual moment about x
m_y = Actual moment about y
n = Amplified nominal coefficient per $1/\Phi$ (see "Application of Phi Factor")
P_{max} = Actual maximum axial load placed on column not considering bending

EQUATIONS

Stress Block Equations - Case 1

$$A_1 = \frac{a^2}{2COS\theta SIN\theta}$$

$$C_1 = 0.85f_c'A_1$$

$$M_{1x} = C1\ (T\ 2 - a\ 3\ COS\theta)$$

$$M_{1y} = C1\ (b/2 - a\ 3\ SIN\theta)$$

Case 2

$$\theta < TAN^{-1}T/b$$

$$A_{11} = \frac{b^2TAN\theta}{2}$$

$$C_{11} = 0.85f_c'A_{11}$$

$$M_{11x} = C_{11}\left(\frac{T}{2} - \frac{bTAN\theta}{3}\right)$$

$$M_{11y} = C_{11}\left(\frac{b}{6}\right)$$

$$A_{21} = \left[a - (P_1 - P_2)\right]\frac{B}{COS\theta}$$

$$C_{21} = 0.85f_c'A_{21}$$

$$M_{21x} = \frac{C_2}{2}\left[T - \left(\frac{a - (P_1 - P_2)}{COS\theta} + bTAN\theta\right)\right]$$

Case 2

$$\theta > TAN^{-1}T/b$$

$$A_{21} = \frac{T^2}{2TAN\theta}$$

$$C_{21} = 0.85f_c'A_{21}$$

$$M_{21x} = C_{21}\ (T/6)$$

$$M_{21y} = C_{21}\left(\frac{b}{2} - \frac{T}{3TAN\theta}\right)$$

$$A_{22} = \left[a - (P_1 - P_4)\frac{T}{SIN\theta}\right]$$

$$C_{22} = 0.85f_c'A_{22}$$

$$M_{22y} = \frac{C_2}{2}\left[b - \left(\frac{a - (P_1 - P_4)}{2SIN\theta} + \frac{T}{TAN\theta}\right)\right]$$

$$M_{22x} = 0.0$$

Case 3

$$A_{31} = \left[bt - \frac{[(P_1 - P_3) - a]^2}{2COS\theta SIN\theta}\right]$$

$$C_{31} = 0.85f_c'A_{31}$$

$$M_{31x} = 0.85f_c'\left[\frac{[(P_1 - P_3) - a]^2}{2COS\theta SIN\theta}\right]\cdot\left[\frac{T}{2} - \frac{((P_1 - P_3) - a)}{3COS\theta}\right]$$

$$M_{31y} = 0.85f_c'\left[\frac{[(P_1 - P_3) - a]^2}{2COS\theta SIN\theta}\right]\cdot\left[\frac{b}{2} - \frac{((P_1 - P_3) - a)}{3SIN\theta}\right]$$

Steel Equations

$$\frac{\Delta\epsilon}{\Delta c} = \frac{0.003}{c}$$

$$\epsilon_{sn} = C - (P_1 - L_n)\frac{\Delta\epsilon}{\Delta c}$$

$f_s = \epsilon_{sn} \leq FY$

$E_s = 29 \cdot 10^6$ psi

T_s or $C_s = A_s f_s$ or $A_s(f_s - 0.85f_c')$

$M_{sx} = A_{sn} f_s x_n$

$M_{sy} = A_{sn} f_s y_n$

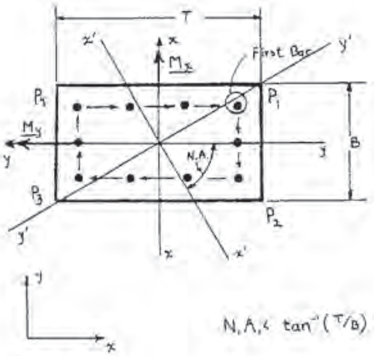
For $P > 0.1f_c'A_g \quad \Phi = 0.7$

For $P < 0.1f_c'A_g \quad \Phi = 0.7 + \frac{0.1f_c'A_g - P}{0.1f_c'A_g}(0.9\text{-}0.7)$

where $\Phi = 0.9$ for pure bending

$A_g = bt$

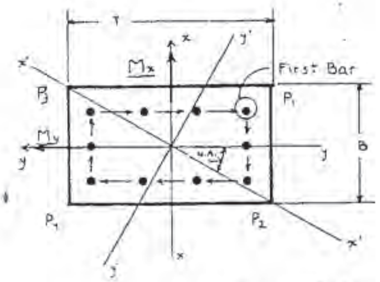
Neutral axis is computed to a 0.001" accuracy and P may vary slightly with input P_u.



Global Axes

N.A.< tan⁻¹(T/B)

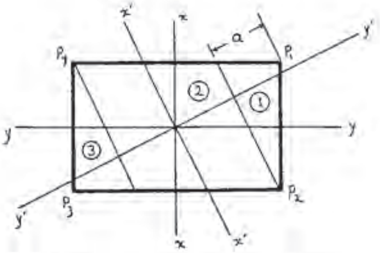
[Fig. 1]



N.A.> tan⁻¹(T/B)

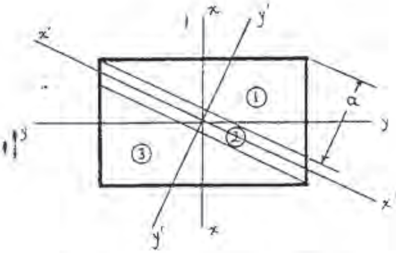
Input moments are shown as vector angles according to the right hand rule.

[Fig. 2]



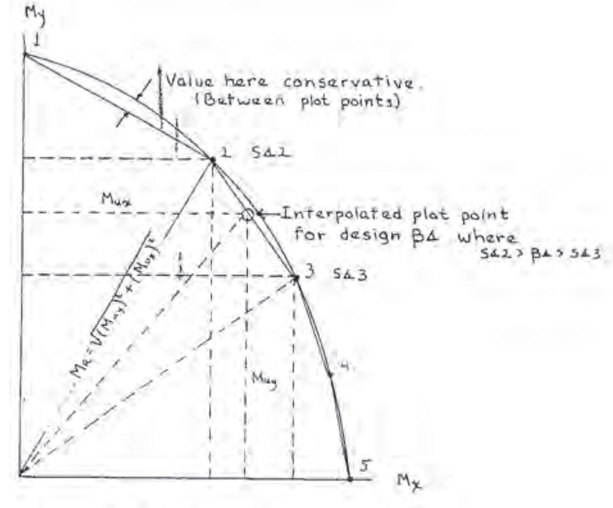
Stress block at N.A.< tan⁻¹(T/B)

[Fig. 3]

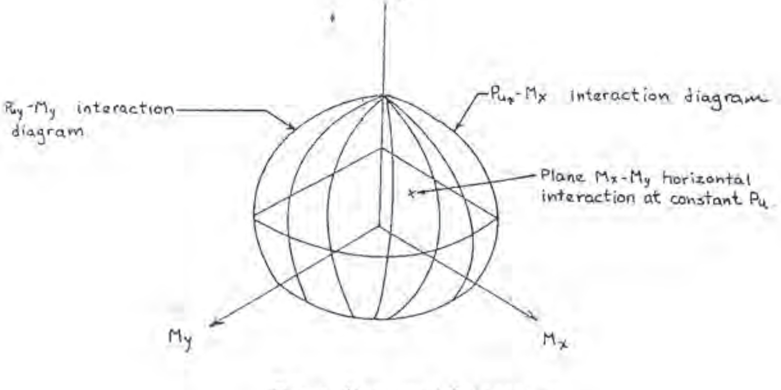


Stress block at N.A.> tan⁻¹(T/B)

[Fig. 4]



Plane Mx-My intersection at constant Pu



Three dimensional interaction diagram.

OPERATING LIMITS AND WARNINGS

1. Program does not solve for axial tension.
2. Program does not solve for $P_u = 0$.
3. If $P_u > P_{max}$, "NO SOLUTION" is printed. If $c \leq$ centroid of 1st rebar when tension controls, "NO SOLUTION" is printed.
4. User should be familiar with concrete theory.

REFERENCES

Wang and Salmon, "Reinforced Concrete Design", 3rd Edition, John Wiley.

"Building Code Requirements for Reinforced Concrete", A.C.I. 318-77.

"C.R.S.I. Concrete Design Manual", 1978, 1980.

"Design Criteria for Reinforced Columns Under Axial Load and Biaxial Bending", A.C.I. Journal Proceedings, V. 57, No. 5, 1960.

Meek, John L. "Ultimate Strength of Columns with Biaxially Eccentric Loads", A.C.I. Journal Proceedings, V. 60, No. 8, 1963.

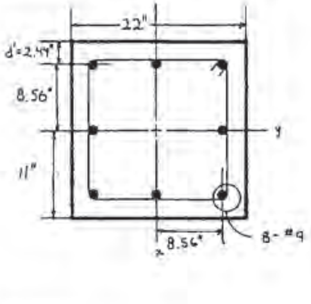
Mattock, A.H., L.B. Kriz and Hognestad, "Rectangular Concrete Stress Distribution in Ultimate Strength Design", A.C.I. Journal Proceedings, V. 57, 1961.

Furlong, Richard W., "Ultimate Strength of Square Columns under Biaxially Eccentric Loads", A.C.I. Journal Proceedings, V. 57, March, 1961.

Heimdahl, Peter D. and Bianchini, Albert C., "Ultimate Strength of Biaxially Loaded Concrete Columns Reinforced with High Strength Steel", SP-50 A.C.I., 1975.

Furlong, Richard W., "Concrete Columns Under Biaxial Eccentric Thrust", A.C.I. Journal Proceedings, V. 76, No. 10, October, 1979.

SAMPLE PROBLEM #1:



A 22" X 22" concrete column is selected from the C.R.S.I. design handbook. The capacity for uniaxial bending as recorded in the table is $P_u = 621$k at an (DRAWING) eccentricity of 8". Verify this C-7 eccentricity.

Data:

$F_y = 60{,}000$ psi (Grade 60)

$F_c = 4{,}000$ psi

$b = 22"$

$T = 22"$

$A_{s1} = 1.00$ in²

$P_u = 621$ k

$M_x = 414$ k'

$M_y = 0$

$INC = 0$

Since $M_x = M_y$ being symmetrical check the eccentricity

$$e = \frac{M_x \cdot 12}{621} = \frac{414.16(12)}{621} = 8.00 \text{ in}$$

This verifies the tabular result.

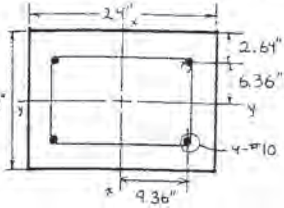
SOLUTION:

Input	Function	Display	Comments
Load "MAG"			
Begin	[XEQ] "MAG"	RECTANGULAR?	Rectangular Column?
Y	[R/S]	SLENDER COLUMN?	
N	[R/S]	MFX = 1.00	Manual magnification factors = 1.00
	[R/S]*	MFY = 1.00	
	[R/S]*	OKAY?	
Y	[R/S]	UL2CON	"UL2CON" is loaded and begins running
		UNIAX "X Y"?	Uniaxial bending about x- y-axes?
	[R/S]	FY =	"Yes" response
60000	[R/S]	Fc =	
4000	[R/S]	b =	
22	[R/S]	T =	
22	[R/S]	AST =	
1	[R/S]	N =	
8	[R/S]	SIZE > = 46.00	If size is already adequate, this step is skipped.
	[XEQ] "SIZE"	SIZE _ _ _	
046	[R/S]	P =	
621	[R/S]	MX =	
414	[R/S]	MY =	
0	[R/S]	INC =	
0	[R/S]	REBAR COORDINATES	Enter x,y coordinates in a clockwise sequence
8.56	[ENTER↑]	X ENT Y	
8.56	[R/S]	X ENT Y	
8.56	[ENTER↑]	If printer is attached values will be recorded	
0	[R/S]	X ENT Y	
8.56	[ENTER↑]		
−8.56	[R/S]	X ENT Y	
0	[ENTER↑]	Be sure to enter rebar coordinates beginning in the upper right hand corner	
−8.56	[R/S]	X ENT Y	
−8.56	[ENTER↑]		
−8.56	[R/S]	X ENT Y	
−8.56	[ENTER↑]		

Input	Function	Display	Comments
0	[R/S]	X ENT Y	
−8.56	[ENTER↑]		
8.56	[R/S]	X ENT Y	
0	[ENTER↑]		
8.56	[R/S]	COMPUTING	Computation takes about 2 1/2 to 3 minutes
		N A = 90.00	
	[R/S]*	P = 621.00	
	[R/S]*	MX = 414.16	
	[R/S]*	MY = 2.68 E−8	
	[R/S]*	SΔ = 3.71 E−9	
	[R/S]*	BΔ = 0.00	
	[R/S]*	COMPUTING	
		N A = −1.00 E−3	
	[R/S]*	P = 621.00	
	[R/S]*	MX = 2.92 E−8	
	[R/S]*	MY = 414.15	
	[R/S]*	SΔ = −90.00	
	[R/S]*	BΔ = 0.00	
	[R/S]*	NEW PRGM?	
Y	[R/S]	PRGM NAME?	Yes, let's run example 2
MAG	[R/S]	RECTANGULAR?	

*If printer is in use, you need not perform this keystroke.

SAMPLE PROBLEM #2:



Determine the ultimate moment capacity of the 18" x 24" concrete column with 4-#10 bars vertical, subject to biaxial bending with the following design conditions.

Data:
FY = 60,000 psi (Grade 60)
F_c = 4,000 psi
b = 18"
INC = 22.5°
T = 24"
AS1 = 1.27 in²
N = 4
P_u = 664.15 k
M_x = 41.15 k'
M_y = 11.13 k'

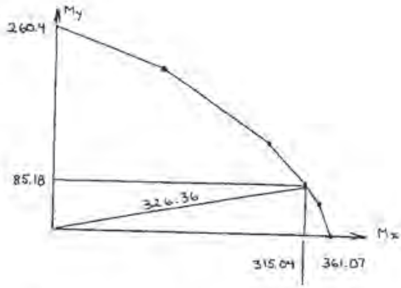
$$M_{R1} = \sqrt{(129.82)^2 + (271.29)^2} = 300.75$$

$$M_{R2} = \sqrt{(55.12)^2 + (336.14)^2} = 340.63$$

$$M_{R3} = 340.63 - \frac{15.13 - 9.31}{25.57 - 9.31}$$

(340.63 − 300.75)

M_{R0} = 326.36
SΔ 25.57,
M_R = 300.75
BΔ = 15.13
SΔ = 9.31
M_R = 340.63



Horizontal Interaction

SΔ=25.57, M_R = 300.15
βΔ = 15.13
SΔ = 9.31, M_R = 340.63

SECTION CAPACITY

P_u = 664.15 K
M_x = 326.36 COS 15.13
= 315.04 K'
M_y = 326.36 SIN 15.13
= 85.18 K'

The section is obviously overdesigned. Reduce section or reinforcing.

SOLUTION:

Input	Function	Display	Comments
Load "MAG"			If continuing from example 1, "MAG" is loaded from "UL2CON" exit routine.
Begin	[XEQ] "MAG"	RECTANGULAR?	
Y	[R/S]	SLENDER COL?	Indicate "yes" response
N	[R/S]*	MFX = 1.00	Indicate "no" response
	[R/S]*	MFY = 1.00	
	[R/S]	OKAY?	
Y	[R/S]	UL2CON UNIAX./X,Y?	
N	[R/S]	FY =	Inputs echo printed if printer is being used
60000	[R/S]	Fc =	
4000	[R/S]	b =	
18	[R/S]	T =	
24	[R/S]	AS1 =	
1.27	[R/S]	N =	
4	[R/S]	P =	If size display occurs, adjust size, press [R/S]
664.15	[R/S]	MX =	
41.15	[R/S]	MY =	
11.13	[R/S]	INC =	22.5° increments
22.5	[R/S]	REBAR COORDINATES X ENT	Y Coordinates will be momentarily displayed or printed out if a printer is in use
9.36	[ENTER↑]		
6.36	[R/S]	X ENT Y	
9.36	[ENTER↑]		

Input	Function	Display	Comments
−6.36	[R/S]	X ENT Y	
−9.36	[ENTER↑]		
−6.36	R/S]	X ENT Y	
−9.36	[ENTER↑]		
6.36	[R/S]	COMPUTING	Computation takes several minutes for each output
		N.A. =90.00	
	[R/S]*	P=664.15	
	[R/S]*	MX=361.07	
	[R/S]*	MY=1.75 E−8	
	[R/S]*	S∆ =2.78 E−9	
	[R/S]*	B∆ =15.13	
	[R/S]*	COMPUTING	Computation takes several minutes
		N.A. =67.50	
	[R/S]*	P=664.15	
	[R/S]*	MX=336.14	
	[R/S]*	MY=55.12	
	[R/S]*	S∆ =9.31	
	[R/S]*	B∆ =15.13	
	[R/S]*	COMPUTING	
		N.A. =45.0	
	[R/S]*	P=664.15	
	[R/S]*	MX=271.29	
	[R/S]*	MY=129.82	
	[R/S]*	S∆ =25.57	
	[R/S]*	B∆ =15.13	
	[R/S]*	COMPUTING	
		N.A. =22.50	
	[R/S]*	P=644.15	
	[R/S]*	MX=139.31	
	[R/S]*	MY=216.52	
	[R/S]*	S∆ =57.24	
	[R/S]*	B∆ =15.13	
	[R/S]*	COMPUTING	
		N.A. = −1.00 E−8	
	[R/S]*	P=644.15	
	[R/S]*	MX=−4.08 E−8	
	[R/S]*	MY=260.40	
	[R/S]*	S∆ =−90.00	
	[R/S]*	B∆ =15.13	
	[R/S]*	NEW PRGM?	
N	[R/S]	0.00	

*If printer is in use, you need not perform this keystroke.

USER INSTRUCTIONS

Step	Instructions	Input	Function	SIZE: 30+2n Display
1	"UL2CON" called from "MAG"			UL2CON UNIAX /X,Y?
2.	For uniaxial solution (solution about axes x and y), press	Y	[R/S]	FY=
	If interaction solution is desired, press	N*	[R/S]	FY=
3	Input material and section properties Yield strength (psi)	F_y	[R/S]	Fc=
	Compressive concrete strength (psi)	F_c	[R/S]	b=
	Width of section (in)	b	[R/S]	T=
	Thickness (in)	T	[R/S]	AS1=
	Area of 1 reinforcing bar (in²)	AS_1	[R/S]	N=
	Number of reinforcing bars	N	[R/S]	P=
4.	If prompt for larger size appears, set size to indicated amount, press	[R/S]	P=	
5.	Input design loads and moments. Input moment will be magnified by "MAG" determined coefficients. Input ultimate axial load (kips)	P_u	[R/S]	MX=
	Ultimate moment about x (K-ft)	M_x	[R/S]	MY=
	Ultimate moment about y (K-ft)	M_y	[R/S]	INC=
	Input angle increment of neutral axis (°) (If uniaxial input INC=0)	INC or 0	[R/S]	REBAR COORDINATES X ENT Y
6†	Input rebar coordinates	$X_{1,n}$	[ENTER↑]	X1
		$Y_{1,n}$	[R/S]	X ENT Y COMPUTING
†	WARNING: Input the upper right hand corner coordinates first, then continue in a clockwise direction.			
7*	Output solution at each specified interval until interaction curve has been completed			N.A. =
			[R/S]*	P=
			[R/S]*	MX=
			[R/S]*	MY=
			[R/S]*	S∆ =
			[R/S]*	B∆ =
			[R/S]	NEW PRGM?
8a.	To begin a new program	Y	[R/S]	PRGM NAME?
	Key in program name	name	[R/S]	
	New program begins			
8b.	If a new program is not desired, press	N	[R/S]	0.00
	To use "UL2CON" again, you MUST load and execute "MAG" first.			

*Pressing only [R/S] also indicates a "no" response.

REGISTERS, STATUS, FLAGS

Data Registers

00 F_y
01 F_c
02 b
03 T
04 AS1
05 N
06 Control, P
07 δs/δc
08 a
09 ϵ_y
10 B_1
11 c

Status

SIZE 30+2n	TOT REG 230+2n
ENG	FIX 2 SCI
DEG X	RAD GRAD

Flags

# SET INDICATES	CLEAR INDICATES
00 Balance solution	
01 N.A. ∆ > ATAN T/b	N.A. ∆ < ATAN T/b
02 Bar under block	Not under
03 Bar in tension	

12 C_b	04 Uniaxial x,y solution		25 Control
13 M_x	05 P equil. found		26 P_1
14 M_y	07 $P > P_b$		27 P_2
15 ϵ_{y}	21 Printer enable	Printer disable	28 P_3
16 P_s (max)	55 Printer attached	No printer	29 P_4
17 P_b			30 B_{1Y}
18 P_{cu}			31 B_{1X}
19 θ (N.A.)			32 B_{2Y}
20 BΔ			33 B_{2X}
21 Φ			34 B_{3Y}
22 INC			35 B_{3X}
23 M_{xx}			36 B_{nY}
24 M_{yy}			37 B_{nX}

PROGRAM LISTINGS

```
 01♦LBL "UL2
CON"
 02 CF 21
 03 "MAG"          Make sure "MAG" has been run
 04 ASTO Y
 05 "RUN MAG
 1ST"
 06 X≠Y?
 07 PROMPT
 08 FS? 55         Print if printer attached
 09 SF 21
 10 DEG
 11 ADV
 12 SF 12
 13 "UL2CON"       Display title
 14 AVIEW
 15 ADV
 16 .013
 17♦LBL 00         Clear flags 0-13
 18 CF IND X
 19 ISG X
 20 GTO 00
 21 CLD
 22 "UNIAX./       Uniaxial/x-, y-axis solution desired?
X,Y?"
 23 AON
 24 STOP
 25 ASTO Y
 26 "Y"
 27 ASTO X
 28 AOFF
 29 X=Y?           If so, set flag 4
 30 SF 04
 31 .005
 32 STO 06
 33 "FY="          Data input
 34 XEQ 01
 35 "Fc="
 36 XEQ 01
 37 "b="
 38 XEQ 01
 39 "T="
 40 XEQ 01
 41 "AS1="
 42 XEQ 01
 43 "N="
```

```
 44♦LBL 01
 45 PROMPT
 46 ARCL X
 47 STO IND
06
 48 FS? 21
 49 AVIEW
 50 ISG 06
 51 RTN
 52 30             Calculate minimum size
 53 RCL 05
 54 2
 55 *
 56 +
 57 "SIZE>="
 58 ARCL X
 59 1
 60 -
 61 SF 25          If necessary,
 62 RCL IND          inform need to adjust size
X
 63 FC?C 25
 64 PROMPT
 65 RCL 06         Move counter to R25
 66 STO 25
 67 RCL 04
 68 RCL 05         Check min, max reinforcement
 69 *
 70 RCL 02
 71 RCL 03
 72 *
 73 /
 74 .01
 75 "P<1%MIN
"
 76 X>Y?
 77 GTO 13
 78 RDN
 79 .08
 80 X>Y?
 81 GTO 07
 82 "P<8%MIN
"
 83♦LBL 13         If out of limits, display error and exit
 84 AVIEW
 85 PSE
```

```
 86 PSE
 87 "A.C.I.
CODE"
 88 AVIEW
 89 PSE
 90 GTO 23
 91♦LBL 07              Continue
 92 ADV
 93 "P="
 94 PROMPT
 95 X<=0?
 96 GTO 18              Input design data
 97 STO 06
 98 ARCL X
 99 FS? 21
100 AVIEW
101 "MX="
102 PROMPT
103 RCL 13
104 *
105 STO 13
106 ARCL X
107 FS? 21
108 AVIEW
109 "MY="
110 PROMPT
111 RCL 14
112 *
113 STO 14
114 ARCL X              N.A. angle increment input
115 FS? 21
116 AVIEW
117 "INC="
118 PROMPT              0.00 input for uniaxial
119 STO 22
120 ARCL X
121 FS? 21
122 AVIEW
123 ADV
124 XEQ 27
125 "REBAR "
126 "⊢COORDI            Input rebar coordinates
NATES"
127 AVIEW
128♦LBL 02              Coordinates routine
129 "X ENT Y
"
130 PROMPT
131 "X="
132 ARCL Y
133 "⊢ Y="
134 ARCL X
135 AVIEW
136 FC? 21
137 PSE
138 STO IND
25
139 X<>Y
140 ISG 25              Compute constants and parameters
141 STO IND
25
```

```
142 ISG 25
143 GTO 02
144 XEQ 12
145 XEQ 22
146 RCL 21
147 ST/ 06
148 RCL 00
149 29 E6
150 /
151 STO 09
152 1 E-8
153 STO 19
154 1 E3
155 ST* 06
156 RCL 02
157 RCL 03
158 *
159 XEQ 09
160 STO 16
161 RCL 05
162 RCL 04
163 *
164 RCL 00
165 XEQ 19
166 *
167 ST+ 16              Pmax
168 RCL 16
169 RCL 06
170 X>Y?
171 GTO 18
172♦LBL 25
173 CLD
174 CF 21
175 "COMPUTI             Display "COMPUTING"
NG"                      for long calculation
176 AVIEW
177 RCL 02
178 2
179 /
180 RCL 03              Compute concrete
181 2                     corners coordinates
182 /
183 XEQ 28
184 STO 26
185 CHS
186 STO 28
187 RCL 02
188 2
189 /
190 CHS
191 RCL 03
192 2
193 /
194 XEQ 28              Determine ATAN(T/b)
195 STO 27
196 X<0?                If negative, set flag 1
197 SF 01
198 CHS
199 STO 29
200 87 E3
201 RCL X
```

```
202 RCL 00
203 +
204 /
205 STO 12
206 RCL 30
207 RCL 31
208 XEQ 28
209 ABS
210 RCL 28
211 -
212 RCL 12
213 *
214 STO 12
215 STO 11
216 SF 00
217 FC? 01              Change concrete corners if
218 GTO 26                N.A. Δ. < ATAN(T/b)
219 RCL 27
220 RCL 29
221 STO 27
222 X<>Y
223 STO 29
224◆LBL 26            Determine location of stress block
225 RCL 11
226 FS? 00
227 RCL 12
228 RCL 10
229 *
230 RCL 26
231 RCL 28
232 -
233 X>Y?
234 X<>Y
235 STO 08
236 RCL 26
237 RCL 27
238 -
239 X>Y?
240 GTO 03
241 RDN
242 RCL 26
243 RCL 29
244 -
245 X>Y?
246 GTO 04
247 RDN
248 RCL 26
249 RCL 28
250 -
251 X>Y?
252 GTO 05
253 RCL 02
254 RCL 03
255 *
256 XEQ 09
257 STO 18
258 FC? 05
259 GTO 08
260 .
261 STO 23
262 STO 24
```

```
263 GTO 08
264◆LBL 03            Stress block case 1
265 RCL 08
266 X↑2
267 RCL 19
268 SIN
269 LASTX
270 COS
271 *
272 2
273 *
274 /
275 XEQ 09
276 STO 18
277 FC? 05
278 GTO 08
279 RCL 08
280 3
281 /
282 RCL 19
283 COS
284 /
285 CHS
286 RCL 03
287 2
288 /
289 +
290 X<>Y
291 *
292 STO 23
293 LASTX
294 RCL 08
295 3
296 /
297 RCL 19
298 SIN
299 /
300 CHS
301 RCL 02
302 2
303 /
304 +
305 *
306 STO 24
307 GTO 08
308◆LBL 04            Stress block case 2
309 FS? 01
310 RCL 03
311 FC? 01
312 RCL 02
313 X↑2
314 2
315 /
316 RCL 19
317 TAN
318 FS? 01
319 /
320 FC? 01
321 *
322 XEQ 09
323 STO 18
```

```
324 FC? 05
325 GTO 04
326 FS? 01
327 RCL 03
328 FC? 01
329 RCL 02
330 3
331 /
332 RCL 19
333 TAN
334 FS? 01
335 /
336 FC? 01
337 *
338 CHS
339 FS? 01
340 RCL 02
341 FC? 01
342 RCL 03
343 2
344 /
345 +
346 RCL 18
347 *
348 FS? 01
349 STO 24
350 FC? 01
351 STO 23
352 FS? 01
353 RCL 03
354 FC? 01
355 RCL 02
356 6
357 /
358 RCL 18
359 *
360 FS? 01
361 STO 23
362 FC? 01
363 STO 24
364◆LBL 04
365 RCL 08
366 RCL 26
367 RCL 27
368 -
369 -
370 FS? 01
371 RCL 03
372 FC? 01
373 RCL 02
374 *
375 RCL 19
376 FS? 01
377 SIN
378 FC? 01
379 COS
380 /
381 XEQ 09
382 ST+ 18
383 FC? 05
384 GTO 08
385 STO 25
386 RCL 08
387 RCL 19
388 FS? 01
389 COS
390 FC? 01
391 SIN
392 FS? 01
393 RCL 03
394 FC? 01
395 RCL 02
396 *
397 -
398 RCL 19
399 FS? 01
400 SIN
401 FC? 01
402 COS
403 /
404 CHS
405 FS? 01
406 RCL 03
407 FC? 01
408 RCL 02
409 RCL 19
410 TAN
411 FS? 01
412 /
413 FC? 01
414 *
415 -
416 FS? 01
417 RCL 02
418 FC? 01
419 RCL 03
420 +
421 2
422 /
423 RCL 25
424 *
425 FS? 01
426 ST+ 24
427 FC? 01
428 ST+ 23
429 GTO 08
430◆LBL 05
431 RCL 26
432 RCL 28
433 -
434 RCL 08
435 -
436 X↑2
437 RCL 19
438 COS
439 LASTX
440 SIN
441 *
442 2
443 *
```

Stress block case 3

```
444 /
445 STO 25
446 CHS
447 RCL 02
448 RCL 03
449 *
450 +
451 XEQ 09
452 STO 18
453 FC? 05
454 GTO 08
455 RCL 25
456 XEQ 09
457 RCL 26
458 RCL 28
459 -
460 RCL 08
461 -
462 3
463 /
464 RCL 19
465 COS
466 /
467 CHS
468 RCL 03
469 2
470 /
471 +
472 *
473 STO 23
474 RCL 25
475 XEQ 09
476 RCL 26
477 RCL 28
478 -
479 RCL 08
480 -
481 3
482 /
483 RCL 19
484 SIN
485 /
486 CHS
487 RCL 02
488 2
489 /
490 +
491 *
492 STO 24
```

Determine forces in rebar

```
493◆LBL 08
494 XEQ 27
495 RCL 11
496 .003
497 X<>Y
498 /
499 STO 07
500◆LBL 10
501 RCL IND
25
502 ISG 25
503 RCL IND
25
504 XEQ 28
505 RCL 08
506 RCL 26
507 RCL Z
508 -
509 X<=Y?
510 SF 02
511 RCL 11
512 X<>Y
513 -
514 RCL 07
515 *
516 STO 15
517 X<0?
518 SF 03
519 ABS
520 RCL 09
521 X>Y?
522 X<>Y
523 FS?C 03
524 CHS
525 29 E6
526 *
527 FS?C 02
528 XEQ 19
529 RCL 04
530 *
531 ST+ 18
532 FS? 05
533 GTO 11
534 ISG 25
535 GTO 10
536 GTO 14
537◆LBL 11
538 1
539 ST- 25
540 RDN
541 RCL IND
25
542 X<>Y
543 *
544 ST+ 24
545 ISG 25
546 LASTX
547 RCL IND
25
548 *
549 ST+ 23
550 ISG 25
551 GTO 10
552◆LBL 14
553 RCL 30
554 RCL 31
555 XEQ 28
556 RCL 26
557 X<>Y
558 -
559 RCL 11
```

If a < 1st rebar, go to "NO SOLUTION"

```
560 X<=Y?
561 GTO 18
562 RCL 18
563 FS?C 05       If flag 5 set, compute moments
564 GTO 15
565 FS?C 00
566 GTO 16
567 FS? 07        Modify location of N.A.
568 GTO 21
569 RCL 17
570 RCL 06
571 -
572 RCL 17
573 RCL 18
574 -
575 /
576 RCL 12
577 RCL 11
578 -
579 *
580 CHS
581 RCL 12
582 +
583 RCL 11
584 ABS
585 X<>Y
586 STO 11
587 ABS
588 X>Y?
589 X<>Y
590 -             If P found, compute moments,
591 .001           initial modify location of N.A.
592 X>Y?
593 SF 05
594 GTO 26
595+LBL 16
596 STO 17
597 RCL 06
598 X>Y?
599 GTO 17
600 RCL 12
601 .8
602 *
603 STO 11
604 GTO 26
605+LBL 17       Modify location of N.A.
606 SF 07
607 X<>Y
608 -
609 RCL 16
610 RCL 17
611 -
612 /
613 RCL 12
614 *
615 LASTX
616 +
617 STO 11
618 GTO 26
619+LBL 21
```

```
620 RCL 06
621 RCL 17
622 -
623 RCL 18
624 RCL 17
625 -
626 /
627 RCL 11
628 RCL 12
629 -
630 *
631 RCL 12
632 +
633 RCL 11
634 ABS
635 X<>Y
636 STO 11
637 ABS
638 X>Y?          If P found, compute moments
639 X<>Y
640 -
641 .001
642 X>Y?
643 SF 05
644 GTO 26
645+LBL 15       Output
646 SF 21
647 ADV
648 1 E3
649 ST/ 18
650 12 E3
651 ST/ 23
652 ST/ 24        Modify values by ϕ- convert units
653 RCL 21
654 ST* 18
655 ST* 23
656 ST* 24
657 RCL 19
658 CHS
659 90
660 +
661 "N.A.="
662 ARCL X
663 AVIEW
664 RCL 18
665 "P="
666 ARCL X
667 AVIEW
668 "MX="
669 RCL 23
670 ARCL X
671 AVIEW
672 "MY="
673 RCL 24
674 ARCL X
675 AVIEW
676 X<>Y
677 /
678 ADV
679 ATAN
```

```
680 "S∡="
681 ARCL X
682 AVIEW
683 RCL 14
684 RCL 13
685 X=0?
686 X<>Y
687 /
688 ATAN
689 "B∡="
690 ARCL X
691 AVIEW
692 ADV
693 RCL 19
694 90
695 X<Y?
696 GTO 23
697 FS? 04
698 GTO 24
699 RCL 22        Increment N.A. angle
700 ST+ 19
701 GTO 25
702♦LBL 24
703 ST+ 19
704 GTO 25        Next loop
705♦LBL 12
706 .85           Compute d
707 STO 10
708 4 E3
709 RCL 01
710 X<=Y?
711 RTN
712 X<>Y
713 -
714 1 E3
715 /
716 INT
717 .05
718 *
719 ST- 10
720 RCL 10
721 .65
722 X<=Y?
723 X<>Y
724 STO 10
725 RTN
726♦LBL 22       Compute Φ and modify for
727 .7              Pu ≤ 0.1 fc'Ag
728 STO 21
729 RCL 02
730 RCL 03
731 *
732 RCL 01
733 *
734 .1
735 *
736 RCL 06
737 1 E3
738 *
739 X>Y?
```

```
740 RTN
741 CHS
742 X<>Y
743 +
744 LASTX
745 /
746 5
747 /
748 .7
749 +
750 .9
751 X>Y?
752 X<>Y
753 STO 21
754 RTN
755♦LBL 18       "NO SOLUTION" routine
756 ADV
757 FS? 55
758 SF 21
759 SF 12
760 TONE 9
761 "NO SOLU
TION"
762 AVIEW
763 PSE
764 CF 12
765 GTO 23
766♦LBL 09
767 .85
768 *
769 RCL 01
770 *
771 RTN
772♦LBL 19
773 .85
774 RCL 01
775 *
776 -
777 RTN
778♦LBL 27       Control set for steel rebar location
779 RCL 05
780 2
781 *
782 29
783 +
784 1 E3
785 /
786 30
787 +
788 STO 25
789 RTN
790♦LBL 28       Locate bars on N.A. perpendicular
791 R-P
792 X<>Y
793 RCL 19
794 X>Y?
795 X<>Y
796 -
797 COS
798 *
```

```
799 RTN
800+LBL 23          Exit routine
801 ADV
802 CLD
803 AON
804 "NEW PRG
M?"
805 STOP            Want new program?
806 ASTO Y          If not, go clean up display
807 "Y"
808 ASTO X
809 X≠Y?            Else get name
810 GTO 06
811 "PRGM NA
ME?"
812 STOP
813 AOFF
814 READP           Read in new program
815+LBL 06
816 AOFF
817 CLX
818 .END.
```

CIRCON

"CIRCON" computes the ultimate capacity for a given concrete circular section subject to a given axial compression load and moments about two perpendicular axes. The section may have up to 124 reinforcing bars placed in either a circular or square pattern. The methods of analysis are based on ultimate strength design following the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

The user chooses one of two solution methods available: the "P" solution and the "e" solution. The "P" solution will solve for the moment capacity M_x and M_y for the specified input "P". The "e" solution solves for "e" (Mr/P) for the specified P, M_x, and M_y input. The capacity of the section at the design eccentricity is output and may be compared to the design input condition. The column may have ties or spirals.

List of Problems "CIRCON" solves:

1. A circular concrete column with circular pattern or square pattern reinforcing subjected to axial compression and moments about two perpendicular axes.
2. Although intended to be a biaxial solution, a uniaxial solution can be be closely approximated. When inputting M_y = 0, the program inserts $1.00 \cdot 10^{-8}$ (0 not permitted and causes a division by 0) and continues execution. For a uniaxial solution about the y-axis, rotate the section 90°.
3. Solution for Pu = 0 may be found by inputting Pu = 0 and using a "P" solution. When 0 is input, the program inserts 0.01 which produces a more accurate solution with the algorithm used. Do not use the "e" solution for this problem since e approaches infinity.
4. A.C.I. provides that when Pu < $0.1f_c'A_g$, the value of Φ capacity reduction factor) may be increased allowing greater capacity. A subroutine is included in the program for this.
5. For circular patterns, reinforcing rebar coordinates are automatically computed.
6. If desired, values may be computed when spiral reinforcing is used.
7. A subroutine is included to check percentage of reinforcing and will not execute if less than 1% or more than 8% according to A.C.I. code.

Method of Computation:

The program structure rotates the neutral axis in a counter-clockwise direction as determined by the input moments M_x and M_y by a rectangular to polar conversion. The initial neutral axis is assumed at balanced equations. From this position, the axial forces on the section and the computed moments corresponding to the strain in the concrete and steel are summed and compared to the input design load ("P" solution) or the input design eccentricity as determined by Mr/p ("e" solution) if they do not agree. A new position of neutral axis is assumed using the same β angle. When the values agree, the capacity of the section is output.

EQUATIONS

Stress Block Equations

$$\theta = \mathrm{COS}^{-1}\frac{r - a}{r}$$

$$A_z = \frac{D^2}{8}(2\theta - \mathrm{SIN}2\theta)$$

$$Y_0 = d\left[\frac{\mathrm{SIN}^3\theta}{3(\theta - \mathrm{COS}\theta\mathrm{SIN}\theta)}\right]$$

Steel Equations

$$\frac{\delta\epsilon}{\delta c} = \frac{0.003}{c}$$

$$\epsilon_{sn} = c - (R_b - L_n)\frac{\delta\epsilon}{\delta c}$$

$$f_s = \epsilon_{sn}(29 \cdot 10^6) \leq FY$$

$$T_s \text{ or } C_s = A_s f_s$$

$$M_s = A_s f_s L_n$$

$\Phi = 0.7$ ties, 0.75 spiral

For $P > 0.1 f_c' A_g$ $\Phi = \Phi$

For $P < 0.1 f_c' A_g$

$$\Phi_1 = \Phi + \frac{0.1f_c'A_g\ 0.1f_c'A_g}{(0.9 - \Phi)} \quad (0.9 - \Phi)$$

where Φ = 0.9 for pure bending

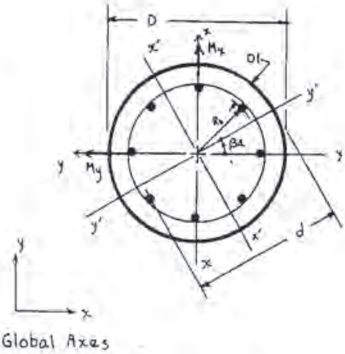
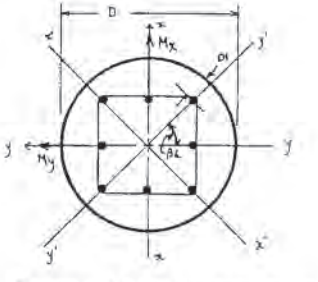


Fig. 1 – Circular pattern reinforcing



Moments Mx and My are shown as vector moments according to the right hand rule.

Fig. 2 ~ Square pattern reinforcing

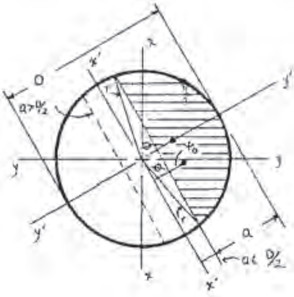
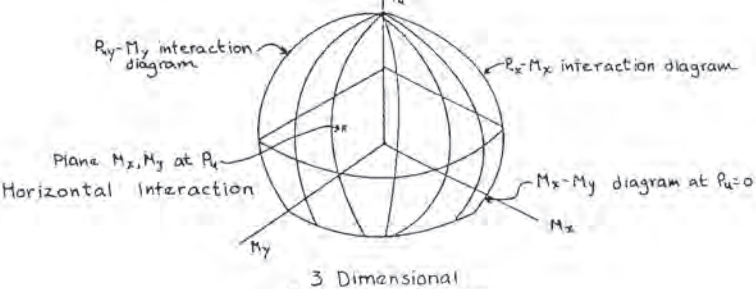


Fig 3 ~ Stress block conditions



3 Dimensional Interaction Diagram

DEFINITIONS

a = Depth of concrete stress block
A = Segmental area of stress block
A_g = Gross concrete area
A_s = Area of steel
$\theta\Delta$ = Rotated angle due to resolved moments M_x, M_y
cR = Location of neutral axis corresponding to rotation
cbR = Location of balanced neutral axis, rotated axis (in)
C_s = Compression force in compression steel
d = Depth from compression face to centroid of farther-most reinforcing bar
D = Diameter of column
D1 = Location of reinforcement from face of concrete of rebar centroid
ecR = Calculated eccentricity corresponding to axis rotation
ebR = Eccentricity at balance condition (in)
f_c' = Ultimate concrete strength
F_y = Yield strength of steel
L_n = Location of bar n
L_1 = Location of bar 1
MbR = Balanced moment on rotated axis (kip in.)
M_x = Moment about x-axis
M_y = Moment about y-axis
P = Axial load
P_bR = Balanced axial load on rotated axis (kips)
θ = See sketch
r = D 2
R_b = Radius of section to centroid of reinforcing
T = Steel tension
$< 0.8 \times P_{max}$ = The maximum concentric ultimate axial load (kips)

OPERATING LIMITS AND WARNINGS

1. Program does not solve for axial tension.
2. Pu = 0 must be solved by a "P" solution.
3. All rebar must have same individual area.

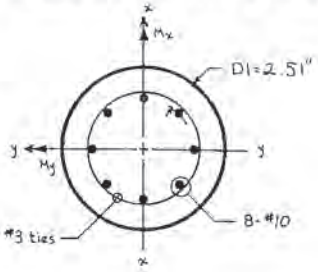
REFERENCES

Wang and Salmon, "Reinforced Concrete Design", 3rd Edition, 1979, John Wiley and Sons.

C.R.S.I. Concrete Design Manual, 1979, 1980.

Building Code Requirements for Reinforced Concrete (A.C.I. 318-77).

SAMPLE PROBLEM #1:



Determine the capacity of a 16" diameter concrete column with 8-#10 subject to to biaxial bending, for the following design conditions.

P_u = 210 K
M_x = 140 K'
M_y = 50 K-ft
slenderness not a factor
F_y = 60,000 psi
Size = 24 + 8 = 32
F_c' = 4,000 psi
D = 16 in
AS_1 = 1.27 in²
N = 8
Use a "P" solution

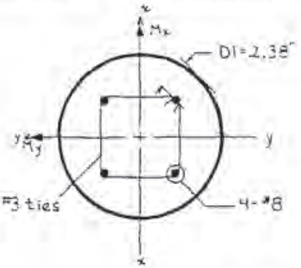
SOLUTION:

Input	Function	Display	Comments
Load "MAG"			
Begin	[XEQ] "MAG"	RECTANGULAR?	
N	[R/S]	SLENDER COL?	
N	[R/S]	MFX = 1.00	
	[R/S]*	MFY = 1.00	
	[R/S]*	OKAY?	
Y	[R/S]	CIRCON	CIRCON is now executing.
		P OR e?	Moment capacity (P) or M_x/P?
P	[R/S]	SPIRAL?	
N	[R/S]	FY =	
60000	[R/S]	Fc =	
4000	[R/S]	D =	
16	[R/S]	D1 =	
2.51	[R/S]	AS1 =	
1.27	[R/S]	N =	
8	[R/S]	SIZE> = 32.00	Does not appear if size ≥ 32
	[XEQ] "SIZE"	SIZE _ _ _	
032	[R/S]	P =	
210	[R/S]	MX =	
140	[R/S]	MY =	
50	[R/S]	REBAR COORDINATES C/S?	Circular or square?
C	[R/S]	FIRST BAR Δ?	
0	[R/S]	Rb = 5.49 Δ = 0.00	
	[R/S]*	Rb = 5.49 Δ = 45.00	
	[R/S]*	Rb = 5.49 Δ = 90.00	
	[R/S]*	Rb = 5.49 Δ = 135.00	
	[R/S]*	Rb = 5.49 Δ = 180.00	
	[R/S]*	Rb = 5.49	

Input	Function	Display	Comments
		Δ=225.00	
	[R/S]*	Rb=5.49	
		Δ=270.00	
	[R/S]*	Rb=5.49	
		Δ=315.00	
	[R/S]*	<8>PMAX=704.85	
	[R/S]*	ebR=12.15	
	[R/S]*	nbR=1929.63	
	[R/S]*	PbR=158.78	
	[R/S]*	cbR=7.79	
	[R/S]*	BΔ=19.65	
	[R/S]*	COMPUTING	The computation takes several minutes
		P=210.99	
	[R/S]*	MX=147.40	
	[R/S]*	MY=52.64	
	[R/S]*	cR=8.27	
	[R/S]*	eCR=0.74	
	[R/S]*	NEW PRGM?	
Y	[R/S]	PRGM NAME?	Yes response
MAG	[R/S]		Load "MAG" for example 2

*If printer is in use, you need not perform this keystroke

SAMPLE PROBLEM #2:



DETERMINE: The ultimate capacity of a 20" diameter column with 4-#8 placed in a square pattern subject to uniaxial bending with the following design condition.

P_u = 450 K
M_x = 150 K

M_y = 0
F_y = 60,000 psi
F_c' = 5,000 psi
D = 20 in
D1 = 2.38 in
AS_1 = 0.79 in²
N = 4
Use "e" solution

SOLUTION:

Input	Function	Display	Comments
		RECTANGULAR?	Display from "MAG"
N	[R/S]	SLENDER COL?	
N	[R/S]	MFX=1.00	
		MFY=1.00	
		OKAY?	
Y	[R/S]	CIRCON	
e	[R/S]	P OR e?	Be sure to press
		SPIRAL?	[SHIFT] to get an "e"
N	[R/S]	FY=	
60000	[R/S]	Fc=	
5000	[R/S]	D=	
20	[R/S]	D1=	
2.38	[R/S]	AS1=	
.79	[R/S]	N=	
4	[R/S]	P=	
450	[R/S]	MX=	
150	[R/S]	MY=	
0	[R/S]	REBAR	
		COORDINATES	
		C S?	Circular or square?
S	[R/S]	X ENT Y	
5.39	[ENTER↑]		
5.39	[R/S]	X ENT Y	
5.39	[ENTER↑]		
−5.39	[R/S]	X ENT Y	
−5.39	[ENTER↑]		
−5.39	[R/S]	X ENT Y	
−5.39	[ENTER↑]		
5.39	[R/S]	<8>PMAX=846.35	
		ebR=8.29	
		MbR=2356.88	
		PbR=284.33	
		cbR=9.11	
		BΔ=3.82	
		E=8	
		P=581.87	
		MX=193.73	
		MY=1.29	
		E=8	
		cR=13.88	
		ecR=0.33	
		NEW PRGM?	
N	[R/S]	0.00	

USER INSTRUCTIONS

Step	Instructions	Input	Function	SIZE: 24+n Display
	Program is called from "MAG"			CIRCON P or e?
1.	Select solution type	P/e	[R/S]	SPIRAL?
2.	If spiral reinforcing	Y	[R/S]	
	If not	N*	[R/S]	FY=
3.	Input material and action properties. (psi)	FY	[R/S]	D=
	Diameter of column (in)	D	[R/S]	D1=
	Rebar centroid to concrete face distance (in)	D1	[R/S]	AS1=
	Area of a reinforcing bar (in²)	AS_1	[R/S]	N=
	Number of bars	N	[R/S]	P=
4.	Input design values	P	[R/S]	
		M_x	[R/S]	
		M_y	[R/S]	REBAR COORDINATES C/S?
5.	Select circular or square pattern			
5a.	If circular	C	[R/S]	FIRST BAR ?
	input angle of first bar	Δ	[R/S]	Rb=nn Δ=vv
	Polar coordinates for n bars will be computed	Rb=nn Δ=vv		
5b.	If square	S	[R/S]	X ENT Y
		x_i	[ENTER↑]	
	Prompts for n rectangular	y_i	[R/S]	X ENT Y

Step	Instructions	Input	Function	Display
	Coordinates will be displayed		[R/S]	
6	Output			<.8>PMAX = nn
6a	Balanced condition	[R/S]**	ebR = nn	
			[R/S]**	MbR = nn
			[R/S]**	PbR = nn
			[R/S]**	CbR = nn
			[R/S]**	R →
			[R/S]**	COMPUTING
			[R/S]**	P = nn
			[R/S]**	MX = nn
			[R/S]**	MY = nn
			[R/S]**	cR = nn
			[R/S]**	ecR = nn
			[R/S]**	NEW PRGM?
7	To solve another problem	Y	[R/S]	PRGM NAME?
	Enter program needed	name	[R/S]	
	Program is loaded and begins execution			
7a	To end session	N	[R/S]	0.00

*Pressing only [R/S] also indicates a "no" response.
**If printer is in use, you need not perform this keystroke

REGISTERS, STATUS, FLAGS

C_i

Data Registers Status

[illegible]	SIZE 24 + N	TOT REG 196 + N
[illegible]	ENG	FIX SCI
	DEG	RAD GRAD

02 D
03 D1
04 AS1
05 N
06 r_y
07 B1
08 C, C_n
09 $\Delta r/\Delta c$
10 a
11 E_c
12 P
13 M_x, M_n
14 M_y
15 eR, ed → P
16 BΔ
17 counter
18 counter
19 counter
20 scratch
21 ψ
22 R_n
23 ϕ
24 C_1
25 C_2
26 C_3
27 C_4

Flags

#	SET INDICATES	CLEAR INDICATES
00	Balance solution	Design solution
01	Spiral reinf	Tie reinf
02	Bar under block	
03	Bar in tension	
05	General purpose	
06	General purpose	
07	P-solution	e-solution
21	Printer enable	Printer disable
55	Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "CIR
CON"
 02 CF 21
 03 "MAG"             Make sure "MAG" has been run
 04 ASTO Y
 05 "RUN MAG
1ST"
 06 X≠Y?
 07 PROMPT
 08 FS? 55            Print if printer attached
 09 SF 21
 10 DEG
 11 ADV
 12 SF 12
 13 "CIRCON"          Display title
 14 AVIEW
 15 PSE
 16 CLD
 17 ADV
 18 FIX 2
 19 .013
 20♦LBL 00            Clear flags 0-13
 21 CF IND X
 22 ISG X
 23 GTO 00
 24 AON
 25 "P OR e?         P or e solution?
"
 26 STOP
 27 ASTO X
 28 "P"
 29 ASTO Y            If P, set flag 7
 30 X=Y?
 31 SF 07
 32 VIEW X
 33 CLD
 34 "SPIRAL?         Spiral reinforcing?
"
 35 STOP
 36 ASTO Y
 37 "Y"
 38 ASTO X
 39 X=Y?              If so, set flag 1
 40 SF 01
 41 AOFF
 42 .005
 43 STO 06            Data input
 44 "FY="
 45 XEQ 01
 46 "Fc="
 47 XEQ 01
 48 "D="
 49 XEQ 01
 50 "D1="
 51 XEQ 01
 52 "AS1="
```

```
 53 XEQ 01
 54 "N="
 55*LBL 01            Control routine for data input
 56 PROMPT
 57 ARCL X
 58 STO IND
06
 59 FS? 21
 60 AVIEW
 61 ISG 06
 62 RTN
 63 24                Size check
 64 RCL 05
 65 +
 66 "SIZE>="          Display minimum size
 67 ARCL X              requirement if necessary
 68 1
 69 -
 70 SF 25
 71 RCL IND
X
 72 FC?C 25
 73 PROMPT
 74 CLD
 75 RCL 06            Move counter from R6 to R17
 76 STO 17
 77 RCL 00
 78 29 E6
 79 /
 80 STO 06            Compute εy
 81 .85
 82 STO 07
 83 4 E3
 84 RCL 01            Check concrete strength
 85 X<=Y?               f'c > 4000 psi
 86 GTO 02
 87 X<>Y
 88 -
 89 1 E3              Deduct .05 from B for each
 90 /                   1000 psi > 4000
 91 INT
 92 .05
 93 *
 94 ST- 07
 95 RCL 07            but not less than .065
 96 .65
 97 X<=Y?
 98 X<>Y
 99 STO 07
100*LBL 02            Data input
101 12.014
102 STO 17
103 CLX
104 .01
105 "P="
106 PROMPT
107 X=0?
108 X<>Y
109 XEQ 03
110 FC? 07
111 .1
```

```
112 X>Y?
113 SF 07
114 RDN
115 RCL 13
116 1 E-8
117 "MX="
118 PROMPT
119 X≠0?
120 X<>Y
121 RDN
122 *
123 XEQ 03
124 RCL 14
125 R↑
126 "MY="
127 PROMPT
128 X≠0?
129 X<>Y
130 RDN
131 *
132*LBL 03            Control for data input
133 ARCL X
134 STO IND
17
135 FS? 21
136 AVIEW
137 ISG 17
138 RTN
139 12
140 *
141 RCL 13
142 12
143 *
144 R-P
145 X<>Y
146 STO 16            Limit angles 0° < Δ ≤ 90°
147 X=0?
148 GTO 18
149 90
150 X=Y?
151 GTO 18
152 RDN
153 X<>Y
154 RCL 12
155 STO 00
156 FC? 07
157 /
158 STO 15
159 XEQ 29            Prepare for rebar data
160 ADV
161 "REBAR "
162 "├COORDI
NATES"
163 AVIEW             Coordinate input
164 CLD
165 RCL 02
166 2
167 /
168 RCL 03
169 -
170 STO 22
```

```
171 "C/S?"           Circular or square?
172 AON
173 STOP
174 ASTO X
175 "S"
176 ASTO Y
177 X=Y?
178 GTO 04           If square, go to 04
179 CLD
180 AOFF
181 "FIRST B         Circular input
AR ∡?"
182 PROMPT
183 STO 23
184 360              Automatic bar placement
185 RCL 05
186 /
187 STO 20
188◆LBL 25
189 FC? 55
190 SF 21
191 RCL 23
192 RCL 22
193 "Rb="
194 ARCL X
195 "├ ∡="           Print polar coordinates
196 ARCL Y
197 AVIEW
198 XEQ 06
199 STO IND
17
200 RCL 20
201 ST+ 23
202 ISG 17
203 GTO 25
204 CLD
205 GTO 07
206◆LBL 04
207 AOFF
208◆LBL 26           Rebar square coordinate input
209 "X ENT Y
"
210 PROMPT
211 "X="
212 ARCL Y
213 "├ Y="
214 ARCL X
215 AVIEW
216 X<>Y
217 R-P
218 XEQ 06
219 STO IND
17
220 ISG 17
221 GTO 26
222 GTO 07
223◆LBL 06           Control routine for input
224 X<>Y
225 RCL 16
226 X>Y?
227 X<>Y
```

```
228 -
229 COS
230 *
231 RTN
232◆LBL 07           Compute concrete force
233 ADV
234 RCL 01
235 .85
236 *
237 PI
238 4
239 /
240 RCL 02
241 X↑2
242 *
243 *
244 STO 12
245 RCL 05
246 RCL 04
247 *
248 STO Y            Check steel percentage
249 PI
250 4
251 /
252 RCL 02
253 X↑2
254 *
255 /
256 .01
257 X<=Y?
258 FS? 00
259 SF 05
260 RDN
261 .08
262 X>Y?
263 FS? 05
264 FS? 00
265 GTO 17
266 "P>8%MAX
"
267 FS?C 05
268 "P<1%MIN
"
269 AVIEW            If P > 8% max or P < 1% min of
270 PSE                code, then display warning and exit
271 "A.C.I.
CODE"
272 AVIEW
273 PSE
274 GTO 21
275◆LBL 17
276 RCL Z
277 29 E6
278 RCL 06
279 *
280 RCL 01
281 .85
282 *
283 -
284 *
285 ST+ 12
```

```
286 .7
287 ENTER↑
288 .75
289 FC? 01
290 X<>Y
291 .8
292 *
293 ST* 12
294 1 E3
295 ST/ 12
296 SF 21
297 "<.8>PMA     Print 80% Pmax
X="
298 ARCL 12
299 AVIEW
300 CLD
301 ADV
302 SF 00
303 .003
304 STO Y       Compute balance condition
305 RCL 06
306 +
307 /
308 STO 08      Cb
309 XEQ 29
310 RCL IND
17
311 ISG 17
312◆LBL 27     Determine most distant bar
313 RCL IND
17
314 X>Y?
315 X<>Y
316 ISG 17
317 GTO 27
318 ABS
319 RCL 02
320 2
321 /
322 +
323 STO 20      Store distance
324 ST* 08
325◆LBL 28     Analyze section
326 RAD
327 RCL 08      Compute stress block area
328 RCL 07        and increment
329 *
330 RCL 02
331 X<=Y?
332 GTO 05
333 2
334 /
335 STO Z
336 X<>Y
337 STO 10
338 -
339 X<>Y
340 /
341 ACOS
342 STO 21
343 2
```

```
344 *
345 RCL X
346 SIN
347 -
348 RCL 02
349 X↑2
350 8
351 /
352 *
353 XEQ 09
354 STO 12      P
355 RCL 21
356 SIN
357 3
358 Y↑X
359 LASTX
360 /
361 RCL 21
362 RCL X
363 COS
364 RCL Y
365 SIN
366 *
367 -
368 /
369 RCL 02
370 *
371 RCL 12
372 *
373 STO 13
374 GTO 08
375◆LBL 05
376 STO 10
377 PI
378 4
379 /
380 RCL 02
381 X↑2
382 *
383 XEQ 09
384 STO 12      Mp
385 0
386 STO 13
387◆LBL 08
388 DEG
389 XEQ 29
390 XEQ 10
391 XEQ 22
392 RCL Z
393 ST* 13
394 ST* 12
395 RCL 15
396 RCL 13
397 RCL 12
398 /
399 1 E3
400 ST/ 13
401 ST/ 12
402 RDN
403 FC?C 00
404 GTO 11
```

```
405 SF 21            Balance condition output
406 "ebR="
407 ARCL X
408 AVIEW
409 "MbR="
410 ARCL 13
411 AVIEW
412 "PbR="
413 ARCL 12
414 AVIEW
415 "cbR="
416 ARCL 08
417 AVIEW
418 "B∡="
419 ARCL 16
420 AVIEW
421 RCL 15
422 FS? 07
423 RCL 12
424 STO 19
425 X>Y?
426 CHS
427 2
428 /
429 ST/ 19
430 3
431 STO 18
432 CF 21
433 "COMPUTI          Display for long calculation
NG"
434 AVIEW
435 GTO 15
436♦LBL 11
437 RCL 12           Check P = 0
438 1 E-8
439 X>Y?
440 GTO 14
441 RDN
442 RDN
443 FS? 07
444 XEQ 20
445 RCL 19
446 X<0?
447 GTO 12
448 RDN
449 X<=Y?
450 GTO 14
451 GTO 15
452♦LBL 20           Routine for P search
453 RCL 12
454 RCL 15
455 RTN
456♦LBL 12
457 RDN
458 X>Y?
459 GTO 14
460♦LBL 15           Increment or decrement c
461 RCL 19            (neutral axis)
462 ST+ 08
463 GTO 28
464♦LBL 14
```

```
465 DSE 18
466 GTO 16
467 SF 21
468 TONE 9           Tone if solution found
469 CLD
470 ADV
471 RCL 16
472 RCL 13
473 12               Convert resolved moment to x and y
474 /
475 P-R
476 STO 13
477 X<>Y
478 STO 14           Output solution
479 "P="
480 ARCL 12
481 AVIEW
482 "MX="
483 ARCL 13
484 AVIEW
485 "MY="
486 ARCL 14
487 AVIEW
488 "cR="
489 ARCL 08
490 AVIEW
491 RCL 14
492 RCL 13
493 R-P
494 RCL 12
495 /
496 "ecR="
497 ARCL X
498 AVIEW
499 29 E6
500 RCL 06
501 *
502 STO 00
503 GTO 21           Exit
504♦LBL 16
505 RCL 19           Increment or decrement
506 ST- 08
507 2
508 RCL 18
509 X≠Y?
510 GTO 16
511 2
512 ST/ 19
513♦LBL 16
514 1 E1
515 ST/ 19
516 GTO 15
517♦LBL 10
518 .003
519 RCL 08
520 /
521 STO 09
522 GTO 31
523♦LBL 09
524 .85
525 *
```

```
526 RCL 01
527 *
528 RTN                  Indirect control for steel
529+LBL 29
530 RCL 05
531 23
532 +
533 1 E3
534 /
535 24
536 +
537 STO 17
538 RTN
539+LBL 31               Compute bar force and moments
540 RCL 10
541 RCL 02
542 2
543 /
544 RCL IND
17
545 -
546 X<=Y?
547 SF 02
548 RCL 08
549 X<>Y
550 -
551 RCL 09
552 *
553 STO 11
554 X<0?
555 SF 03
556 ABS
557 RCL 06
558 X>Y?
559 X<>Y
560 FS?C 03
561 CHS
562 29 E6
563 *
564 FS?C 02
565 XEQ 19
566 RCL 04
567 *
568 ST+ 12
569 RCL IND
17
570 *
571 ST+ 13
572 ISG 17
573 GTO 31               Reiterate
574 RTN
575+LBL 22               Compute Φ
576 .7
577 ENTER↑
578 .75
579 FC? 01
580 X<>Y
581 PI
582 4
583 /
```

```
584 RCL 02
585 X↑2
586 *
587 RCL 01
588 *
589 .1
590 *
591 1 E3
592 /
593 RCL 00
594 X>Y?
595 RTN
596 RCL Y
597 X<>Y
598 -
599 X<>Y
600 /
601 5
602 /
603 +
604 .9
605 X>Y?
606 X<>Y
607 STO Z
608 RTN
609+LBL 18               Error routine
610 BEEP
611 CF 21
612 "  ERROR
"
613 AVIEW
614 PSE
615 GTO 21
616+LBL 19
617 .85
618 RCL 01
619 *
620 -
621 RTN
622+LBL 21               Exit routine
623 ADV
624 CLD
625 CF 21
626 AON
627 "NEW PRG            See if user wants new program
M?"
628 STOP
629 ASTO Y
630 "Y"
631 ASTO X
632 X≠Y?                 If not, exit, else get new program
633 GTO 23                 name and read in
634 "PRGM NA
ME?"
635 STOP
636 AOFF
637 READP
638+LBL 23               Clean up display and quit
639 AOFF
640 CLX
```

CONBM

"CONBM" allows analysis and design of reinforced concrete beams. Analysis mode allows the user to analyze any Tee or rectangular shaped concrete beam with any compression/tension reinforcing whether or not compression reinforcing is needed. When compression reinforcement is included but not required, the program checks the strain on the reinforcement to determine if a yield condition exists. If the reinforcement has not yielded, the actual stress is computed and used. This is accomplished by locating the neutral axis to equate the tension force to the compression force and solving the resulting quadratic equation.

Design mode uses the Ultimate Strength Method to compute the required steel areas and cross sectional parameter, K_{max}, which determines bd² from a given moment. The program uses the methods of "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77).

Special Features

1. Design and analysis mode.
2. Minimum reinforcement check by A.C.I. code.
3. Option to limit reinforcement percentage to $0.18F_c'/F_Y$. Unlike the Structural Analysis Pac program, a message "RHO>0.18c/FY" is displayed if the computed percentage is greater, instead of computing the reinforcement. This allows the user to change bean dimensions or use A_s as $0.18F_c' \cdot b_d F_Y$ and add, if desired, compression reinforcing. In analysis mode, a section is easily checked for capacity.
4. After a completed run in design mode, an analysis check may be executed using the reinforcing selected by the user.
5. Depth to compression steel centroid, d1, is automatically prompted for when compression steel is required in the design mode and always prompted for in the analysis mode. An input of 0 is allowed if no compression reinforcement is being used.
6. For T beams, the neutral axis is always located. If it falls within the flange, the section will be designed and analyzed as a rectangular beam with the width equal to the flange width.

EQUATIONS

Design - Tension reinforcement only

$$C = T$$

$$M_n = M_u/\Phi$$

$$K = \frac{M_u}{\Phi bd^2} = \rho F_y \left(1 - \frac{1}{2}\rho m\right)$$

$$M_n = (C \text{ or } T)\left(d - \frac{a}{2}\right)$$

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2mK}{F_y}}\right)$$

$$a = \frac{(C \text{ or } T)}{0.85F_c'b}$$

$$\rho_{min} = \frac{200}{F_y}$$

$$m = \frac{F_y}{0.85F_c'}$$

$$\rho_b = \frac{0.85B_1F_c'}{f_y}\left(\frac{87000}{87000 + F_y}\right)$$

$$B_1 = 0.85 \text{ for } F_c' \leq 4000 \text{ psi}$$

$$B_1 = 0.85 - 0.05\left(\frac{F_c' - 4000}{1000}\right) \geq 0.65$$

$$K_{max} = 0.75\,\rho_b F_y \left(1 - \frac{1}{2}(0.75\,\rho_b m)\right)$$

$$\Phi = 0.9 \text{ for flexure}$$

Design - Tension and Compression Reinforcing

$$C_c + C_s = T$$

$$A_s = \frac{C_{c\,max} + C_s}{F_y} = \frac{T}{F_y}$$

$$M_n = C_c\left(d - \frac{B_1 c}{2}\right) + C_s(d - d1)$$

$$C_b = \left(\frac{87000}{87000 + F_y}\right) d$$

$$C_{max} = 0.75c_b$$

$$C_{max} = 0.85\,F_c'b\beta_1 c_{max}$$

$$a = \beta_1 c_{max}$$

$$M_n(max) = C_{max}\left(d - \frac{a}{2}\right)$$

$$\text{If } M_n(max) = M_{nc}$$

$$M_{comp\,steel} = M_{ns}$$

$$M_{ns} = M_n - M_{nc}$$

$$C_s = \frac{M_n - M_{nc}}{d - d1}$$

$$A'_s = \frac{C_s}{F_y - 0.85\,F_c'}$$

*It is noted that the components of the compressive force nominally are the portions carried by the steel and by the concrete, respectively. For the convenience of knowing the point of action, however, the compressive force in the concrete is taken larger than the real amount by stressing $0.85F_c'$ over the steel area, whereas the compressive force in the steel is taken less by the same amount. The total compressive force is correct. The components C_c and C_s will be computed this way in the program. (See NOTE.)

Stress in compressive steel

1. $\epsilon_s \geq \frac{F_y}{E_s}, F_y - 0.85\,F_c'$

2. $\epsilon_s < \frac{F_y}{E_s}, \epsilon_y - 0.85\,F_c'\,E_s$

NOTE: This method was not used in the Structural Analysis Pac. See reference in Structual Analysis Pac Manual. For this program, see Wang and Salmon 3rd Edition, 1979.

Design - T Beams

With N.A. within the flange (determined by program) see rectangular sections.

N.A. below flange

$$A_{sf} = \frac{(b - b_t)t \cdot 0.85f_c'}{F_y}$$

$$M_{sf} = A_{sf}F_y\left(d - \frac{t}{2}\right)$$

$$K = \frac{M_n - M_{sf}}{bd^2}$$

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{mK}{Fy}}\right)$$

$$A_{s1} = \rho bd$$

$$A_{st} = A_{s1} + A_{sf}$$

Analysis - Tension and Compression Reinforcing

When compression reinforcing exists and $\rho_{total} \leq 0.75\,\rho b$, it is assumed that A2 does not yield.

$$\therefore \epsilon_s < \frac{F_y}{E_s}$$

equaling C = T then

$$(0.85F_c'b\beta_1)c^2 + (E_s d1A2 - 0.85F_c'A2 - A1F_y)c - E_s d_1{}^2A2 = 0$$

$$A = 0.85\,F_c'b\beta_1$$

$$B = (E_s d1A2 - 0.85F_c'A2 - A1F_y$$

$$C = \frac{-B + \sqrt{B^2 - 4AC}}{2A}$$

equaling C = T then

$$(0.85F_c'b\beta_1)^2 + (E_s d1A2 - 0.85F_c'A2 - A1F_y)c - E_s d_1{}^2A2 = 0$$

$$A = 0.85\,F_c'b\beta_1$$

$$B = (E_s d1A2 - 0.85F_c'A2 - A1F_y$$

$$C = \frac{-B + \sqrt{B^2 - 4AC}}{2A}$$

$$C = E_s d_1{}^2A2$$

$$a = \beta_1 c$$

$$C_s = F_s'A2$$

$$C_c = 0.85F_c'ba$$

$$T = C_c + C_s$$

$$\epsilon_s = \frac{c - d1}{c} \quad (0.003)$$

$$M_n = C_c\left(d - \frac{a}{2}\right) + C_s(d - d1)$$

$$\epsilon_s \geq \frac{F_y}{E_s} \text{ use } F_y$$

$$\epsilon_s < \frac{F_y}{E_s} \text{ use } F_s = \epsilon_s E_s$$

so $F'_s = F_s - 0.85F_c'$ (see comment page)

Analysis - Tension and Compression Reinforcing

$\rho_{total} > 0.75\rho b$

$$a = \frac{C_c}{0.85F_c b}$$

$T = A_{s}F_{y}$

$C_s = (F_y - 0.85F_c)A2$

$$c = \frac{a}{\beta_1}$$

$C_c = 0.85F_c ba = T - C_s$

$$M_u = C_c\left(d - \frac{a}{2}\right) - C_s(d - d')2$$

Analysis Tee beam

If N.A. is within flange analyze as rectangular section.

If N.A. is greater than flange determine moment

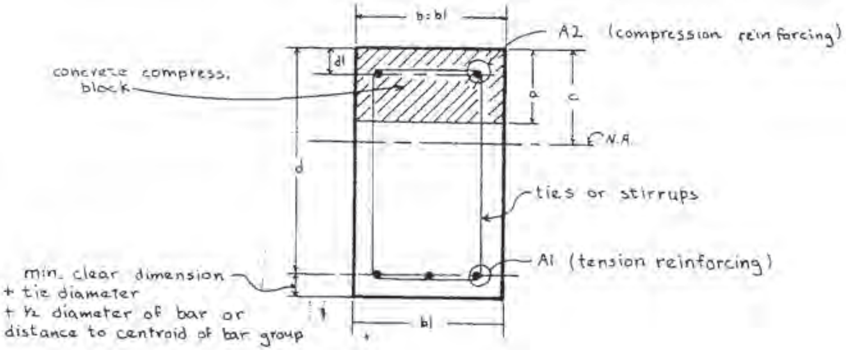
$$\frac{(b - b1)t \cdot 0.85F_c'}{F_y} \cdot F_y\left(d - \frac{t}{2}\right)$$

for flange projection

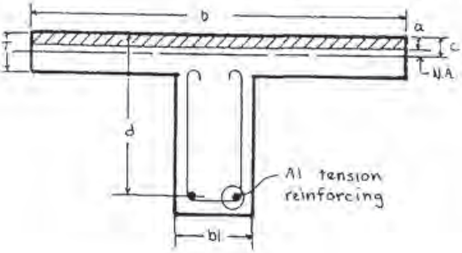
Then analyze remaining rectangular section and add equivalent moment

When analyzing the equivalent rectangular section by taking $A_s - A_{sf}$ as tension steel area

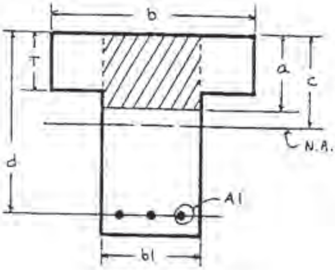
If A_{sf} is greater than A_s the program will analyze the section a rectangular section



Typical Rectangular Section



T section with N.A. within flange.
Designed as a rectangular section with bl= b.



T section with N.A. below flange.

DEFINITIONS

a = Depth of concrete stress block
A1 = Total tension reinforcing
A2 = Compression reinforcing
A_s = Steel reinforcing, tensile stress only
A's = Area of compression, steel reinforcing
A_sf = Equivalent steel area to balance force in T beam flange
b = Beam width (flange width of T beam)
b1 = Stem width of T beam
c = Location of neutral axis
C_b = Location of neutral axis at balance
C_c = Compression force in concrete
C_s = Compression force in compression steel
d = Beam depth from compression face to centroid of tension reinforcing
d1 = Location of compression reinforcement from compression face to steel centroid
E_s = Modulus of elasticity for steel
F_c' = Ultimate compressive strength of concrete
FY = Yield strength of steel
K = Flexural coefficient
K_{max} = Flexural coefficient at 75% Pb
M_n = Design moment (= Mu/Φ, done with program)
Mu = Ultimate design moment
N.A. = Neutral axis
P = Steel ratio A_s/bd
.75 Pb = 75% balanced steel percentage
εc = Strain in concrete equal to 0.003
εs = Strain in steel equal to FY/E_s
T = Tension force
t = Thickness of flange
Φ = Capacity reduction factor; = 0.9 for flexure

OPERATING LIMITS AND WARNINGS

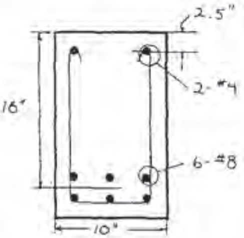
1. The program deals with flexure only. A complete design requires that shear, deflection (short term and long term), torsion, and reinforcing development length (see program "REBAR") should be considered.
2. The program does not check span depth ratios.
3. A thorough understanding of the principles of concrete and ultimate design is suggested.

REFERENCES

Wang and Salmon, "Reinforced Concrete Design", 3rd Edition, Harper and Row, 1979

"Building Code Requirements for Reinforced Concrete", A.C.I. 318-77

SAMPLE PROBLEM #1:



Design a concrete beam for flexure, using tension reinforcement only. Select the required reinforcing and add 2 #4 top to provide additional stiffness and support for the stirrups. Check the ultimate capacity for the steel provided.

FY = 40,000 psi
F'c = 3,000 psi

M_u = 2000 K-in

$$bd^2 = \frac{M_u}{0.9 K_{max}}$$

$$d = \sqrt{\frac{2000 \cdot 10^3}{10(783.41)}}$$

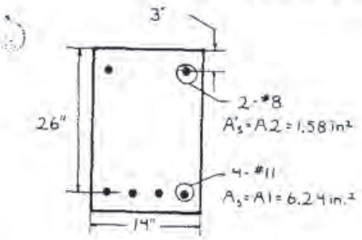
= 15.98
use 16

SOLUTION:

Input	Function	Display	Comments
Load CONBM			
Begin	[XEQ] CONBM	CONBM	
		A? D?	Analysis or Design?
D	[R/S]	RECT T	Choose rectangular or T section
	[R/S]	FY =	[R/S] chooses rectangular section
40000	[R/S]	Fc =	
3000	[R/S]	.75Pb = 0.03	Number of digits shown depends on display setting
	[R/S]*	.9KMAX = 783.41	
	[R/S]*	WIDTH =	
10	[R/S]	DEPTH =	
2000000	[ENTER↑]	2,000,000.00	Calculate depth
10	[÷]	200,000.00	
783.41	[÷]	255.29	
	[√x]	15.98	Use 16
16	[R/S]	LMT REIN?	
N	[R/S]	MOMENT =	
2000	[R/S]*	K = 868.06	
	[R/S]*	A1 = 4.44	
	[R/S]*	CHK MOM?	
	[R/S]	DEPTH COMP =	Use 6 #8 at 4.74 in², add 2 #4 top A's = 0.4 in²
2.5	[R/S]	A1 =	
4.74	[R/S]	A2 =	
.4	[R/S]	M = 2,458.44	
	[R/S]*	NEW PRGM?	
N	[R/S]	0.00	

*If printer is in use, you need not perform this keystroke

SAMPLE PROBLEM #2:



Analyze the capacity of the 14" x 26" concrete beam with 4 #11 bottom and 2 #8 top. Since actual A_s is less than A_{sb} = 9.13 in² the compression steel does not yield.

b = 14"
FY = 60,000 psi
d = 26"

F_c = 5000 psi
d1 = 3"
Computed moment
= 7865.21 K''
= 655.43 K'

if $M_u = \frac{M_n}{\phi}$ M_u = 728.26 K

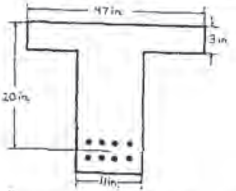
Φ = 0.9

SOLUTION:

Input	Function	Display	Comments
Load "CONBM"			
Begin	[XEQ] "CONBM"	CONBM	If you have run Sample Problem 1, press [R/S]
		A?/D?	
A	[R S]	RECT/T	
	[R S]	FY=	
60000	[R S]	Fc=	
5000	[R S]	.75Pb=0.03	
	[R S]*	.9KMAX=1117.10	
	[R S]*	WIDTH=	
14	[R S]	DEPTH=	
26	[R S]	DEPTH COMP=	
3	[R S]	A1=	
6.24	[R S]	A2=	
1.58	[R S]	M=7,865.21	
	[R S]*	NEW PRGM?	
N	[R S]	0.00	

*If printer is in use, you need not perform this keystroke.

SAMPLE PROBLEM #3:



Determine the reinforcing for the following "T" beam
FY = 60,000 psi
F_c = 3,000 psi
b = 47.0"
b1 = 11.0"

d = 20.00"
d1 = 2.50 (if required)
T = 3.0 in.
M_u = 6,400 K in.
Then provide reinforcing and check capacity.

SOLUTION:

Input	Function	Display	Comments
Load "CONBM"			
Begin	[XEQ] "CONBM"	CONBM	
		A?/D?	
D	[R S]	RECT/T	
T	[R/S]	FY=	
60000	[R/S]	Fc=	
3000	[R/S]	.75Pb=0.02	
	[R/S]*	.9KMAX=702.54	
	[R/S]*	WIDTH=	
47	[R S]	STEM WIDTH=	
11	[R S]	DEPTH=	
20	[R S]	THICKNESS=	
3	[R S]	LMT REIN?	
N	[R S]	MOMENT=	
6400	[R S]	K=458.23	
	[R S]*	A1=6.46	
	[R S]*	CHK MOM?	
	[R S]	DEPTH COMP=	Provide 4 #9 and 4 #7 2 layers. A1 = 6.40 in²
0	[R S]	A1=	
6.4	[R S]	A2=	
0	[R S]	M=6,351.00	
	[R S]*	NEW PRGM?	
N	[R S]	0.00	Moment is slightly less than design moment, add different reinforcing and re-analyze the beam or say OK since moment variation is 0.8%

*If a printer is in use, you need not perform this keystroke.

USER INSTRUCTIONS

Step	Instructions	Input	Function	SIZE: 21 Display
1.	Load "CONBM"			
2.	Begin		[XEQ] "CONBM"	CONBM A?/D?
3.	Choose analysis or design mode			
	If analysis	A	[R/S]	
	If design	D	[R/S]	RECT/T?
4	Choose section type			
	If rectangular	R	[R/S]	
	If T	T	[R/S]	FY=
5.	Input steel yield strength (psi)	FY	[R/S]	Fc=
	Input ultimate compressive concrete strength (psi)	Fc	[R/S]	
6.	Output 75% balanced steel ratio			.75Pb=nn
	Output phi times flexural coefficient		[R/S]*	.9KMAX=nn
	Φ = 0.9 for flexure		[R/S]*	WIDTH=
7.	Input section dimensions			
	For rectangular section			
	Input width (in)	b	[R/S]	DEPTH=
	Input depth (in)	d	[R/S]	
	For T section			
	Input width (in)	b	[R/S]	STEM WIDTH=

Step	Instructions	Input	Function	Display
	Input stem width (in)	b1	[R/S]	DEPTH=
	Input depth (in)	d	[R/S]	THICKNESS=
	Input flange thickness (in)	T	[R/S]	
8.	For design mode, go to step 11			DEPTH COMP=
9.	Input depth to compression reinforcement	d1	[R/S]	A1=
	Input tension reinforcing area	A1	[R/S]	A2=
10.	Input compression reinforcing area	A2	[R/S]	M=nn
11.	Go to step 15 Design Mode			LMT REIN?
12.	To limit reinforcement percentage to 0.18 F_c F_y	Y	[R/S]	
	OR give a "no" response	N	[R/S]	MOMENT=
13.	Input design moment (kip-in)	Mu	[R/S]	
14.	Outputs flexural coefficient K=nn if compression reinforcement required. "DEPTH COMP" will be prompted for after output of K.		[R/S]	A1=nn CHK MOM?
15.	To compute ultimate capacity using selected reinforcement	Y	[R/S]	DEPTH COMP=
	Input depth to compress. rein	D1	[R/S]	A1=
	Input selected tension steel area	A1	[R/S]	A2=
	Input selected compression steel area	A2	[R/S]	M=nn NEW PRGM?
16.	If you desire a new program	Y	[R/S]	PRGM NAME?
	Key in name of program	name	[R/S]	
	If you do not,	N	[R/S]	0.00
	Press [R/S] to begin "CONBM"			

*If printer is in use, you need not perform this keystroke.

REGISTERS, STATUS, FLAGS

Data Registers

00 F_y
01 F_c
02 b
03 b1
04 d
05 d1, K = r_{max}
06 T
07 A1
08 A2
09 Asf
10 bd²
11 0.85
12 B1
13 M, 0.85F
14 0.75 ρ_b
15 K_{max}
15 counter
17 used
18 A
19 B c
20 c a f_s

Status

SIZE 021
ENG
DEG RAD GRAD

TOT REG 165
FIX 2 SCI

Flags

#	SET INDICATES	CLEAR INDICATES
00	T beam	Rectangular beam
01	Analysis mode	Design mode
02	$p > 0.18 F_c F_y$	$p < 0.18 F_c F_y$
03	$\epsilon_s < F_y E_s$	$\epsilon_s \geq F_y E_s$

PROGRAM LISTINGS

```
 01♦LBL "CON
BM"
 02 CF 21
 03 FS? 55
 04 SF 21
 05 SF 12
 06 "CONBM"
 07 AVIEW
 08 PSE
 09 CF 00          Initialize flags
 10 CF 01
 11 CF 02
 12 CF 03
 13 CF 12
 14 CLD
 15 "A/D?"         Analysis or Design mode?
 16 AON
 17 STOP
 18 ASTO Y
 19 "A"
 20 ASTO X
 21 X=Y?           If analysis, set flag 01
 22 SF 01
 23 ADV
 24 "RECT/T?       Rectangular or Tee section
"
 25 STOP
 26 ASTO Y
 27 "T"
 28 ASTO X         If Tee section, set flag 00
 29 AOFF
 30 X=Y?
 31 SF 00
 32 ADV
 33 FC? 55
 34 SF 21          Size check
 35 "SIZE>=2
1"
 36 SF 25
 37 RCL 20
 38 FC?C 25        If necessary,
 39 PROMPT           prompt for minimum size
 40 .006
 41 STO 16
 42 0
 43 STO 07
 44 STO 08
 45 STO 05
```

```
 46 "FY"
 47 XEQ 01
 48 "Fc"
 49 XEQ 01          Input material properties
 50 ADV
 51 .85
 52 STO 11          Compute B1 at 0.85 less
 53 STO 12           .05 for each 1000 psi > 4000,
 54 4 E3             but not less than 0.65
 55 RCL 01
 56 X<=Y?
 57 GTO 02
 58 X<>Y
 59 -
 60 1 E3
 61 /
 62 INT
 63 .05
 64 *
 65 ST- 12
 66 RCL 12
 67 .65
 68 X<=Y?
 69 X<>Y
 70 STO 12
 71♦LBL 02          Compute Pb and Kmax
 72 RCL 00
 73 RCL 11
 74 /
 75 RCL 01
 76 /
 77 STO 13
 78 1/X
 79 RCL 12
 80 *
 81 RCL 00
 82 87 E3
 83 /
 84 1
 85 +
 86 1/X
 87 *
 88 .75
 89 *
 90 STO 14
 91 STO 18
 92 ".75Pb="         Balanced steel ratio
 93 ARCL X
 94 AVIEW
 95 RCL 00
 96 *
 97 ENTER↑
 98 X↑2
 99 1.7
100 /
101 RCL 01
102 /
103 -
104 STO 15
105 .9

106 *
107 ".9KMAX=         Flexural coefficient
"
108 ARCL X
109 AVIEW
110 ADV
111 "WIDTH"         Section property input
112 XEQ 01
113 RCL 02
114 "STEM WI
DTH"
115 XEQ 00
116 "DEPTH"
117 XEQ 01
118 ISG 16
119 "THICKNE
SS"
120♦LBL 00
121 FC? 00
122 GTO 00
123♦LBL 01          Control for input
124 "⊢="
125 PROMPT
126 ARCL X
127 FS? 55
128 PRA
129♦LBL 00
130 STO IND
16
131 0
132 ISG 16
133 RTN
134 ADV
135 RCL 02
136 RCL 04
137 X↑2
138 *
139 STO 10
140 ADV
141 FC? 00
142 GTO 00
143 RCL 02
144 RCL 03
145 -
146 RCL 06
147 *
148 RCL 13
149 /
150 STO 17
151♦LBL 00
152 FS? 01
153 GTO 03
154 "LMT REI
N?"
155 AON
156 STOP
157 ASTO Y
158 "Y"
159 ASTO X
160 AOFF
```

```
161 X=Y?
162 XEQ 08
163 ADV
164 "MOMENT=     Input design moment, Mu
"
165 PROMPT
166 ARCL X
167 FS? 55
168 PRA          Mu to Mn by Mu/0.9
169 .9
170 /
171 1 E3
172 *
173 STO 16
174 FS? 00       If Tee beam,
175 XEQ 09         check location of stress block
176 RCL 04
177 X↑2
178 RCL 03
179 *
180 STO 10
181 /
182 "K="         Compute K = Mu/bd²Φ
183 ARCL X
184 AVIEW
185 RCL 15       If K < Kmax, compute A1 for
186 X<=Y?          single reinforcement
187 GTO 03
188 RDN
189 RCL 13
190 *
191 2
192 *
193 RCL 00
194 /
195 CHS
196 1
197 +
198 SQRT
199 CHS
200 1
201 +
202 RCL 13
203 /
204 RCL 18
205 X<Y?
206 GTO 11
207 RDN
208 RCL 03
209 *
210 RCL 04
211 *
212 STO 07
213 GTO 04
214♦LBL 03      Double reinforcement required
215 FS?C 02
216 GTO 11
217 -
218 STO 05
219 "DEPTH C
OMP="
```

```
220 PROMPT
221 ARCL X
222 FS? 55
223 PRA
224 X<> 05
225 FS? 01
226 GTO 01
227 RCL 10       Compute compresion reinforcing
228 *
229 RCL 04
230 RCL 05
231 -
232 /
233 STO 20
234 RCL 00
235 87 E3
236 +
237 LASTX
238 /
239 RCL 05
240 *
241 RCL 04
242 /
243 CHS
244 1
245 +
246 87 E3
247 *
248 RCL 00
249 X<=Y?
250 X<>Y
251 RDN
252 RCL 01
253 .85
254 *
255 -
256 /
257 STO 08       A2
258 RCL 15
259 RCL 03
260 *
261 RCL 04
262 *
263 87 E3
264 RCL X
265 RCL 00
266 +
267 /
268 RCL 12
269 *
270 .375
271 *
272 CHS
273 1
274 +
275 /
276 RCL 20
277 +
278 RCL 00
279 /
280 STO 07       A1
```

```
281♦LBL 04
282 RCL 17
283 FS? 00          Add to A1 equivalent
284 ST+ 07           Tee beam flange reinforcement
285 RCL 07
286 RCL 03
287 RCL 04
288 *
289 200
290 RCL 00
291 /
292 *
293 "AMIN="
294 ARCL X
295 X>Y?
296 AVIEW
297 "A1="
298 ARCL 07
299 AVIEW
300 RCL 08
301 X<=0?
302 GTO 00
303 "A2="
304 ARCL X
305 AVIEW
306♦LBL 00
307 "CHK MOM        After selecting reinforcement,
?"                   check ultimate moment if desired
308 AON
309 PROMPT
310 ASTO Y
311 "Y"
312 ASTO X
313 AOFF
314 X≠Y?            If not, exit
315 GTO 06
316 1               Set up stack for label 3 return
317 ENTER↑
318 0
319 ADV
320 SF 01
321 GTO 03
322♦LBL 01
323 "A1="
324 PROMPT          Input supplied reinforcement
325 ARCL X
326 FS? 55
327 PRA
328 STO 07
329 "A2="
330 PROMPT          If Tee beam, compute equivalent
331 ARCL X           moment and Ast
332 FS? 55
333 PRA
334♦LBL 12
335 STO 08
336 RCL 04
337 RCL 06
338 2
339 /
```

```
340 -
341 RCL 02
342 RCL 03
343 -
344 RCL 06
345 *
346 RCL 13
347 /               If Ast > A1,
348 STO 17           analyze as a rectangular section
349 RCL 07
350 STO 09
351 X<=Y?
352 GTO 10
353 RDN
354 ST- 07          Else subtract Ast from A1
355 *
356 RCL 00
357 *
358 STO 16
359 RCL 07
360 RCL 03
361 RCL 04          Check P = A1/bd
362 *
363 /
364 RCL 14
365 X<=Y?           If < 0.75 Pb, check strain on
366 GTO 05           compressive reinforcement if it
367 RCL 01           exists. If εs > Fy/Es, go to 05
368 RCL 11
369 *
370 STO 13
371 RCL 03
372 *
373 RCL 12
374 *
375 STO 18          A
376 RCL 05
377 RCL 08          Compute B
378 *
379 29 E3
380 *
381 RCL 13
382 RCL 08
383 *
384 -
385 RCL 07
386 RCL 00
387 *
388 -
389 STO 19          Store B
390 RCL 05
391 X↑2             Compute C
392 RCL 08
393 *
394 29 E3
395 *
396 CHS
397 STO 20          Store C
398 RCL 19
399 X↑2
```

```
400 RCL 18        Solve quadratic equation
401 RCL 20
402 *
403 4
404 *
405 CHS
406 +
407 SQRT
408 RCL 19
409 CHS
410 +
411 RCL 18
412 2
413 *
414 /
415 STO 19        C (neutral axis)
416 RCL 12
417 *
418 RCL 06        Compare A to T if [illegible] exists
419 X>Y?
420 GTO 10
421 RDN
422 STO 20
423 2
424 /
425 CHS
426 RCL 04
427 +
428 RCL 18        C_c
429 RCL 19
430 *
431 *
432 ST+ 16
433 .003
434 RCL 19
435 /
436 LASTX
437 RCL 05
438 -
439 *
440 29 E6
441 *
442 RCL 00        F_s or FY
443 X<=Y?
444 X<>Y
445 RDN
446 RCL 13
447 -
448 RCL 08        C_s
449 *
450 RCL 04
451 RCL 05
452 -
453 *
454 ST+ 16
455 0
456 X>Y?
457 GTO 12
458 GTO 07
```

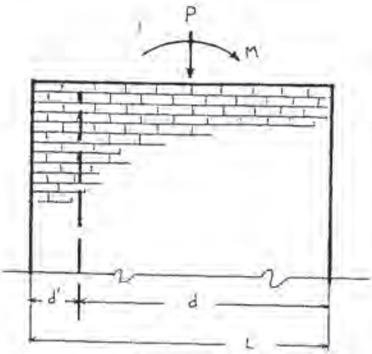
```
459♦LBL 05        Compute ultimate capacity if
                    compression steel yields or check
                    yield and use actual f's if not
460 RCL 07
461 RCL 00
462 *
463 LASTX
464 RCL 20
465 FS? 03
466 X<>Y
467 RDN
468 RCL 01
469 .85
470 *
471 STO 13
472 -
473 RCL 08
474 *
475 STO 18        C_c
476 -
477 RCL 13
478 RCL 03
479 *
480 /
481 STO 20        C_s
482 LASTX
483 *
484 RCL 04
485 RCL 20
486 2
487 /
488 -
489 *
490 ST+ 16
491 RCL 18
492 RCL 04
493 RCL 05
494 -
495 *
496 ST+ 16
497 FS?C 03
498 GTO 07
499 RCL 20
500 RCL 12
501 /
502 .75           Check compressive steel yield
503 /
504 .003
505 X<>Y
506 /
507 LASTX
508 RCL 05
509 -
510 *
511 29 E6
512 *
513 RCL 00
514 X<=Y?
515 GTO 07
516 SF 03
517 X<>Y          If not yielding, go to 05
```

```
518 STO 20
519 0
520 STO 16
521 GTO 05
522♦LBL 07
523 .9
524 ST* 16
525 1 E3
526 ST/ 16        Output ultimate moment, Mu
527 "M="
528 ARCL 16
529 AVIEW
530 GTO 06        Exit
531♦LBL 08
532 SF 02         Compute 0.18 f'c/fy
533 .18
534 RCL 01
535 *
536 RCL 00
537 /
538 STO 18
539 RTN
540♦LBL 09
541 RCL 04        Ask for Tee beam
542 RCL 06
543 2
544 /
545 -
546 RCL 00
547 *
548 /
549 RCL 02
550 RCL 04
551 *
552 /
553 RCL 04
554 *
555 RCL 13
556 *
557 RCL 12
558 /
559 RCL 06        Check location of "a" to flange
560 X>Y?
561 GTO 10
562 RCL 16
563 RCL 04
564 RCL 06
565 2
566 /
567 -
568 RCL 17
569 *
570 RCL 00
571 *
572 -
573 RTN
574♦LBL 10        Set Tee beam to rectangular beam
575 RCL 02
576 STO 03
577 CF 00
578 RCL 16
579 FC? 01
580 RTN
581 0
582 STO 06
583 RCL 09
584 STO 07
585 RCL 08
586 GTO 12
587♦LBL 11        Reinforcing limit message
588 "RHO>.18
FC/FY"
589 AVIEW
590 PSE
591♦LBL 06        Exit routine
592 ADV
593 CLD
594 CF 21
595 AON
596 "NEW PRG      Ask if new program desired
M?"
597 STOP
598 ASTO Y
599 "Y"
600 ASTO X
601 X≠Y?
602 GTO 12        If not, exit, else get name and read in
603 "PRGM NA
ME?"
604 STOP
605 AOFF
606 READP
607♦LBL 12
608 AOFF          Clean up stack and quit
609 CLX
```

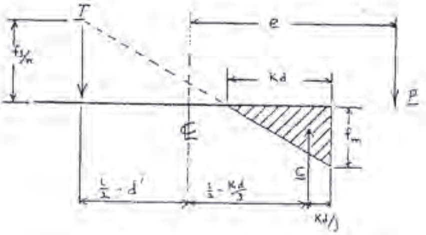
MWALL

"MWALL" uses the evaluation of forces based on static equilibrium of $\Sigma F = 0$ and $\Sigma M = 0$ to analyze a reinforced masonry shear wall.

The necessary input describing the wall properties are determined by the user. The basis of analysis is to equate tension to compression of internal and external forces and moments to compute the location of the neutral axis. When the neutral axis has been calculated by using the quadratic equation, the individual forces may easily be computed and hence the required reinforcing steel area. A check must be made on the computed f_m (actual masonry stress) to determine if the allowable stress has been exceeded.



Partial Elevation



Stress Diagram

EQUATIONS

$$C = \frac{1}{2} t k_d f_m$$

$$T = C - P$$

$$f_a = \frac{P}{Lt}$$

$$F_a = 0.2f'_m \left[1 - \left(\frac{12h}{40t} \right)^3 \right]$$

$F_b = 0.33f'_m$ but not to exceed 900 psi

$$f_b = F_b \left(1.33 - \frac{f_a}{F_a} \right)$$

$$f_m = f_a + f_b$$

$$K = \frac{k_d}{d}$$

$$f_s = \left(\frac{1 - k}{k} \right) n f_m$$

$$A_s = \frac{T}{f_s}$$

$$k_d = \frac{\frac{1}{2} tf_m (l - d') - \sqrt{\left(\frac{1}{2} tf_m (l - d') \right)^2 - 4 \left(\frac{1}{6} tf_m \right) \left[P \left(\frac{L}{2} - d' \right) + M \right]}}{2 \left(\frac{1}{6} \right) f_m t}$$

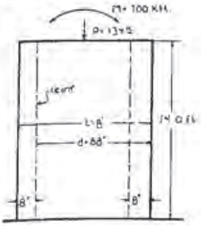
DEFINITIONS

A = Area of reinforcing steel required (in²)
C = Compression force (kips)
d = Distance to steel centroid from compression face (in)
$d1$ = Distance to steel centroid from tension (cracked) face (in)
f_s = Steel stress (psi)
f_m = Masonry stress (psi)
K = Unbraced length
L = Length of wall
M = Moment (kip-ft)
n = Modular ratio Es/Em
P = Axial load in kips
T = Tension force in kips
t = Thickness of wall

REFERENCES

"Reinforced Masonry Engineering Handbook", 3rd Edition, Masonry Institute of America, 1978.

SAMPLE PROBLEM



Design the masonry shear wall as shown with the following given data:
10" nominal block
M = 700 k

F-2 f'm = 3,000 psi
k = 134 k
n = 10
Wall No. 1
f_s = 20,000 psi max

SOLUTION:

Input	Function	Display	Comments
Load "MWALL"			
Begin	[XEQ] "MWALL"	MWALL	
		SIZE >= 17	Displayed only if size < 17
	[XEQ] "SIZE"	SIZE _ _ _	
17	[R S]	WALL NO	
1	[R S]	NO. 1	
		T=	
9.63	[R S]	L=	
8	[R S]	d1=	
8	[R S]	H=	
14	[R S]	P=	
134	[R S]	M=	
700	[R S]	FM=	
3000	[R S]	N=	
10	[R S]	A=2.54	
	[R S]*	F=1104.86	
	[R S]*	Kd=33.69	
	[R S]*	FS=17,809.07	
	[R S]*	C=179.24	
	[R S]*	T=45.24	
	[R S]*	INPUT NEW F?	
N	[R S]	NEW PRGM?	
N	[R/S]	0.00	

*If printer is in use, you need not perform this keystroke.

USER INSTRUCTIONS

SIZE: 17

Step	Instructions	Input	Function	Display
1.	Load program			
2.	Begin		[XEQ] "MWALL"	MWALL
	If size > = 17 occurs,			
3.	Input wall number	n	[R/S]	T=
	Input wall thickness (in)	t	[R/S]	L=
	Input wall length (ft)	L	[R/S]	d1=
	Input distance from tension face to steel centroid (in)	d1	[R S]	H=
	Input height	H	[R S]	P=
	Input axial load (K)	P	[R S]	M=
	Input moment (K ft)	M	[R S]	FM=
	Input masonry stress (psi)	fm	[R S]	N=
	set size			SIZE > = 17
	then press		[R S]	WALL NO
	Input modular ratio (Es/Em)	n	[R S]	
4.	Outputs			
	Area of required reinforcing steel			A=nn
	Actual masonry stress		[R S]*	F=nn
	Neutral axis		[R S]*	Kd=nn
	Steel stress		[R S]*	FS=nn
	Compression force		[R S]*	C=nn
	Tension force		[R S]*	T=nn
			[R S]*	INPUT NEW F?
5.	If C<P or fs is higher than allowable stress, try a lower value for f	t	[R S]	
	or simply press		[R S]	NEW PRGM?
6a.	If you desire a new program	Y	[R S]	PRGM NAME?
	Input name	name	[R S]	
6b	Or press	N	[R S]	0.00

*If printer is in use, you need not perform this keystroke.

REGISTERS, STATUS, FLAGS

Data Registers

00 t
01 L
02 d1
03 H
04 P
05 M
06 FM
07 n
08 d
09 f
10 a
11 b,k
12 f_s
13 $0.2\,[1-(12b/40t)^3]$
14 fa
15 counter, c
16 T

Status

SIZE 017
ENG
DEG

TOT REG 73
FIX 2 SCI
RAD GRAD

Flags

# SET INDICATES	CLEAR INDICATES
12 Double-wide print	Single-wide print
13 Print lower case	Print default case
21 Printer enable	Printer disable
25 Error ignore on	No error ignore
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "MWA
LL"
 02 CF 21
 03 FS? 55
 04 SF 21
 05 SF 12
 06 "MWALL"         Print/display title
 07 AVIEW
 08 CF 12
 09 ADV
 10 CF 13
 11 "SIZE>=1        Size check
7"
 12 SF 25
 13 RCL 16
 14 FC?C 25         Display minimum size if necessary
 15 PROMPT
 16♦LBL 02
 17 FIX 0
 18 "  WALL         Get wall number
NO."
 19 PROMPT
 20 ASHF
 21 ARCL X
 22 FIX 2
 23 AVIEW
 24 PSE
 25 ADV
 26 .007
 27 STO 15          Data input
 28 "T="
 29 XEQ 01
 30 "L="
 31 XEQ 01
 32 12
 33 ST* 01
 34 "d1="
 35 XEQ 01
 36 "H="
 37 XEQ 01
 38 "P="
 39 XEQ 01
 40 "M="
 41 XEQ 01
 42 "FM="
 43 XEQ 01
 44 "N="
 45♦LBL 01          Input control subroutine
 46 PROMPT
 47 ARCL X
 48 STO IND
15
 49 FS? 21
 50 AVIEW
 51 ISG 15
 52 RTN
 53 CLD
 54 RCL 01
```

```
 55 RCL 02
 56 -
 57 STO 08
 58 12 E3
 59 ST* 05
 60 1 E3
 61 ST* 04
 62 RCL 03
 63 RCL 00
```

Compute $0.2\left[1 - \left(\frac{12h}{40l}\right)^{3}\right]$

```
 64 /
 65 12
 66 *
 67 40
 68 /
 69 3
 70 Y↑X
 71 CHS
 72 1
 73 +
 74 .2
 75 *
 76 STO 13
 77 RCL 04
 78 RCL 00
 79 /
 80 RCL 01
 81 /
 82 STO 14
 83 RCL 06
 84 RCL 13
 85 *
 86 /
 87 CHS
 88 1.33
 89 +
 90 RCL 06
 91 3
 92 /
 93 900
 94 X>Y?
 95 X<>Y
 96 X<>Y
 97 RDN
 98 *
 99 RCL 14
100 +
101♦LBL 00
102 STO 09
103 RCL 00
104 *
105 6
106 /
107 STO 10
108 RCL 00
109 RCL 08
110 *
111 RCL 09
112 *
```

```
113 /
114
115 CHS
116 STO 11          b
117 RCL 01
118 2
119 /
120 RCL 02
121 -
122 RCL 04
123 *
124 RCL 05
125 +
126 RCL 10
127 *
128 4
129 *
130 CHS
131 RCL 11
132 X↑2
133 +
134 SQRT
135 CHS
136 RCL 11
137 -
138 RCL 10
139 /
140 2
141 /
142 RCL 08
143 /
144 STO 11
145 CHS
146 1
147 +
148 RCL 11
149 /
150 RCL 09
151 *
152 RCL 07
153 *
154 STO 12          fs
155 RCL 00
156 RCL 11
157 *
158 RCL 08
159 *
160 RCL 09
161 *
162 2
163 /
164 STO 15          C
165 RCL 04
166 -
167 STO 16          T
168 RCL 12
169 /
170 X<=0?
171 CLX
172 SF 21
173 1 E3
174 ST/ 15
175 ST/ 16
176 RDN
177 ADV
178 "A="           Output solution
179 ARCL X
180 AVIEW
181 "F="
182 ARCL 09
183 AVIEW
184 RCL 11
185 RCL 08
186 *
187 "Kd="
188 ARCL X
189 AVIEW
190 "FS="
191 ARCL 12
192 AVIEW
193 "C="
194 ARCL 15
195 AVIEW
196 "T="
197 ARCL 16
198 AVIEW
199 CF 21
200 ADV
201 CF 22
202 "INPUT N      Change Ts if desired
EW F?"
203 PROMPT
204 FS? 22
205 GTO 00          Rerun
206 AON
207 "NEW PRG      Desire new program?
M?"
208 PROMPT
209 ASTO Y
210 "Y"
211 ASTO X
212 X≠Y?           If not exit
213 GTO 03
214 "PRGM NA      Else, get name and read in
ME?"
215 PROMPT
216 READP
217♦LBL 03         Clean up display and quit
218 AOFF
219 CLX
```

TILTUP

"TILTUP" is a program for the design of cast in place concrete or precast concrete tilt-up walls using the Ultimate Strength Design method. With tilt-up walls, the presence of lateral loads and high end eccentricities together with the influence of variable moment of inertia and effects of deflections presents a complex problem for analysis. By the use of numerical methods, this program provides a solution to the problem. Slenderness limitations are

$$20\ Kl_u/h \leq 50$$

Reinforcing may be 1-layer centered or 1-layer each face, with compression force neglected.

Restraint Conditions

The wall panel is considered hinged along its loaded edges and free along its vertical edges. Lateral restraint offered by the floor slab depends on construction details between wall panel and slab. If adequate restraint is developed by the slab, the reduced unrestrained height of the wall may be advantageously used.

EQUATIONS

$$\frac{f_c}{f_c'} = \left[2.3 \left(\frac{\epsilon_x}{\epsilon_0} \right) - 1.35 \left(\frac{\epsilon_x}{\epsilon} \right)^2 \right]$$

$$\epsilon_x = \frac{\epsilon_{cx}}{K_d}$$

$$K_d = \frac{\epsilon_c d}{\epsilon_c + \epsilon_y}$$

$$F_c = bf_c' \int_{x=0}^{x=kd} 2.3 \frac{\epsilon_{cx} dx}{\epsilon_0 K_d} - 1.35 \frac{\epsilon_c^2 x^2\, dx}{\epsilon_0^2 (K_d)^2}$$

$$= bf_c' \left[\frac{2.3\, \epsilon_c (K_d)^2}{2\, \epsilon_0 K_d} \right] - 1.35 \frac{\epsilon_c^2 (K_d)^3}{3\, \epsilon_0^2 (K_d)^2}$$

$$= bf_c' \left[1.15 \left(\frac{\epsilon_c}{\epsilon_0} \right) - 0.45 \left(\frac{\epsilon_c}{\epsilon_0} \right)^2 \right] K_d$$

$$\therefore F_c' = bf_c' \,[1.15\,(500)\, \epsilon_c - 0.45\,(500)^2\, \epsilon_c^2]\, K_d$$

$$F_c = 6000\, f_c' \,[1.15\, \epsilon_c - 225 \epsilon_c^2]\, K_c$$

$$\epsilon_c = 0.002$$

$$\frac{1}{\epsilon_c} = 500$$

$$M_c = bf_c' \int_{x=0}^{x=kd} 2.3 \left(\frac{\epsilon_x}{\epsilon_0} \right) xdx - 1.35 \left(\frac{\epsilon_x}{\epsilon_0} \right)^2 xdx$$

Solving and simplifying

$$M_c = 6000\, f_c' \,[0.767\, \epsilon_c - 168.8\, \epsilon_c^2]\, (K_d)^2$$

$$MA = \frac{M_c}{F_c} = \frac{500\, bf_c' \,(0.767\epsilon_c - 168.8\epsilon_c^2)(K_d)^2}{500\, bf_c' \,(1.15\epsilon_c - 225\, \epsilon_c^2)(K_d)}$$

which reduces to $\left(\frac{440\, \epsilon_c - 2}{587\, \epsilon_c - 3} \right) K_d$

Resisting moment about section center line

$$M_n = A_s f_y \left(d - \frac{h}{2} \right) + \left(\frac{h}{2} - K_d + MA \right) F_c$$

$$= A_s f_y \left(d - \frac{h}{2} \right) + \left[\frac{h}{2} - K_d \left(\frac{440\epsilon_c - 2}{587\epsilon_c - 3} - 1 \right) \right] F_c$$

$$\phi M_n =$$

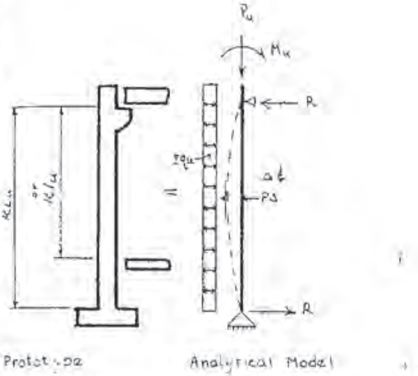
$$\phi \left[A_s f_y \left(d - \frac{h}{2} \right) + \left[\frac{h}{2} + K_d \left(\frac{440\epsilon_c - 2}{587\epsilon_c - 3} - 1 \right) \right] F_c \right]$$

$M_A = M_t\ P\Delta$ (applied moment at ϵ_c)

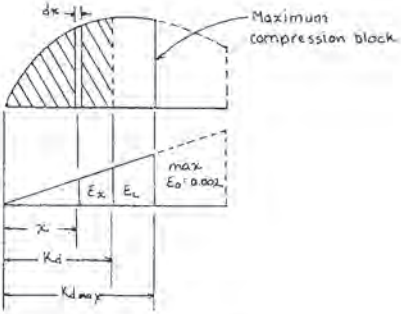
$$= M_t + \frac{\phi (Kl_u)^2}{9.6} \left(P_{u1} + \frac{P_{u2}}{2} \right)$$

$$\phi = \frac{\epsilon_c}{K_d}$$

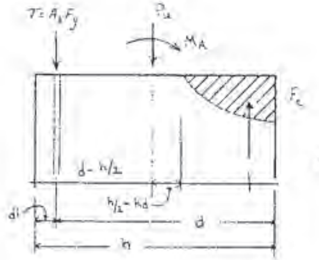
$$M_A = M_t + \frac{\epsilon_c (Kl_u)^2 \left(P_{u1} + \frac{P_{u2}}{2} \right)}{9.6\, K_d}$$



Prototype Analytical Model



Stress-strain relationship



Compression rebar neglected.

Force diagram

DEFINITIONS

A = Empirical coefficient
A_s = Steel area required (in²)
b = Unit wall width, 1 foot
d = Distance to steel centroid
e = Eccentricity to center line of wall
e_1 = Eccentricity to center line of wall (in)
ϵ_x = See stress strain relationship diagram
ϵ_c = See stress strain relationship diagram
ϵ_s = Steel strain
F_c = Stress
f_c = Stress of concrete at any point
f'_c = Ultimate concrete strength (ksi)
f_y = Yield strength of steel (ksi)
h = Total thickness (in)
K_d = Depth of stress block
Kl_u = Lateral unbraced length (in)
M_a = Applied moment
M_i = Internal moment
M_r = Resisting moment
M_c = Concrete moment
PΔ = Additional moment caused by axial load x wall deflection

P_{u1} = Live load + dead load, top of wall (kips)
P_{u2} = Dead load, top of wall
q_u = Lateral uniform load, if it exists (klf)
θ = Internal rotation
$\emptyset M_r$ = Resisting moment (k-in)
Φ = Capacity reduction factor

OPERATING LIMITS AND WARNINGS

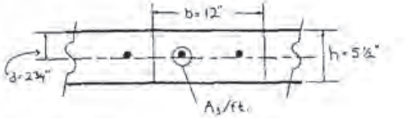
1. For $\Phi < 0.7$ increase H, d, or e.
2. For $\epsilon_c > 0.002$ increase H, d, or e.
3. For $Kl_u/h > 50$ increase H, d, or e.

REFERENCES

Kripanarayanan, K. M., "Tilt-up Load Bearing Walls - A Design Aid", Portland Cement Association.

"Building Code Requirements for Reinforced Concrete", A.C.I. 318-77

SAMPLE PROBLEM:



Determine if the tilt-up wall shown is adequate for the following given data

P_{u1} = 1.10 k
P_{u2} = 0.963 k
h = 5.5 (in)
d = 2.75 (in)
e = 6.25 (in)
q_u = 0.028 k/f
Kl_u = 240 (in)
F_c' = 4 ksi
F_y = 60 ksi

SOLUTION:

Input	Function	Display	Comments
Load "TILTUP"			
Begin	[XEQ] "TILTUP"	TILTUP SIZE ≥ =17	Does not appear if size ≥ 17
	[XEQ] "SIZE"	SIZE _ _ _	
017	[R/S]	PU1=	
1.10	[R/S]	PU2=	
.963	[R/S]	H=	
5.5	[R/S]	d=	
2.75	[R/S]	e=	
6.25	[R/S]	QU=	
.028	[R/S]	KLU=	
240	[R/S]	FC=	
4	[R/S]	FY=	
60	[R/S]	AS=0.19<0.29%>	
	[R/S]*	EC=8.25 E−4	
	[R/S]*	MR=30.51	
	[R/S]*	MA=30.22	
	[R/S]*	NEW PRGM?	
N	[R/S]	0.00	

*If printer is in use, you need not perform this keystroke

USER INSTRUCTIONS

SIZE: 17

Step	Instructions	Input	Function	Display
1	Load "TILTUP"			
2	Begin		[XEQ] "TILTUP"	TILTUP PU1=
3	Input live load + dead load (kips)	P_{u1}	[R/S]	PU2=
	Input dead load, top half of wall (kips)	P_{u2}	[R/S]	H=
	Input total thickness (in)	h	[R/S]	d=
	Input distance to steel centroid (in)	d	[R/S]	e=
	Input eccentricity to center line of wall (in)	e	[R/S]	QU=
	Input lateral uniform load (kips/lineal ft)	qu	[R/S]	KLU=
	Input lateral unbraced length (in)	Kl	[R/S]	FC=
	Input ultimate concrete strength (ksi)	f_c	[R/S]	FY=
	Input yield strength of steel (ksi)	f_y	[R/S]	
4	Outputs			
	steel area required (in)			AS=nn
			[R/S]*	EC=nn
	resisting moment (k ft)		[R/S]*	MR=nn
	applied moment (k ft)		[R/S]*	MA=nn
			[R/S]*	NEW PRGM
5	If a new program is desired	Y	[R/S]	PRGM NAME?
	Key in desired program name	name	[R/S]	
	Else press	N	[R/S]	0.00

*If printer is in use, you need not perform this keystroke.

REGISTERS, STATUS, FLAGS

Data Registers Status

00 P
01 P_u
02 P_{u2}
03 h
04 d
05 e
06 q_u
07 kL_u
08 F_c
09 F_y
10 A_s
11 E_c
12 Φ
13 M_r
14 F_c & MA
15
16 control, ΦMn

SIZE 017
ENG
DEG

TOT REG 92
FIX 2 SC
RAD GRAD

Flags

# SET INDICATES	CLEAR INDICATES
12 Double-wide print	Single-wide print
13 Print lower case	Print default case
21 Printer enable	Printer disable
22 Data entry	No data entry
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "TIL
TUP"
 02 CF 21          Initialize
 03 FS? 55
 04 SF 21
 05 FIX 2
 06 ADV
 07 SF 12
 08 "TILTUP"
 09 AVIEW
 10 PSE
 11 CF 12
 12 "SIZE>=1       Size check
7"
 13 SF 25
 14 RCL 16
 15 FC?C 25
 16 PROMPT         Display minimum size if necessary
 17 ADV
 18 1.009
 19 STO 16
 20 "PU1="         Data input
 21 XEQ 01
 22 "PU2="
 23 XEQ 01
 24 SF 13
 25 "H="
 26 XEQ 01
 27 "d="
 28 XEQ 01
 29 "e="
 30 XEQ 01
 31 "QU="
 32 XEQ 01
 33 "KLU="
 34 XEQ 01
 35 "FC="
 36 XEQ 01
 37 "FY="
 38♦LBL 01         Input control routine
 39 PROMPT
 40 STO IND
16
 41 ARCL X
 42 FS? 21
 43 AVIEW
 44 ISG 16
 45 RTN
 46 CLD
 47 CF 13
 48 50
 49 RCL 07         Check if Klu/h > 50
 50 RCL 03
 51 /
 52 X>Y?
 53 GTO 05
 54 RCL 01
 55 RCL 02         Calculate and store Pu
 56 +
 57 STO 00
 58 6
 59 /
 60 RCL 08         Calculate and store Φ = 0.9 − Pu1/5f'ch
 61 /
 62 RCL 03
 63 /
 64 CHS
 65 .9
 66 +
 67 STO 12         Store Φ
 68 .7
 69 X<=Y?          If Φ ≤ .7, display
 70 GTO 02
 71 "PHI<0.7
"
 72 ADV
 73 AVIEW
 74 PSE
 75 "INCREAS
E H,d,e"
 76 AVIEW
 77 PSE
 78 GTO 06
 79♦LBL 02         Calculate initial moment
 80 RCL 06
 81 RCL 07
 82 X↑2
 83 *
 84 96
 85 /
 86 RCL 01
 87 RCL 05
 88 *
 89 2
 90 /
 91 +
 92 STO 13         Mi
 93 1.25
 94 *
 95 RCL 09         Calculate initial As
 96 /
 97 RCL 04
 98 /
 99 STO 10         Same iteration
100♦LBL 08         Reiterate As
101 RCL 10
102 RCL 09
103 *              Fc required
104 RCL 00
105 RCL 12
106 /
107 +
108 STO 14
109 RCL 09         Calculate initial Ec
110 SQRT
111 *
```

```
112 18700
113 /
114 RCL 04          Same iteration
115 /
116 RCL 08          $\epsilon_{cr} = \frac{F_{cR} \sqrt{FY}}{18700 f_c' d}$ (empirical)
117 /
118 15 E-5
119 +
120 STO 11          $C_{cr}$
121+LBL 09
122 RCL 11          Limit $E_c$ to 0.002
123 .002
124 X>Y?
125 GTO 03
126 "Ec>0.00        Display
2"
127 ADV
128 AVIEW
129 PSE
130 "INCREAS        Increase H, d, e
E H,d,e"
131 AVIEW
132 PSE
133 GTO 06
134+LBL 03          Calculate $F_c$ furnished =
135 RCL 11           $6000 f_c'k \cdot \frac{E_{cr}}{[illegible]}$
136 1.15
137 *
138 RCL 11
139 X↑2
140 225
141 *
142 -
143 RCL 08
144 *
145 6 E3
146 *
147 XEQ 04          If .85 $f_c'$ is used,
148 *                change 6000 to 5100
149 RCL 14
150 X<>Y
151 X>Y?
152 GTO 10
153 5 E-5           If $F_c$ furnished < $F_c$ required,
154 ST+ 11           increment $E_c$ by .00005
155 GTO 09
156+LBL 10          Calculate resisting moment
157 RCL 11
158 440
159 *
160 2
161 -
162 RCL 11
163 587             $\Phi M_R = \Phi \left[ A_s f_y \left( d - \frac{h}{2} \right) \right] +$
164 *
165 3               $\left[ \frac{h}{2} + k_d \left( \frac{440\epsilon_c - 2}{587\epsilon_c - 3} \right) - 1 \right] F_c$
166 -
167 /
168 1
169 -
```

```
170 XEQ 04
171 *
172 RCL 03
173 2
174 /
175 +
176 RCL 14
177 *
178 RCL 04
179 RCL 03
180 2
181 /
182 -
183 RCL 10
184 *
185 RCL 09
186 *
187 +
188 RCL 12
189 *
190 STO 16          Store $\Phi M_R$
191 RCL 11
192 RCL 07
193 X↑2
194 *
195 RCL 02
196 2
197 /
198 RCL 01          Calculate applied moment MA
199 +
200 *
201 9.6
202 /
203 XEQ 04
204 /
205 RCL 13
206 +
207 STO 14
208 RCL 16
209 X>Y?            MA replaces $F_c$
210 GTO 11
211 .02             If $\Phi M_R < M_A$ increment $A_s$ by 0.02
212 ST+ 10
213 GTO 08
214+LBL 11
215 ADV
216 FC? 55
217 SF 21
218 RCL 10
219 RCL 03
220 /
221 12
222 /
223 1 E2
224 *
225 "AS="           Output solution
226 ARCL 10
227 "├ <"
228 ARCL X
229 "├%>"
```

```
230 AVIEW
231 "Ec="
232 ARCL 11
233 AVIEW
234 "MR="
235 ARCL 16
236 AVIEW
237 "MA="
238 ARCL 14
239 AVIEW
240 GTO 06
241•LBL 04          Kd subroutine = εcd / (εc + fc/29E3)
242 RCL 11
243 RCL 04
244 *
245 RCL 09
246 29 E3
247 /
248 RCL 11
249 +
250 /
251 RTN
252•LBL 05          Klu/r >= 50 display
253 "KLU/H>5
0"
254 AVIEW
255 PSE
256•LBL 06          Exit routine
257 CLD
258 AON
259 CF 21
260 "NEW PRG          Does user want new program?
M?"
261 STOP
262 ASTO Y
263 "Y"
264 ASTO X
265 X≠Y?             If not, exit, else get program name
266 GTO 07              and read it in
267 "PRGM NA
ME?"
268 STOP
269 AOFF
270 READP
271•LBL 07          Clean up display and quit
272 AOFF
273 CLX
```

RIGID

"RIGID" computes the coefficients for deflection and rigidity of masonry or concrete walls and piers for distribution of lateral forces in a box-type structure. The walls or piers may be considered cantilevered or fixed as determined by the designer.

The user may choose to use default values for P, the unit lateral force $(1 \cdot 10^{5})$, and E, the modulus of elasticity $(1 \cdot 10^{6})$ or use other values.

EQUATIONS

Fixed Wall or Pier

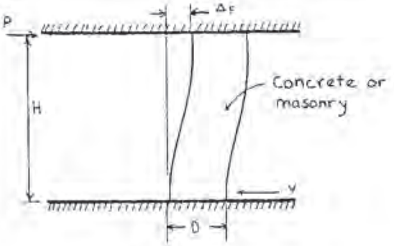
$$\Delta f = \frac{P}{Et}\left[\left(\frac{H}{D}\right)^{3} + 3\left(\frac{H}{D}\right)\right]$$

$$R_f = \frac{1}{\Delta f} = \text{Rigidity}$$

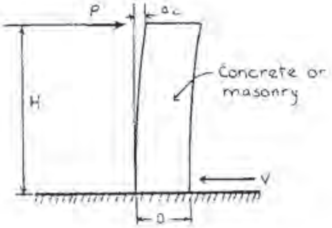
Cantilever Wall or Pier

$$\Delta c = \frac{P}{Et}\left[4\left(\frac{H}{D}\right)^{3} + 3\left(\frac{H}{D}\right)\right]$$

$$R_c = \frac{1}{\Delta c} = \text{Rigidity}$$

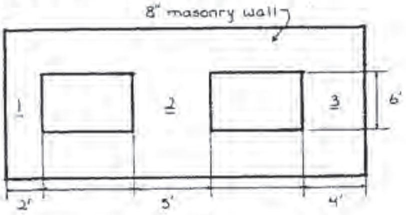


Fixed wall or pier



Cantilever wall or pier

SAMPLE PROBLEM:



Wall Elevation

Using the program default for P and E, compute the deflection and rigidity for piers 1, 2, and 3, and compute the summation of rigidity. Consider the piers fixed at their top and bottoms.

SOLUTION:

Input	Function	Display	Comments
Load "RIGID"			
Begin	[XEQ] "RIGID"	RIGID	
		SIZE> =05	Only shows if size < 05
	[XEQ] "SIZE"	SIZE _ _ _	
005	[R/S]	SELECT P,E?	No, use default values
N	[R/S]	H=	
6	[R/S]	D=	
2	[R/S]	T=	
8	[R/S]	FIXED WALL?	
Y	[R/S]	DEF=0.450	
		R=2.22	
		OUTPUT ΣR?	
N	[R/S]	H=	
6	[R/S]	D=	
5	[R/S]	T=	
8	[R/S]	FIXED WALL?	
Y	[R/S]	DEF=0.67	
		R=15.02	
		OUTPUT ΣR?	
N	[R/S]	H=	
6	[R/S]	D=	
4	[R/S]	T=	
8	[R/S]	FIXED WALL?	
Y	[R/S]	DEF=0.098	
		R=10.16	
		OUTPUT ΣR?	
Y	[R/S]	ΣR=27.40	
		NEW PRGM?	
N	[R/S]	0.00	

USER INSTRUCTIONS

SIZE: 5

Step	Instructions	Input	Function	Display
1	Load "RIGID"			
2	Begin		[XEQ] "RIGID"	RIGID SELECT P,E?
3a	If you want to select values for P and E press	Y	[R/S]	P=
	Key in wall lateral force	P	[R/S]	E=
	Key in modulus of elasticity	E	[R/S]	H=
3b	If you want to use default values (P = 1x10⁵ E = 1X10⁶) press	N*	[R/S]	H=
4	Key in wall or pier height (ft)	H	[R/S]	D=
5	Key in wall length or pier depth (ft)	D	[R/S]	T=
6	Key in wall thickness	t	[R/S]	FIXED WALL?
7a	If fixed wall, press	Y	[R/S]	
7b	For cantilevered wall, press	N	[R/S]	DEF=nn R=nn OUTPUT ΣR?
8a	If another wall or pier exists [illegible]	N	[R/S]	
8b	If complete	Y	[R/S]	ΣR=nn NEW PRGM?
9a	If you desire a new program	Y	[R/S]	PRGM NAME?
	Key in program name	name	[R/S]	
9b	If you do not desire another program	N	[R/S]	0.00
	To begin a new problem, press then go to step 3		[R/S]	RIGID

*Pressing only [R/S] also indicates a "no" response.

REGISTERS, STATUS, FLAGS

Data Registers Status

00 P	SIZE 005	TOT REG 46
01 E	ENG	FIX 2 SCI
02 t	DEG	RAD GRAD
03 D H		
04 ΣR		

Flags

# SET INDICATES	CLEAR INDICATES
01 Cantilever wall	Fixed wall
12 Double-wide print	Single-wide print
21 Printer enable	Printer disable
25 Error ignore	No error ignore
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01+LBL "RIG
ID"
 02 CF 01          Initialize flags
 03 CF 21
 04 FS? 55
 05 SF 21
 06 FIX 2
 07 "RIGID"        Display name
 08 SF 12
 09 AVIEW
 10 PSE
 11 CF 12
 12 ADV
 13 "SIZE>=0       Check size
5"
 14 SF 25
 15 RCL 04
 16 FC?C 25        If necessary, prompt for
 17 PROMPT          minimum size, initialize ΣR register
 18 0
 19 STO 04
 20 CLD
 21 AON
 22 "SELECT        See if user wants to specify P and E
P,E?"
 23 STOP
 24 ASTO Y
 25 "Y"
 26 ASTO X
 27 AOFF
 28 X=Y?           If not, use default value
 29 GTO 01
 30 1 E5
 31 STO 00
 32 1 E6
 33 STO 01
 34+LBL 04         Input section
 35 ADV
 36 "H="
 37 XEQ 03
 38 STO 03
 39 "D="
 40 XEQ 03
 41 ST/ 03         Calculate D/H
 42 "T="
 43 XEQ 03
 44 STO 02
 45 "FIXED W
ALL?"
 46 AON
 47 STOP
 48 ASTO Y
 49 "Y"
 50 ASTO X
 51 AOFF
 52 X≠Y?           If not fixed, set flag 01
 53 SF 01
 54 RCL 03
```

```
 55 RND          Compute deflection
 56 3
 57 Y↑X
 58 4
 59 FS? 01
 60 *
 61 FC? 01
 62 RDN
 63 RCL 03
 64 RND
 65 3
 66 *
 67 +
 68 RCL 00
 69 *
 70 RCL 01
 71 RCL 02
 72 *
 73 /
 74 FIX 3
 75 SF 21
 76 "DEF="       Output deflection and rigidity
 77 ARCL X
 78 ENTER↑
 79 1/X
 80 FIX 2
 81 "├ R="
 82 ARCL X
 83 AVIEW
 84 ST+ 04
 85 CF 01
 86 CLD
 87 AON
 88 "OUTPUT
ΣR?"
 89 STOP
 90 ASTO Y
 91 "Y"
 92 ASTO X
 93 AOFF
 94 X=Y?         If output, exit,
                  else go back for more values
```

```
 95 GTO 06
 96 GTO 04
 97+LBL 01       User's specified P and E subroutine
 98 "P="
 99 XEQ 03
100 "E="
101 XEQ 03
102 STO 01
103 RDN
104 STO 00
105 GTO 04
106+LBL 03       Control for input routines
107 PROMPT
108 ARCL X
109 FS? 55
110 PRA
111 RTN
112+LBL 06       Exit routine
113 "ΣR="
114 ARCL 04      Display sum of rigidity
115 AVIEW
116 ADV
117 CF 21
118 CLD
119 AON
120 "NEW PRG      Ask if new program desired
M?"
121 STOP
122 ASTO Y
123 "Y"
124 ASTO X
125 X≠Y?         If not, exit,
126 GTO 05        else get program name and read i
127 "PRGM NA
ME?"
128 STOP
129 AOFF
130 READP
131+LBL 05       Clean up display and quit
132 AOFF
133 CLX
```

REBAR

"REBAR" computes the development lengths for reinforcing steel in concrete elements according to the "Building Code Requirements for Reinforced Concrete" (A.C.I. 318-77). The basic length, l_d, is first computed. The program prompts for data input corresponding to several modifying factors specified in the code.

EQUATIONS

Tension Requirements

For bars #3 to #11

$l_d = 0.04A_b\,FY/\sqrt{F_c} \geq 0.0004\,d_c\,FY$

For bar #14

$l_d = 0.085\,FY/\sqrt{F_c}$

For bar #18

$l_d = 0.11\,FY/\sqrt{F_c}$

For top reinforcing

$l_d = 1.4\,l_d$

$F_y > 60\,000$ psi

$$l_d = l_d\left(2 - \frac{60000}{FY}\right)$$

Lightweight aggregate

$l_d = l_d(1.33 - 0.15$
(fraction of lightweight sand to total aggregate)

Spacing ≥ 6", cover ≥ 3"

$l_d = 0.8\,l_d$

Excessive reinforcing

$$l_d = l_d\left(\frac{A_s\text{ required}}{A_s\text{ provided}}\right)$$

Spiral ≥ 1/4" diameter pitch ≤ 4"

$l_d = 0.75\,l_d$

3 bar bundle

$l_d = 1.2\,l_d$

4 bar bundle

$l_d = 1.33\,l_d$, but not less than 12"

Compression Requirements

$l_d = 0.02\,d_b\,FY/\sqrt{F_c} \geq 0.0003\,d_b\,FY$

Excessive reinforcing

$$l_d = l_d\left(\frac{A_s\text{ required}}{A_s\text{ provided}}\right)$$

Spiral ≥ 1/4" diameter pitch ≤ 4"

$l_d = 0.75\,l_d$

Bundled bars same as for tension

DEFINITIONS

A_b = area of single bar
A_s = area of steel
d_b = diameter of bar
F_c = compressive concrete strength
F_y = yield stress of reinforcing steel
l_d = required development length

REINFORCING BARS - DIAMETERS AND AREAS

Bar#	Diameter (in)	Area (in²)
2	0.250	0.05
3	0.375	0.11
4	0.500	0.20
5	0.625	0.31
6	0.750	0.44
7	0.875	0.60
8	1.000	0.79
9	1.128	1.00
10	1.270	1.27
11	1.410	1.56
14	1.693	2.25
18	2.257	4.00

REFERENCES

"Building Code Requirements for Reinforced Concrete", A.C.I. 318-77.

SAMPLE PROBLEM #1:

For F_c = 3,000 psi and F_y = 60,000 psi, compute the development length for a #5 bar in tension located at the top of a member. All other factors not required.

SAMPLE PROBLEM #2:

For F_c = 4,000 psi and F_y = 60,000 psi, compute the development length for a #4 bar bottom bar with spacing > 6" with excessive reinforcement of A_sR/A_sP = 0.85.

SOLUTION:

Input	Function	Display	Comments
Load "REBAR"			Begin Sample Problem #1
Begin	[XEQ] "REBAR"	REBAR SIZE>=06	If size is adequate, display does not occur
	[XEQ] "SIZE"	SIZE _ _ _	
006	[R/S]	FY=	
60000	[R/S]	FC=	
3000	[R/S]	C/T?	
T	[R/S]	T Db=	
.625	[R/S]	TOP?	
Y	[R/S]	TOP LT.WT?	
	[R/S]	SPA>=6?	
N	[R/S]	EX REF?	
	[R/S]	SPIRAL?	
N	[R/S]	GROUP? <3,4>	
	[R/S]	Ld=21.[illegible]	
	[R/S]	NEW PRGM?	
N	[R/S]	0.00	Begin Sample Problem #2
	[R/S]	REBAR FY=	
60000	[R/S]	FC=	
4000	[R/S]	C/T?	
T	[R/S]	T Db=	
.5	[R/S]	TOP?	
N	[R/S]	LT.WT?	
	[R/S]	SPA>=6?	
	[R/S]	EX REF?	
.85	[R/S]	SPIRAL?	
N	[R/S]	GROUP? <3,4>	
	[R/S]	Ld=12.00	
	[R/S]	NEW PRGM?	
N	[R/S]	0.00	

USER INSTRUCTIONS

SIZE: 6

Step	Instructions	Input	Function	Display
1.	Load "REBAR"			
2.	Begin		[XEQ] "REBAR"	REBAR* FY=
3	Key in yield stress of reinforcing steel	F_y	[R/S]	FC=
4	Key in compressive concrete strength	F_c	[R/S]	C/T?
5	For compression	C	[R/S]	
	For tension	T	[R/S]	Db=
6	Key in bar diameter (in)	d_b	[R/S]	TOP?
7a	If top bar	Y	[R/S]	
7b	If bottom bar	N**	[R/S]	LT.WT?
8a	If lightweight concrete input fraction of lightweight aggregate	frac	[R/S]	
8b	If regular weight, press only		[R/S]	SPA>=6?
9a	If spacing ≥ 6"	Y	[R/S]	
9b	If spacing < 6"	N	[R/S]	EX REF?
10a	If needed, input ratio of A_s required to A_s provided			
10b	If not, press		[R/S]	SPIRAL REIN?
11a	If spiral reinforcement	Y	[R/S]	
11b	If no spiral reinforcement	N	[R/S]	GROUP? <3,4>
12a	For 3 bar group key 3, for 4 bar group key 4	3 or 4	[R/S]	
12b	For single bars		[R/S]	Ld=
			[R/S]	NEW PRGM?
13a	For a new program	Y	[R/S]	PRGM NAME?
	Key in program name	name	[R/S]	
13b	If you do not want a new program program	N	[R/S]	0.00
14	To execute REBAR again		[R/S]	REBAR

*If the display "SIZE>=06" appears, set size to at least 6 and press [R/S] to continue.

**Pressing only [R/S] also indicates a "no" response.

REGISTERS, STATUS, FLAGS

Data Registers **Status**

00 L_d
01 control
02 F_c
03 F_y
04 $FY/\sqrt{F_c}$
05 D_b

SIZE 006
ENG
DEG

TOT REG 81
FIX 2 SCI
RAD GRAD

Flags

#	SET INDICATES	CLEAR INDICATES
02	#14 and #18 bars	Not #14 or #18
12	Double-wide print	Single-wide print
21	Printer enable	Printer disable
22	Data entry	No data entry
25	Error ignore on	No error ignore
55	Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL "REB
AR"
 02 CF 02          Initialize flags
 03 CF 21
 04 FS? 55
 05 SF 21
 06 SF 12
 07 "REBAR"
 08 AVIEW
 09 PSE
 10 CF 12
 11 "SIZE>=0       Size check
6"
 12 SF 25
 13 RCL 05
 14 FC?C 25
 15 PROMPT         Display minimum size if necessary
 16♦LBL 21
 17 ADV
 18 "FY="          Input Fy Fc
 19 XEQ 01
 20 STO 03
 21 "FC="
 22 XEQ 01
 23 STO 02
 24 SQRT
 25 /
 26 STO 04
 27 "C"            Check for compression or
 28 ASTO Y           tension problem
 29 "C/T?"
 30 AON
 31 PROMPT
 32 AOFF
 33 ASTO X
 34 VIEW X
 35 X=Y?
 36 GTO 02         If compression, branch
 37 "Db="
 38 XEQ 01         Bar input
 39 1.6
 40 X<>Y
 41 X>Y?           Check for oversize
 42 XEQ 00
 43 FS?C 02
 44 GTO 12
 45 STO 05
 46 4 E-4
 47 *
 48 RCL 03
 49 *
 50 RCL 05
 51 X↑2
 52 PI
 53 4
 54 /
 55 *
```

```
 56 RCL 04
 57 *
 58 .04
 59 *
 60 X<Y?
 61 X<>Y
 62♦LBL 12         Basic bar development length
 63 STO 00
 64 "     TOP?     Questions to modify basic length
"
 65 ASTO Z
 66 AON
 67 PROMPT
 68 ASTO Y         Top or bottom?
 69 "Y"
 70 ASTO X
 71 AOFF
 72 X=Y?
 73 XEQ 05         If top, alter
 74 6 E4
 75 ENTER↑
 76 RCL 03
 77 X>Y?           Fy > 6E4?
 78 XEQ 06
 79 " LT.WT?       Lightweight concrete aggregate?
"                   If so, denote by data entry
 80 ASTO Y
 81 CF 22
 82 PROMPT
 83 FS? 22
 84 XEQ 07
 85 "SPA>=6?       Spacing ≥ 6"?
"
 86 ASTO Z
 87 AON
 88 PROMPT
 89 ASTO Y
 90 "Y"
 91 ASTO X
 92 AOFF
 93 X=Y?
 94 XEQ 08
 95 "EX REF?       If needed, key in As provided/As
"                   required ratio
 96 ASTO Y
 97 CF 22
 98 PROMPT
 99 FS? 22
100 XEQ 09
101 "SPIRAL?       Spiral reinforcing
"
102 ASTO Z
103 AON
104 PROMPT
105 ASTO Y
106 "Y"
107 ASTO X
```

```
108 AOFF
109 X=Y?
110 XEQ 10
111 CF 22
112 " GROUP?     If 3 or 4 bar group
<3,4>"         rather than single, key in group
113 ASTO Y
114 PROMPT
115 FS? 22
116 XEQ 11
117 GTO 04
118♦LBL 00
119 2
120 X<>Y
121 X>Y?
122 GTO 00
123 RCL 04
124 .085
125 *
126 SF 02
127 RTN
128♦LBL 00
129 RCL 04
130 .11
131 *
132 SF 02
133 RTN
134♦LBL 05     Top bar alteration
135 XEQ 03
136 1.4
137 ST* 00
138 RTN
139♦LBL 06     Fy > 6E4 alteration
140 XEQ 03
141 /
142 2
143 X<>Y
144 -
145 ST* 00
146 RTN
147♦LBL 07     Light aggregate alteration
148 XEQ 03
149 .15
150 *
151 1.3
152 X<>Y
153 -
154 ST* 00
155 RTN
156♦LBL 08     Spacing ≥ 6" alteration
157 XEQ 03
158 .8
159 ST* 00
160 RTN
161♦LBL 09     As provided/As required alteration
162 XEQ 03
163 ST* 00
164 RTN
165♦LBL 10     Spiral reinforcement alteration
166 XEQ 03
```

```
167 .75
168 ST* 00
169 RTN
170♦LBL 11      3 or 4 bar group alteration
171 XEQ 03
172 3
173 X=Y?
174 GTO 11
175 .9
176 ST/ 00
177♦LBL 11
178 1.2
179 ST* 00
180 RTN
181♦LBL 03      View Routine
182 VIEW Z
183 RTN
184♦LBL 02      Compression case bar diameter input
185 "Db="
186 XEQ 01
187 STO 05
188 3 E-4
189 *
190 RCL 03
191 *
192 RCL 05
193 .02
194 *
195 RCL 04
196 *
197 X<Y?
198 X<>Y
199 STO 00
200 "EX REF?     As required/As provided ratio
"               if necessary
201 ASTO Y
202 CF 22
203 PROMPT
204 FS? 22
205 XEQ 09
206 "SPIRAL?     Spiral reinforcing?
"
207 ASTO Z
208 AON
209 PROMPT
210 ASTO Y
211 "Y"
212 ASTO X
213 AOFF
214 X=Y?
215 XEQ 10
216 GTO 04
217♦LBL 01
218 PROMPT
219 ARCL X
220 FS? 55
221 AVIEW
222 RTN
223♦LBL 04      Output routine
224 12
```

```
225 RCL 00
226 X<=Y?
227 X<>Y
228 FIX 0
229 RND
230 FIX 2
231 "Ld="
232 ARCL X
233 SF 21
234 AVIEW          Exit sequence
235 CLD
236 AON
237 CF 21
238 ADV
239 "NEW PRG      See if new program desired
M?"
240 PROMPT
241 ASTO Y
242 "Y"
243 ASTO X
244 X≠Y?          If not, exit, else get name and read in
245 GTO 14
246 "PRGM NA
ME?"
247 PROMPT
248 AOFF
249 READP
250•LBL 14       Clean up display and quit
251 AOFF
252 CLX
```

TRUSS

This subprogram is a design aid to a user familiar with structural design methods and engineering mechanics. The program applies the laws of statics ΣF_x and ΣF_y applied at each joint and solves for the unknown forces. Only two unknown forces are allowed per joint. Where the truss is a compound truss, or if three unknown forces occur at a join, consult any engineering mechanics or elementary structural analysis textbook, for arriving at a solution.

All forces acting at a joint are input as vector quantities with forces and angles being positive. Unknown forces are identified by the program by the use of flag 22, therefore, when the unknown force is to be input simply press [R/S] with no keyboard entry. Compression force is output negative (−) and tension force is output positive (+). The unknown forces should be input last and assumed acting away from the joint (!)

The vector quantity should be expressed from 0° counterclockwise to 360°.

EQUATIONS

Matrix method of solution

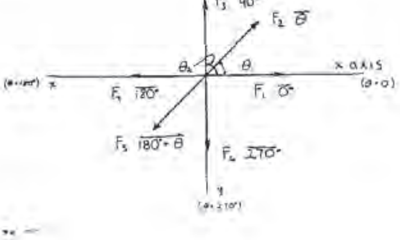
$$A = \begin{bmatrix} F_{1x} & F_{2x} \\ F_{1y} & F_{2y} \end{bmatrix} = \begin{bmatrix} \Sigma F_x \\ \Sigma F_y \end{bmatrix} = B$$

$$|A| = F_{1x}F_{2y} - F_{2x}F_{1y}$$

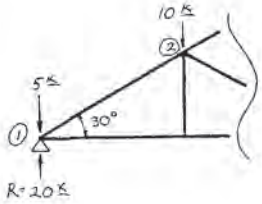
$$A^{-1} = \frac{1}{|A|}\begin{bmatrix} F_{2y} & -F_{2x} \\ -F_{1y} & F_{1x} \end{bmatrix} \text{provided } |A| \neq 0.$$

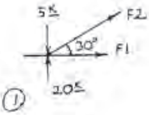
$$\begin{bmatrix} F_1 \\ F_2 \end{bmatrix} = \frac{1}{|A|}\begin{bmatrix} F_{2y} & -F_{2x} \\ -F_{1y} & F_{1x} \end{bmatrix}\begin{bmatrix} \Sigma F_x \\ \Sigma F_y \end{bmatrix} \text{provided } |A| \neq 0.$$

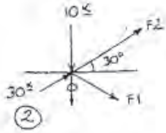
Reactions due to applied loadings must be computed first.



SAMPLE PROBLEM:







For the partially drawn truss solve joints 1 and 2

SOLUTION:

Input	Function	Display	Comments
Load "TRUSS"			
Begin	[XEQ] "TRUSS"	TRUSS	
		SIZE> = 10	This prompt does not occur if size ≥ 10
	[XEQ] "SIZE"	SIZE _ _ _	
010	[R/S]	N =	
4	[R/S]	∆4. =	
270	[R/S]	F4. =	
5	[R/S]	∆3. =	
90	[R/S]	F3. =	
20	[R/S]	∆2 =	
30	[R/S]	F2. =	
	[R/S]	∆1 =	Don't know F2
0	[R/S]	F1 =	
	[R/S]	F2. = −30.00	Don't know force 1
	[R/S]	F1. = 25.98	
	[R/S]	NEW PRGM?	
N	[R/S]	0.00	
	[R/S]	TRUSS	Begin joint 2 solution
	[R/S]	N =	
5	[R/S]	∆5. =	
270	[R/S]	F5. =	
10	[R/S]	∆4. =	
30	[R/S]	F4. =	
30	[R/S]	∆3 =	
90	[R/S]	F3. =	
0	[R/S]	∆2. =	
30	[R/S]	F2 =	
	[R/S]	∆1 =	
330	[R/S]	F1. =	
	[R/S]	F2. = −20.00	
	[R/S]	F1. = −10.00	
	[R/S]	NEW PRGM?	
N	[R/S]	0.00	

USER INSTRUCTIONS

SIZE: 10

Step	Instructions	Input	Function	Display
1	Load "TRUSS"			
2	Begin		[XEQ] "TRUSS"	TRUSS
3	Input number of forces known and unknown acting on joint	N	[R/S]	∡n=
4	Input known vector angles	∡n	[R/S]	Fn=
	and forces	F	[R/S]	∡n−1=
5	Input unknown forces with known angles last	∡n−1	[R/S]	Fn−1=
	Signify by no data input		[R/S]	
6	Output			F2=nn
			[R/S]	F1=nn
			[R/S]	NEW PRGM?
7a	If you desire a new program	Y	[R/S]	PRGM NAME?
	Input program name	name	[R/S]	
7b	If you do not want another	N	[R/S]	0.00
8	To solve another joint go to step 3		[R/S]	TRUSS

*Pressing only [R/S] also indicates a "no" response.

REGISTERS, STATUS, FLAGS

Data Registers	Status	
00 F_{1x}	SIZE 010	TOT. REG 55
01 F_{2x}	ENG	FIX 2 SCI
02 F_{1y}	DEG	RAD GRAD
03 F_{2y}		
04 F1		
05 F2		
06 # of forces counter		
07 # of unknowns counter		
08 ΣFx		
09 ΣFy		

Flags

# SET INDICATES	CLEAR INDICATES
00 Compute forces	Go to output
01 Compute inverse	Get inputs
02 Unknown force	Know force
12 Double-wide print	Single-wide print
21 Printer enable	Printer disable
22 Data entry	No data entry
25 Error ignore on	No error ignore
55 Printer attached	No printer

PROGRAM LISTINGS

```
 01♦LBL  "TRU
SS"
 02  CF  01          Initialize
 03  CF  02
 04  CF  21
 05  FS?  55
 06  SF  21
 07  SF  12          Display or print title
 08  "TRUSS"
 09  AVIEW
 10  PSE
 11  CF  12
 12  ADV
 13  "SIZE>=1        Size check
0"
 14  SF  25          If size too small, prompt
 15  RCL  09
 16  FC?C  25
 17  PROMPT
 18  DEG
 19♦LBL  00
 20  0               Initialize unknown, ΣF registers
 21  STO  07
 22  STO  07
 23  STO  08
 24  STO  09
 25  CF  01
 26  "N="            Get number of forces at joint
 27  XEQ  01         Input force
 28  STO  06
 29♦LBL  06
```

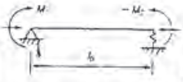
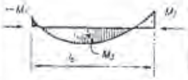
```
 30  FIX  0
 31  "∡"             Input ∡n
 32  ARCL  06
 33  "⊢="
 34  XEQ  01
 35  CF  22
 36  FIX  0
 37  "F"
 38  ARCL  06
 39  "⊢="
 40  XEQ  01
 41  FS?C  02
 42  GTO  03
 43  X<>Y            Check for negative values,
 44  X<0?             if negative, call error
 45  GTO  09
 46  X<>Y
 47  X<0?
 48  GTO  09
 49  P-R             Compute ΣFx, ΣFy
 50  ST-  08
 51  X<>Y
 52  ST-  09
 53  DSE  06
 54  GTO  06
 55♦LBL  01         Control routine for input display
 56  FIX  2
 57  PROMPT
 58  FC?  22
 59  XEQ  07
 60  FS?  22
```

```
 61 ARCL X
 62 FS? 55
 63 PRA
 64 CLD
 65 RTN
 66♦LBL 07          If unknown, attach a "?",
 67 "⊢?"              set flag 02
 68 SF 02
 69 RTN
 70♦LBL 03
 71 1
 72 ST+ 07          Increment number of unknowns
 73 RCL 07
 74 3               If 3 unknowns, call error
 75 X=Y?
 76 GTO 09
 77 RDN
 78 RDN
 79 P-R             Compute x and y coefficients and
 80 FS? 01            set up force matrix
 81 GTO 04
 82 STO 00
 83 X<>Y
 84 STO 02
 85 SF 01
 86 DSE 06
 87 GTO 06
 88♦LBL 04
 89 STO 01
 90 X<>Y
 91 STO 03
 92 RCL 00
 93 RCL 03
 94 *
 95 RCL 01          Compute inverse
 96 RCL 02
 97 *
 98 -
 99 1/X
100 RCL 00
101 RCL 03
102 STO 00
103 RDN
104 STO 03
105 RDN
106 1
107 CHS
108 ST* 01
109 ST* 02
110 RDN
111 SF 00
112 .005
113 STO 06
114 RDN
115 XEQ 05
116 XEQ 05
117 XEQ 05
118 CF 00
```

```
119♦LBL 05          Multiply forces Σ by inverse
120 ST* IND
06
121 ISG 06
122 FS? 00
123 RTN
124 RCL 09
125 RCL 08
126 RCL 00
127 *
128 X<>Y
129 RCL 01
130 *
131 +
132 STO 04
133 RCL 09
134 RCL 08
135 RCL 02
136 *
137 X<>Y
138 RCL 03          Output unknown forces
139 *
140 +
141 STO 05
142 ADV
143 SF 21
144 "F2="
145 ARCL 04
146 AVIEW
147 "F1="
148 ARCL 05
149 AVIEW
150 GTO 08
151♦LBL 09          Error subroutine
152 BEEP
153 "   *ERRO
R*"
154 AVIEW
155 PSE
156♦LBL 08          Exit routine
157 CLD
158 AON
159 "NEW PRG         See if user wants new program
M?"
160 STOP
161 ASTO Y          If not, exit, else get name and read in
162 "Y"
163 ASTO X
164 X≠Y?
165 GTO 09
166 "PRGM NA
ME?"
167 STOP
168 AOFF
169 READP
170♦LBL 09          Clean up display and quit
171 AOFF
172 CLX
```

APPENDIX A

TABLE C 1.6.1.1

Category	Loading conditions ($f_a > 0.15F_a$)	f_b	C_m	Remarks
A	Computed moments maximum at end; joint translation not prevented	$\frac{M_2}{S}$	0.85	 $M_1 < M_2$; $\frac{M_1}{M_2}$ negative as shown. Check both Formulas (1.6-1a) & (1.6-1b)
B	Computed moments maximum at end; no transverse loading; joint translation prevented	$\frac{M_2}{S}$	$\left(0.6 \pm 0.4\frac{M_1}{M_2}\right)$ but not less than 0.4	 Check both Formulas (1.6-1a) & (1.6-1b)
	Transverse loading; joint translation prevented	$\frac{M_3}{S}$ Using Formula (1.6-1b) $\frac{M_2}{S}$ Using Formula (1.6-1a)	$1 + \psi\frac{f_a}{F'_e}$	 Check both Formulas (1.6-1a) & (1.6-1c)

Values of C_m and C_m

TABLE C 1.6.1.2

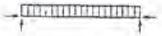
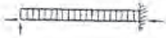
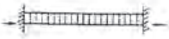
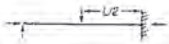
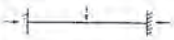
Case	ψ	C_m
	0	1.0
	−0.3	$1 - 0.3\frac{f_a}{F'_e}$
	−0.4	$1 - 0.4\frac{f_a}{F'_e}$
	−0.2	$1 - 0.2\frac{f_a}{F'_e}$
	−0.4	$1 - 0.4\frac{f_a}{F'_e}$
	−0.6	$1 - 0.6\frac{f_a}{F'_e}$

TABLE C 1.8.1

	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0

End condition code

Rotation fixed and translation fixed

Rotation free and translation fixed

Rotation fixed and translation free

Rotation free and translation free

Values of K, and K_y

Sidesway Uninhibited

The subscripts A and B refer to the joints at the two ends of the column section being considered. G is defined as

$$G = \frac{\sum \frac{I_c}{L_c}}{\sum \frac{I_g}{L_g}}$$

in which Σ indicates a summation of all members rigidly connected to that joint and lying in the plane in which the buckling of the column is being considered. I_c is the moment of inertia and L_c the unsupported length of a column section, and I_g is the moment of inertia and L_g the unsupported length of a girder or other restraining member. I_c and I_g are taken about axes perpendicular to the plane of buckling being considered.

For column ends supported by but not rigidly connected to a footing or foundation, G is theoretically infinity, but, unless actually designed as a true friction free pin, may be taken as "10" for practical designs. If the column end is rigidly attached to a properly designed footing, G may be taken as 1.0. Smaller values may be used if justified by analysis.

Alignment Chart for Effective Length of Columns in Continuous Frames