COMPUTER PROGRAM SERIES

IBM 360 / PROGRAM USER'S MANUAL / IBM 1130

Strength Design of Reinforced Concrete Column Sections

By Engineering Services Department
Portland Cement Association

PORTLAND CEMENT ASSOCIATION

The original version of this computer program was developed by Mr. Jose M. Nieves while serving as Manager of Computer Services, Portland Cement Association.

While the Portland Cement Association has taken every precaution to utilize the existing state of the art and to assure the correctness of the analytical solution and design techniques used in this program, the responsibility for modeling the structure to develop input data, applying engineering judgment to evaluate the output, and implementation into engineering drawings remains with the structural engineer of record. Accordingly, Portland Cement Association does and must disclaim any and all responsibility for defects or failures in structures in connection with which this program is used.

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STRENGTH DESIGN OF REINFORCED CONCRETE COLUMN SECTIONS

1. PROGRAM DESCRIPTION

1.1 Introduction

The purpose of this program is to give engineers the capability to design reinforced concrete compression members to resist a given combination of loadings or to investigate the adequacy of a given cross section to resist a similar set of loadings. Each loading case consists of an axial compressive load combined with uniaxial or biaxial bending. The method of solution is based on accepted ultimate strength theories for reinforced concrete design.

The program is written in FORTRAN IV language for the IBM 1130 computer with 16-K core capacity. The program is also available for operation on the IBM 360 computer.

This manual provides background information on the technical aspects of the program; it also gives details related to program operation.

1.2 Design Specifications

Design conforms with the provisions of either of the following two design specifications:

"Standard Specifications for Highway Bridges," 1973 Interim Specifications, Section 5, Part 6 - LOAD FACTOR DESIGN, published by the American Association of State Highway and Transportation Officials (AASHTO), Washington, D. C.

"Building Code Requirements for Reinforced Concrete (ACI 318-71)," published by the American Concrete Institute, Detroit, Michigan.

1.3 Types of members

The program recognizes round and rectangular concrete cross sections with circular or rectangular reinforcement patterns. For the purpose of definition, member types are classified as Round, Spiral, and Tied. A round member defines a circular cross section with a circular reinforcement pattern, a spiral member defines a rectangular cross section with a circular reinforcement pattern, and a tied member a rectangular cross section with a rectangular reinforcement pattern.

In the investigation option it is also possible to define irregular reinforcement patterns by means of individual bar areas and location.

1.4 Design Capabilities

Under the design option, the program will find the size, number and distribution of bars that will result in the minimum area of reinforcement with all bars of the same size required to satisfy all the loading conditions imposed on the cross section. For tied members the number of bars in the sides may be different than in the top and bottom of the cross section.

1.5 Investigation Capabilities

At the option of the engineer, the program has the capability of generating interaction data or of determining the adequacy of a cross section to resist a given combination of loads. For the latter case, the program will hold the eccentricity of the axial load equal to that of the case being investigated. The strength of the cross section for the eccentricity will then be computed, and the relationship between the strength and the applied loading will be reported.

1.6 Input/Output

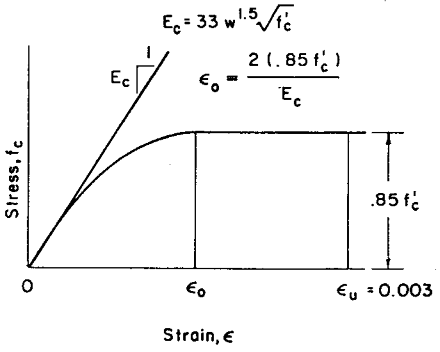
Input requirements vary depending on the type of problem being solved. It consists of that information required to define the problem, member cross section, and loadings. Complete details are given in the section "DIRECTIONS FOR PREPARING INPUT DATA."

Likewise, the output is dependent on the type of problem. Complete details are given in the section "DESCRIPTION OF OUTPUT."

1.7 Method of Solution

The method of solution is based on accepted ultimate strength theories for reinforced concrete design. Where applicable, the design assumptions and limits used conform to the provisions of both specifications cited in Paragraph 1.2 Design Specifications. A brief summary of the method of solution follows:

(1) Computations of strength are based on the satisfaction of the applicable conditions of equilibrium and compatibility of strains. The stress-strain relationship for concrete is assumed as shown below.



For $0 < \epsilon \le \epsilon_o$:
$f_c = .85 f'_c \left[2\left(\frac{\epsilon}{\epsilon_o}\right) - \left(\frac{\epsilon}{\epsilon_o}\right)^2 \right]$

For $\epsilon_o < \epsilon < \epsilon_u$:
$f_c = .85 f'_c$

For $\epsilon < 0$:
$f_c = 0$

(a) Concrete

There are provisions in the input to enable the user to change some of the parameters which affect the shape of the compression block.

(2) Concrete displaced by reinforcement in compression is deducted from the compression block.

(3) Stress in the reinforcement below the design yield strength, f_y, is directly proportional to the strain. For strains greater than that corresponding to the design yield strength, the reinforcement stress remains constant and equal to f_y. The modulus of elasticity, E_s, is taken as 29,000,000 psi, unless otherwise changed in the input data.

(4) Stress in the reinforcement is based on the strain at the actual location of each bar. Reinforcement is defined by the area of each bar and x-y coordinates referred from the centroidal axis of the cross section.

(5) All moments are referenced to the centroid of the gross concrete section whether the reinforcement pattern is symmetrical or unsymmetrical.

(6) Computations for biaxial loading are based on a three-dimensional interaction surface. The method of solution is presented in PCA Advanced Engineering Bulletins No. 18 and 20.[1]

(7) The program first computes the theoretical strength of a member on the basis of the strength of the materials, then reduces the theoretical strength to the design strength by the capacity reduction factor.

2. PREPARATION OF INPUT DATA

The input form defines the records, fields, and formats required for the program. The rules for expressing input quantities conform to standard FORTRAN.

2.1 Problem Identification and Heading Information

Input data proper may be preceded by any number of header cards containing alphabetical information. These cards must be identified by an asterisk (*) in c.c. 1. 79 columns are available in each card. All information given in these columns will be printed as a heading in the output sheet. Use of these cards is optional.

2.2 Problem Definition

The first card after the heading information must define the type of problem as follows:

c.c. 1 = D if this is a design problem
I if this is an investigation problem

c.c. 2 = must be blank

c.c. 3 = R for round member
S for spiral member
T for tied member

c.c. 4 = must be blank

c.c. 5 - 80 not used

For the purpose of this program the member types are defined as follows:

Round: Circular cross section with circular reinforcement pattern.

Spiral: Rectangular cross section with circular reinforcement pattern.

Tied: Rectangular cross section with rectangular reinforcement pattern.

2.3 Design Data

Member size

B = Dimension parallel to the x-x axis in a rectangular cross section, or diameter of round cross section (in.).

T = Dimension parallel to the y-y axis in a rectangular cross section, or diameter of round cross section (in.).

Strength of Materials

f'_c = compressive strength of concrete (ksi)

f_y = yield strength of reinforcement (ksi)

The member size and strength of materials are required input for all problems. The following data is optional and must be given only if the user wishes to change the values set by the program. Only the quantities that change need to be filled in.

Capacity Reduction Factors

The program uses a constant value of φ equal to φ_c when the axial load strength, P_u, is equal to or greater than $0.10f'_cA_g$. When P_u is less than $0.10f'_cA_g$, the program computes a variable reduction factor. If φ_c is the value of φ for compression and φ_b the value of φ for pure flexure, then for an axail load strength less than $0.10f'_cA_g$, an interpolated value of φ as defined by the following equation, is used.

$$\varphi = \varphi b - (\varphi_b - \varphi_c) \frac{P_u}{0.10f'_cA_g}$$

where φ_b = capacity reduction factor for flexure

φ_c = capacity reduction factor for compression

P_u = axial load strength

A_g = gross area of section

This variable reduction factor allows an increase from the value for compression to the value for flexure as the axial load strength, P_u, decreases from $0.10f'_cA_g$ to zero.

Unless otherwise entered in the input data, the program uses the following capacity reduction factors:

Type of Member	φ_c	φ_b
Round	.75	.90
Spiral	.75	.90
Tied	.70	.90

The above values may be changed by entering the desired values in the fields provided in the input form. If a constant value of φ is desired for the full range of P_u, φ_b must be equal to φ_c. See also "GENERAL NOTES ON DESIGN OPTION."

Design Reinforcement

This information is considered only under the design option of the program. It sets limits for the amount of reinforcement to be considered. Unless otherwise given in the input data, the program uses the following values:

Minimum reinforcement ratio	=	0.01
Maximum reinforcement ratio	=	0.08
Minimum clear spacing	=	1.5 in.

These values may be altered by the user to set restrictions or to speed up the selection of reinforcement. See also "GENERAL NOTES ON DESIGN OPTION."

Modifiable Constants

Computations for the strength of a member are based on the satifaction of the applicable conditions of equilibrium and compatibility of strains using a parabolic stress-strain relationship for concrete. See Item (1) under Paragraph 1.7 Method of Solution. Unless otherwise specified, the following values are used in the program:

$f_c = .85\ f'_c$ = concrete stress intensity at the maximum usable strain of 0.003 (ksi).

$E_c = (145)^{1.5} 33\sqrt{f'_c}$ = Modulus of Elasticity for concrete (ksi).

$E_s = 29,000$ = Modulus of Elasticity for reinforcement (ksi).

$\epsilon_u = .003$ = Maximum Usable Strain at the extreme concrete compression fiber. (in/in)

Any of the above values may be changed by the user to alter the stress-strain relationships for concrete and steel.

2.4 Reinforcement Data

In general the program considers the reinforcement as individual bars defined by the area of the bar and located with respect to a set of x-y coordinates through the centroid of the cross section. The maximum number of bars that can be accepted is 50.

Bar sizes are in accordance with standard bar designations in ASTM A615. Bars #14 and #18 can be so designated, however, the program changes the designation to #12 and #13 respectively. Either set of bar sizes is accepted in the input.

Cover must be defined in all cases and refers to the clear distance from the main reinforcement to the face of the member, i.e., cover must include the diameter of ties or spirals.

The type and amount of reinforcement data to be given depends on the type of problem being processed. The design and investigation options are discussed separately in the paragraphs that follow.

2.5 Reinforcement Data for Design

RMode

This one digit field in c.c.1 defines the type of reinforcement pattern to be used in the design as follows:

RMode = 1

Under Mode 1 bars will be equally distributed in a circular pattern for round and spiral members. For tied members one bar will be placed in each corner and, if more are required, an equal number of bars will be placed in each face between the corner bars. Thus, the total number of bars in the latter case will always be a multiple of 4.

RMode = 2

Mode 2 is only applicable to tied members. In this mode the number of bars in the sides (rows 3 and 4) may be different from that in the top and bottom (rows 1 and 2). The selected pattern in this mode will always be symmetrical about the centroidal x-x and y-y axis.

Only the digits 1 and 2 are valid in the design option. Any other digit will cause an "INPUT ERROR." In both modes, the size of the bars is the same all around. There is no provision in the program to combine different bar sizes under the design option.

Number of Bars and Bar Size

These two fields are not used in the design option.

Cover

Enter the cover distance to the main reinforcement in inches, if this is constant all around the perimeter of the cross section. For a rectangular spiral member, cover must be the amount of cover in the least dimension. For tied members, if the amount of cover in the side rows is different from that in the top and bottom rows, cover must then be defined for each row as described further on.

Lower Limit (1, 2)

For round and spiral members enter the minimum number of bars and the minimum size to be considered in the design. If the number field is left blank, the minimum number of bars will be set to 6, and if the size field is left blank, the minimum size will be set to #5. (The #5 minimum bar size is a requirement of the AASHTO Specifications).

For tied members enter the minimum number of bars and the minimum size to be accepted in the top row (Row 1). If the number field is less than 2, the minimum number of bars in Row 1 will be set to 2, and if the size field is left blank, the minimum size will be set to #5. Under both RModes 1 and 2, these same bar limits will be used for the bottom row (Row 2). For RMode 1, these limits will also suffice to define the reinforcement limits in the side rows.

Enter under cover the amount of cover for Row 1. This same cover will be used for Row 2.

Upper Limit (1, 2)

For round and spiral members enter the maximum number of bars and the maximum size to be considered in the design. If the number field is left blank, the maximum number will be set to 50, and if the size field is left blank, the maximum size will be set to #11.

For tied members enter the maximum number of bars and the maximum size to be accepted in the top row (Row 1). If the number field is left blank, the maximum number in Row 1 will be set to 13, and if the size field is left blank, the maximum size will be set to #11. Under both RModes 1 and 2 these same bar limits will be used for Row 2. For RMode 1 these limits will also suffice to define the reinforcement limits in the side rows.

The cover field in this block is not used. Under the design option the cover for Row 2 will be set equal to that of Row 1.

Lower Limit (3, 4)

This block of data is required only for RMode 2 and tied members. It is not used for round and spiral members and for tied members under RMode 1. Since corner bars are always included in Rows 1 and 2, the number of bars in the side rows always refers to bars between, and not including, the corner bars. The program will locate these bars equally spaced between the corner bars.

Enter under number the minimum number of bars to be accepted in Row 3. If the field is left blank, the minimum number will be set to zero. The size field is not used since bar sizes will be the same as for Row 1.

Enter under Cover the amount of cover for the side rows if different from that previously defined for Row 1 or as Constant all around.

Upper Limit (3, 4)

The first paragraph under Lower Limit (3, 4) above also applies.

Enter under number the maximum number of bars to be accepted in Row 3. If the field is blank or zero, the program will not place bars in the side rows. In this case the minimum number of bars given in the Lower Limit (3, 4) must also be zero (see paragraph above). The size field is not used since bar sizes will be the same as for Row 1.

The cover in this block is not used. Under the design option the cover for Row 4 is assumed equal to that of Row 3.

2.6 Reinforcement Data for Investigation

RMode

This one digit field in c.c. 1 defines the reinforcement pattern to be investigated as follows:

RMode = 1

Mode 1 defines bars equally distributed around the perimeter of the pattern and all bars the same size.

For round and spiral members these bars will be equally spaced in a circle whose radius is determined from the member dimensions and the amount of cover. The first bar is always placed on the positive y-axis.

For tied members one bar will be placed in each corner and the remaining bars will be distributed equally among the four faces. When the number of bars is not a multiple of four, the extra bars are placed in Rows 1 and 2.

RMode = 2

RMode 2 is applicable only to tied members. This mode allows for the definition of the reinforcement pattern by rows parallel to each face. The number of bars and the size of the bars in any row may be different from the other rows. The row designations and definitions are illustrated in the input form. The four blocks of data (one for each row) provided in the input form must be used when this mode is used.

RMode = 3

RMode 3 is provided to enable the investigation of irregular reinforcement patterns which do not fall in the categories available under Modes 1 and 2. It may be used for the three types of members available. When this mode is designated, the number of bars must be given in the field provided, and the rest of the card is not used. The area and location of each bar must then be given in the following cards as will be described later.

Number of Bars and Bar Size

The total number of bars and the size of bars must be entered whenever RMode 1 is indicated. The number of bars must be between 4 and 50, and in the case of tied members, it must be even. The size must be a standard bar designation. Failure to comply with these limits will cause an "INPUT ERROR."

Under RMode 2, the number of bars is not used, since the bars are defined per row. However, the size of the bars may be defined under bar size, if the size is the same in all rows.

Under RMode 3, the exact number of bars must be given. The rest of the card is not used, and that many bars will be read from the following input cards, as will be described later.

Cover

Enter the cover distance to the main reinforcement, in inches, if this is constant around the perimeter of the cross section. For a rectangular spiral member, cover must be the amount of cover in the least dimension. For tied members under RMode 1, or under RMode 2 if the cover is constant all around, this cover will be used in all faces.

Reinforcement Pattern Definition by Rows

Four blocks are provided, one for each row, to be used for the investigation of tied members under RMode 2. Row designation and definition is illustrated in the input form. For each row the number of bars in that row must be given. Rows 1 and 2 include the corner bars, thus at least 2 bars must be defined in each of these rows. The number of bars in Rows 3 and 4 do not include the corner bars and thus may be zero for either or both rows.

The bar size in a row must be given unless it is the same for all rows and the size was given under bar size in the block of the card.

Cover for a row must be given unless it is the same for all rows and the cover was given in the first block. If the cover in the sides is to be different from the cover in the top and bottom rows, the cover in Rows 3 and 4 must be given, even if there are no bars in these rows, in order to properly place the corner bars with respect to their x-coordinates.

The sum of the bars in all four rows must be equal to or less than 50 and bar sizes must be standard bar designations. Failure to comply with this limit will cause an "INPUT ERROR."

Irregular Reinforcement Patterns

As previously mentioned, members with irregular reinforcement patterns can be investigated by using RMode = 3. In this case, the number of bars must be entered in the second field of the reinforcement data card. This card must then be immediately followed by the number of cards required to define the given number of bars.

Each card has room for four bars in the form of one block of three fields for each bar:

First field:	Area of bar in sq. in.
Second field:	x-coordinate of bar in inches
Third field:	y-coordinate of bar in inches

Negative coordinates must be given thus: -XX. XXX

The number of cards required will depend on the number of bars stated. If additional lines are required than provided in the input form, extra forms may be used. There must be no blank blocks between the first and last bar. The maximum permissible number of bars is 50.

2.7 Load Mode Definition

This card is used to define the manner in which the loadings are given in the problem, and to request the type of output desired in the investigation option.

LMode

This is a one digit field in c. c. 1 which defines loading mode. Digits 0, 1, 2, and 3 are valid in the investigation option. Only the digit 3 is valid for the design option. Any other digit will cause an "INPUT ERROR." The load modes are defined as follows:

LMode = 0

No loadings are given. The user is requesting only the control points in the interaction diagram. (see Description of Output).

LMode = 1

Only axial (P) loads are given, and each load is defined. The user is requesting interaction diagram.

LMode = 2

Axial (P) loads are given as groups of loads, each group consisting of an initial value of P, a final value and an increment. The user is requesting interaction diagram.

The above three modes are acceptable only under the investigation option.

LMode = 3

Mode 3 may be used for investigation option, and must be used for the design option. This mode means that the loadings are given in the form of applied axial loads combined with uniaxial or biaxial moments. It automatically implies that the user is requesting a comparison between the applied loadings and the strength of the cross section. (see also the Description of Output).

Number of Cards

Whenever LMode is 1, 2, or 3, this field must contain the number of load cards that follow. That number of cards will be read to determine the number of loading conditions that the program is to process. This field is not used when LMode is zero.

IOX and IOY

Each of these two one-digit numeric fields serves as an indicator which is examined for zero (or blank) or non-zero condition during the input phase.

The functions of these indicators depend on whether the program is operating under the design or investigation option as follows:

(1) Design option

The IOX and IOY indicators enable the user to input axial loads alone for design. The indicators are interrogated whenever a loading condition is encountered in which both applied moments MX and MY are equal to zero. If the indicators are not zero, the program will supply design moments in accordance with the specification requirements for minimum eccentricities as follows:

IOX	IOY		
1	0	-	Minimum moment will be provided about the x-axis only.
0	1	-	Minimum moment will be provided about the y-axis only.
1	1	-	Minimum moments will be provided about both the x and y axes.

The indicators are not used for any loading condition where real values are given for MX or MY. If both indicators are zero (or blank), then each loading case must have at least one non-zero moment, otherwise an "INPUT ERROR" will result. More details are given in the directions for preparing the LOAD CARDS.

(2) Investigation option

The IOX and IOY indicators enable the user to specify what axis of bending is to be considered and reported in the output for the investigation option.

If IOX = 1 (or non-zero) it signifies that the user is requesting interaction information about the x-axis. If IOX = 0 or blank, the program will examine IOY before deciding on the output option.

If IOY = 1 (or non-zero) it signifies that the user is requesting interaction information about the y-axis. If IOY = 0 or blank, the output mode will depend on the status of IOX.

The following output is obtained depending on the condition of IOX and IOY:

IOX	IOY		
1	0	-	Only information about the x-axis is given.
0	1	-	Only information about the y-axis is given.
1	1	-	Interaction information is furnished about both x and y axis and also about the diagonal axis to enable the computation of biaxial bending strength of the cross section.

Under the investigation option, and LMode 3, the program assumes that if IOX = 1 and IOY = 0, only MX moments are given in the load cards. Similarly, if IOX = 0 and IOY = 1, the program assumes that only MY moments are given. In either of these conditions, the computations for biaxial bending interaction are by-passed.

2.8 Load Cards

Data given in the load cards will depend on the LMode defined in CARD 5 previously discussed in Paragraph 2.7 Load Mode Definition. In all cases, the first field of each card must contain in c.c. 2-3 the number of loads or the number of groups in that card. All axial loads must be given in kips, and all moments in kip-feet, right justified in its field and no decimal points are required. Negative values of P or M are invalid, and will result in an "INPUT ERROR". All applied axial loads and moments must be multiplied by appropriate load factors and, where applicable, slenderness effects included.

Load data shall be given as follows:

If LMode = 1

The number of P loads in the card shall be entered in c.c. 2-3 and that many loads must be given in that card. Up to 15 loads can be given in each card. A maximum of 70 loads can be stored in the load data file.

If LMode = 2

The number of load groups in the card shall be entered in c.c. 2-3 and that many groups must be given in that card. Up to 5 load groups can be given in each card. A load group consists of a block of three fields as follows:

1st field = IP = Initial value of P in this group

2nd field = FP = Final value of P in this group

3rd field = ΔP = Increment value of P for this group

Values of P are computed by incrementing the initial value until the final value of P is obtained. Each value of P thus obtained is considered as one loading condition and stored in the Load Data File. The total number of loads must not exceed 70.

If LMode = 3

The number of loading conditions in the card must be entered in c.c. 2-3 and that many loadings must be given in that card. Up to 5 loadings can be given in one card. Each loading consists of a block of three fields as follows:

1st field = P = Applied axial load (with load factors).

2nd field = MX = Applied moment component in the direction of the x-axis (with load factors)

3rd field = MY = Applied moment component in the direction of the y-axis (with load factors)

Each loading must contain at least one non-zero field and no negative fields are accepted. Failure to comply will result in an "INPUT ERROR."

Under the design option it is possible for the user to specify a loading condition consisting of an axial load and the minimum design eccentricity. To do this, the axis (or axes) of bending must be designated by filling in the IOX and IO Y indicators in the Load Mode Definition card. The magnitude of the axial load P must then be input in the first field of the loading condition under consideration. The MX and MY fields must be left blank (or zero). The program will then supply minimum design moments for that loading case as follows:

If IOX = 1 (Bending about the x-axis):

MX = .05 (T/12) * P or P/12, whichever is greater, for round and spiral members

= .10 (T/12) * P or P/12, whichever is greater, for tied members

If IOY = 1 (Bending about the y-axis):

MY = .05 (B/12) * P or P/12, whichever is greater, for round and spiral members

= .10 (B/12) * P or P/12, whichever is greater, for tied members.

It should be noted that if IOX = 1 and IOY = 1, the above moments will be applied simultaneously as biaxial bending. It should also be noted that the program supplied these minimum moments only when MX and MY are zero in the input card, i.e., any positive, non-zero input value for either MX or MY will be assumed to be the actual applied moments specified by the user, and thus will be the moments used in the design.

For circular members, a considerable amount of computer time can be saved if moments are given about one axis only. For this case, when the actual member is subjected to biaxial bending, the user can resolve the two components into one resultant and input this as a uniaxial moment. In the design option, the axis chosen must be the same for all loadings. In the investigation option, the axis chosen must be the one indicated in Card 5 under IOX or IOY.

2.9 Last Card

The last card is more the concern of the computer operator. However, the user filling the input form can take advantage of the batch processing option to design different members in one computer run. When columns 1-2 of the last card contain two asterisks (**) the program will automatically return to the beginning to process another set of input data.

Thus, the user can call for the design of the minimum reinforcement for different member sizes, or different member types, by repeating the reinforcement and loading data in additional input forms, but changing the member dimensions. He will then be able to choose from the computed output the combination of section and reinforcement that best satisfies the design requirements.

3. DESCRIPTION OF OUTPUT

3.1 Introduction

Output listings are for the most part self-explanatory. After the program identification, the information given in the header cards is printed out, followed by the problem type option, and the type of member defined in the input.

Pertinent dimension data for the member will be printed on the next line. If the option is investigation, the given reinforcement data will be printed on the next line. If the option is design, the data for the selected reinforcement will be printed after the design is completed. If no reinforcement pattern was found to satisfy the loading conditions, a message will be printed so stating.

The form of the output that will follow the reinforcement data will depend on the type of problem being solved, and on the information given in the load cards. All axial loads are given in kips and moments are given in kip-feet. The data will be printed as follows:

3.2 Design Option Output

For each loading condition, the following data will be printed:

(1) Loading Case Number
(2) The applied loadings as given in the input

AP = Applied axial load
AMX = Applied moment component in the direction of the x-axis
AMY = Applied moment component in the direction of the y-axis

(3) The computed strength under combined flexure and axial load for the selected reinforcement assuming that the eccentricity of the axial load remains constant

UP = P_u = Axial load strength

UMX = M_x = Moment strength component in the direction of the x-axis

UMY = M_y = Moment strength component in the direction of the y-axis

(4) The ratio of the axial load strength to the applied axial load (UP/AP). This ratio will always be larger than .990.

3.3 Investigation Option Output

LMode = 0

The control points of the interaction diagram will be printed for each of the axes requested in the input. Control points are identified as follows:

PZ = P_o = axial load strength of section in pure compression

PB = P_b = axial load strength of section at simultaneous assumed ultimate strain of concrete and yielding of tension reinforcement (balanced conditions)

MB = M_b = moment strength of section at simultaneous assumed ultimate strain of concrete and yielding of tension reinforcement (balanced conditions)

MZ = M_o = moment strength in pure flexure ($P_u = 0$)

LMode = 1 or 2

Moment strengths will be printed for each axial load listed in the input (combined bending and axial load strengths). If uniaxial interaction data was requested in the input, only the moment strength about the specified axis will be printed.

If biaxial interaction data was requested in the input, the following information will be printed for each axial load:

(1) Loading Case Number

(2) UP = P_u = axial load strength

UMX = M_{ux} = moment strength in the direction of the x-axis with bending considered about the x-axis only

UMY = M_{uy} = moment strength in the direction of the y-axis with bending considered about the y-axis only

DXM = M_x = moment strength component in the direction of the x-axis when the neutral axis is parallel to the diagonal axis through the corners of a rectangular cross section or a 45^{o} axis for circular cross sections.

DYM = M_y = moment strength component corresponding to DXM above

DRM = the resultant of the DXM and DYM moments defined above. For a circular or a square cross section DRM is the moment strength for biaxial bending about the diagonal axis.

BETA = β = a coefficient which defines the interaction contour for the biaxial moment relationship (see reference cited under Item (6), Paragraph 1.7 Method of Solution).

EXP = n = exponent used in the biaxial bending design formula:

$$\left(\frac{M_x}{M_{ux}}\right)^n + \left(\frac{M_y}{M_{uy}}\right)^n = 1$$

For the use of this formula refer to the references cited under Item (6), Paragraph 1.7 Method of Solution.

LMode = 3

Under this mode the output will be a comparison between the applied loadings given in the input and the computed strength of the cross section under combined flexure and axial load. The form of the output will be identical to that printed for the design option output. The adequacy of the section investigated to resist the applied loadings can be readily determined from the ratio of UP/AP printed in the last column of the listing.

4. GENERAL NOTES ON DESIGN OPTION

The design phase of this program determines the minimum amount of reinforcement that will satisfy all the loading conditions given in the input. The reinforcement pattern to be used, and any restrictions as to number of bars and bar sizes, is under the control of the engineer through the stipulations given in the input data.

If no restrictions are given, the program will investigate the full range of number of bars and bar sizes, until the optimum area of steel is found. Even though there are built in procedures to eliminate the checking of obviously inadequate bar patterns (such as total area of reinforcement outside the reinforcement ratios permitted by the specifications, bar patterns which result in bar spacings where the clear distance between bars is less than allowed by the specifications, total area of steel more than an area which has already been found satisfactory, etc.) the amount of computer time required to solve the problem increases proportionally with the number of load cases to be checked, and the range of the limits set for number of bars and bar sizes.

Obviously, the engineer can be of great help in increasing the efficiency of the computer operation. By using proper judgment and previous experience, input data can be prepared that will shorten the computer run to solve a given problem. There are several means available:

(1) A minimum and maximum ratio of reinforcement can be input in card no. 3, if it can be predetermined that the ratio of reinforcement will be within a narrower range than the .01 to .08 used in the program.

(2) The minimum acceptable clear spacing of bars can be increased in the input if this is a detailing requirement.

(3) If the approximate number of bars can be predetermined, or if restrictions can be set for bar sizes, the limits can be input in card no. 4.

In the design option, when it is determined that a certain bar arrangement is satisfactory, the program proceeds to compute the strength of the cross section under combined flexure and axial load, and compare this to the applied loadings. Each loading is checked in the same sequence given in the input. The first time that one of the loadings is not satisfied the checking procedure is terminated and the bar arrangement is rejected. A bar arrangement is accepted only when all the applied loadings are satisfied. In order to speed up the checking procedure, the more critical loading conditions should be input first.

The program rejects any cross section when the load strength is less than 0.99 of the applied load. It should be noted that the computed theoretical strength is reduced by the capacity reduction factor φ before the comparison is made. For axial loads less than $0.10f'_c A_g$, the φ factor varies between that for compression members to that for pure flexure.

The engineer may also wish to set standards for acceptance of a cross section. For example, a strength "overstress" of 5% may be acceptable instead of the 1% programmed. The 5% acceptance criteria can be adopted by inputting larger φ factors in card no. 3. A φ factor of 0.735 will result in computed strengths 5% larger than those computed for $\varphi = 0.7$.

It should also be noted that the method used in this solution of the strength design of compression members is more rigorous than most other methods used in current standards and design aids. For example, the solution uses a parabolic stress diagram for concrete, stress-strain compatibility is used in computing stresses, reinforcement is considered as the actual bars in the actual location (instead of the usual simplifying assumption of a line, which leads to an over-estimation of the contribution of the bars to the strength of the section), and the area of concrete displaced by bars in compression is deducted in the computations. Therefore, the solution has eliminated some of the simplifications which, because of the possible excess load effects, require larger safety factors in the present specifications. For these reasons, it is reasonable to suggest that the engineer can use less strength reduction (higher φ factors) when using this program for design of reinforced concrete compression members.

The engineer should be aware that this program computes the strength of the cross section based on moments about the geometric centroid of the gross cross section. Therefore, all input moments must also be referenced to the geometric axes of the concrete section, and all output data should be interpreted likewise. The design capabilities of the program are limited to finding the minimum area of steel for symmetrical reinforcement patterns only.

However, under the investigation option, the program accepts any type of reinforcement configuration, including unsymmetrical patterns. If the engineer desires to compare applied loadings with computed strengths (LMode = 3), then the input moments must be given about the geometric centroid.

It should be noted that any reference axis can be used for a design, as long as the applied moments and resisting moments are both referenced to that axis. The geometric centroid is most convenient, since its location is fixed and does not depend on the amount or distribution of the reinforcement. Furthermore, the frame analysis of the structure is usually made using the geometric centroid of the gross cross section. The moments thus obtained can then be used directly as input to the program. If the engineer has computed applied moments about any other axis, then the moments can be easily transferred to the geometric axis by adding a moment equal to the axial load times the distance between the two axes.

Of course, it is not the intention of this program to dictate standards or procedure for design. Every effort has been made to allow maximum flexibility to give the engineer the capability of setting his own criteria for design, and conform with the normal practices in his office. The validity of the solution, and the accuracy of the results, have been thoroughly checked and found satisfactory for all the cases tested. However, to assure proper use, it is advisable that results of the program be first checked against previous designs.

5. ILLUSTRATIVE PROBLEMS

Two sample problems are included to illustrate proper input procedure.

Problem No. 1 is the design of a 36-inch round column for five applied loading conditions.

Problem No. 2 is an investigation of a 24 x 42 cross section for load-moment interaction data.

The input sheets and output data are included.

REFERENCES

1. Advanced Engineering Bulletin 18, "Capacity of Reinforced Rectangular Columns Subject to Biaxial Bending" and Advanced Engineering Bulletin 20, "Biaxial and Uniaxial Capacity of Rectangular Columns" published by the Portland Cement Association.

PORTLAND CEMENT ASSOCIATION

INPUT FORM FOR R.C. COLUMN DESIGN PROGRAM
ULTIMATE STRENGTH THEORY

1 2	3	4 5 6	7	8 9 10 11 12
//		XEQ		PCAUC

PROBLEM IDENTIFICATION AND HEADING INFORMATION

	1–80
1.	*SAMPLE PROBLEM NO. 1 - DESIGN OF 36 IN ROUND COLUMN
	*
	*

2.

1	2	3	4
D	▨	R	▨

PROBLEM TYPE: D=DESIGN; I=INVESTIGATION
COLUMN TYPE: R=ROUND; S=SPIRAL; T=TIED
REQUIRED INPUT
OPTIONAL INPUT

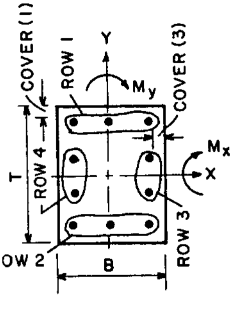
COLUMN SIZE		STRESSES		CAPACITY REDUCTION FACTORS		DESIGN REINFORCEMENT			MODIFIABLE CONSTANTS			
B in.	T in.	f'_c ksi.	f_y ksi.	ϕ_C	ϕ_B	MIN. RATIO	MAX. RATIO	MIN. CLEAR SPACING	f_c ksi.	E_c ksi.	E_s ksi.	ϵ_u in./in.
1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19 20 21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36 37	38 39 40 41 42	43 44 45 46 47	48 49 50 51 52 53	54 55 56 57 58 59	60 61 62 63 64 65	66 67 68 69 70
3. 36.000	36.000	5.000	60.000	.75	.90	.	.	.	.	.	.	.

4.

R MODE	NO. OF BARS	BAR SIZE	COVER (IF SAME ALL AROUND)	ROW 1 OR LOWER LIMIT (1,2)			ROW 2 OR UPPER LIMIT (1,2)			ROW 3 OR LOWER LIMIT (3,4)			ROW 4 OR UPPER LIMIT (3,4)		
				NO.	SIZE	COVER	NO.	SIZE	COVER	NO.	SIZE	COVER	NO.	SIZE	COVER
1	2 3	4 5	6 7 8 9 10	12 13	14 15	16 17 18 19 20	22 23	24 25	26 27 28 29 30	32 33	34 35	36 37 38 39 40	42 43	44 45	46 47 48 49 50
1			2.000	23	8	.	25	10	.			.			.

IF INVST. TIED RMODE 2.
IF DESIGN.
IF INVST. RMODE 3, ENTER AREA AND LOCATION OF EACH BAR

A_i	X_i	Y_i	A_j	X_j	Y_j	A_k	X_k	Y_k	A_n	X_n	Y_n
1–6	7–13	14–20	21–26	27–33	34–40	41–46	47–53	54–60	61–66	67–73	74–80
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.



5.

L MODE	NO. OF CARDS	IOX ?	IOY ?
1	2 3	4	5
3	1		

AXIAL LOADS (P) IN KIPS, MOMENTS IN K-FT, RIGHT JUSTIFIED, NO DECIMAL POINT

IF 1	NO. OF P's/CARD	P_i	P	P	P	P	P	P	P	P	P	P	P	P	P_n
IF 2	NO. OF GPS./CD	IP_i	FP_i	ΔP_i	IP_j	FP_j	ΔP_j	IP_k	FP_k	ΔP_k	IP_m	FP_m	ΔP_m	IP_n	FP_n	ΔP_n
IF 3	NO. OF LOADS/CD	P_i	MX_i	MY_i	P_j	MX_j	MY_j	P_k	MX_k	MY_k	P_m	MX_m	MY_m	P_n	MX_n	MY_n
1	2 3 4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80
6. ▨	5	90	1240		540	1500		990	1640		1580	1600		2040	1480	

7.

1	2
/	*

LAST CARD: ** TO PROCESS ANOTHER COLUMN; ☐ (BLANK) TO CALL EXIT

```
P.C.A. - STRENGTH DESIGN OF R.C. COMPRESSION MEMBERS

SAMPLE PROBELM NO.1 - DESIGN OF 36 IN ROUND COLUMN

DESIGN OF
ROUND COMPRESSION MEMBERS

B= 36.00   T= 36.00   FC= 5.000   FY= 60.000   PHIC= 0.750   PHIB= 0.900

USE- 24 NO. 9 BARS.  AST = 24.00 SQ.IN. = 2.36 PCT.   COVER = 2.000 IN.


 LOAD      APPLIED  LOADS         COMPUTED  STRENGTH
 CASE        AP     AMX     AMY       UP     UMX      UMY        UP/AP

   1         90.   1240.     0.      104.   1443.      0.        1.164
   2        540.   1500.     0.      544.   1506.      0.        1.004
   3        990.   1640.     0.      997.   1648.      0.        1.005
   4       1580.   1600.     0.     1591.   1610.      0.        1.006
   5       2040.   1480.     0.     2048.   1488.      0.        1.004
```

1 2	3	4 5 6	7	8 9 10 11 12
//		XEQ		PCAUC

PORTLAND CEMENT ASSOCIATION

INPUT FORM FOR R.C. COLUMN DESIGN PROGRAM

ULTIMATE STRENGTH THEORY

PROBLEM IDENTIFICATION AND HEADING INFORMATION

1. (columns 1–80)

*SAMPLE PROBLEM NO.2 - INVESTIGATION OF 24x42 TIED MEMBER

*REQUESTING INTERACTION DIAGRAM

*PHI=1.0 FOR THEORETICAL STRENGTH

2.

1	2	3	4
I	▨	T	▨

PROBLEM TYPE: D=DESIGN; I=INVESTIGATION

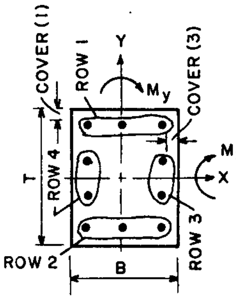
COLUMN TYPE: R=ROUND; S=SPIRAL; T=TIED

REQUIRED INPUT

OPTIONAL INPUT

3.

COLUMN SIZE		STRESSES		CAPACITY REDUCTION FACTORS		DESIGN REINFORCEMENT			MODIFIABLE CONSTANTS			
B in.	T in.	f'c ksi.	fy ksi.	φC	φB	MIN. RATIO	MAX. RATIO	MIN. CLEAR SPACING	fc ksi.	Ec ksi.	Es ksi.	εu in./in.
1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19 20 21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36 37	38 39 40 41 42	43 44 45 46 47	48 49 50 51 52 53	54 55 56 57 58 59	60 61 62 63 64 65	66 67 68 69 70
24.000	42.000	5.000	60.000	1.00	1.00	.	.	.	.	.	.	.



4.

R MODE	NO. OF BARS	BAR SIZE	COVER (IF SAME ALL AROUND)	ROW 1 OR LOWER LIMIT (1,2)				ROW 2 OR UPPER LIMIT (1,2)				ROW 3 OR LOWER LIMIT (3,4)				ROW 4 OR UPPER LIMIT (3,4)			
				☰	NO.	SIZE	COVER	☰	NO.	SIZE	COVER	☰	NO.	SIZE	COVER	☰	NO.	SIZE	COVER
1	2 3	4 5	6 7 8 9 10	11	12 13	14 15	16 17 18 19 20	21	22 23	24 25	26 27 28 29 30	31	32 33	34 35	36 37 38 39 40	41	42 43	44 45	46 47 48 49 50
2			2.000	▨	6	10	.	▨	6	10	.	▨	8	8	.	▨	8	8	.

IF INVST. TIED RMODE 2.

IF INVST. RMODE 3, ENTER AREA AND LOCATION OF EACH BAR

Ai	Xi	Yi	Aj	Xj	Yj	Ak	Xk	Yk	An	Xn	Yn
1 2 3 4 5 6	7 8 9 10 11 12 13	14 15 16 17 18 19 20	21 22 23 24 25 26	27 28 29 30 31 32 33	34 35 36 37 38 39 40	41 42 43 44 45 46	47 48 49 50 51 52 53	54 55 56 57 58 59 60	61 62 63 64 65 66	67 68 69 70 71 72 73	74 75 76 77 78 79 80
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.

5.

L MODE	NO. OF CARDS	IOX?	IOY?
1	2 3	4	5
2	1	1	0

AXIAL LOADS (P) IN KIPS, MOMENTS IN K-FT, RIGHT JUSTIFIED, NO DECIMAL POINT

6.

IF																
1	NO. OF P's/CARD		Pi	P	P	P	P	P	P	P	P	P	P	P	P	P	Pn
2	NO. OF GPS./CD		IPi	FPi	ΔPi	IPj	FPj	ΔPj	IPk	FPk	ΔPk	IPm	FPm	ΔPm	IPn	FPn	ΔPn
3	NO. OF LOADS/CD		Pi	MXi	MYi	Pj	MXj	MYj	Pk	MXk	MYk	Pm	MXm	MYm	Pn	MXn	MYn
1	2 3	4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80
▨	1	▨	0	5800	200											
▨		▨														
▨		▨														

7.

1	2

LA[illegible]CARD: ** TO PROCESS ANOTHER COLUMN; ☐☐ (BLA[illegible]) TO CALL EXIT

```
P.C.A. - STRENGTH DESIGN OF R.C. COMPRESSION MEMBERS

SAMPLE PROBLEM NO.2 - INVESTIGATION OF 24X42 TIED MEMBER
REQUESTING INTERACTION DIAGRAM
PHI=1.0 FOR THEORETICAL STRENGTH

INVESTIGATION OF
TIED COMPRESSION MEMBERS

B= 24.00  T= 42.00  FC= 5.000  FY= 60.000  PHIC= 1.000  PHIB= 1.000

WITH 28 NO. 8 BARS.  AST = 27.87 SQ.IN. = 2.77 PCT.   COVER = 2.000 IN.

          ROW 1        ROW 2        ROW 3        ROW 4

BARS     6 NO.10      6 NO.10      8 NO. 8      8 NO. 8
COVER     2.000        2.000        2.000        2.000


 UNIAXIAL INTERACTION REQUESTED

 LOAD       UP     UMX

   1         0.   2454.
   2       200.   2667.
   3       400.   2855.
   4       600.   3012.
   5       800.   3145.
   6      1000.   3258.
   7      1200.   3341.
   8      1400.   3401.
   9      1600.   3439.
  10      1800.   3446.
  11      2000.   3389.
  12      2200.   3295.
  13      2400.   3198.
  14      2600.   3097.
  15      2800.   2989.
  16      3000.   2873.
  17      3200.   2748.
  18      3400.   2612.
  19      3600.   2460.
  20      3800.   2293.
  21      4000.   2110.
  22      4200.   1912.
  23      4400.   1699.
  24      4600.   1485.
  25      4800.   1267.
  26      5000.   1043.
  27      5200.    815.
  28      5400.    580.
  29      5600.    332.
  30      5800.     58.
```

6. DESCRIPTION OF PROGRAM SOURCE DECK

6.1 Source Deck Details

The FORTRAN source deck for the program is available for use on either the IBM 1130 or the IBM 360 computer, with at least a 16-K core capacity. All cards are identified in c.c. 73-80 with the label PCAC followed by a 4 digit sequence number.

The source deck consists of five main line programs and thirty subprograms as follows:

Main line programs: PCAUC DESRS DESTT INVST REPRT

Subprograms:
ATYX
BICPM
BISPM
CHECK
CLEAR
COMPZ
CRCPM
FBBUC
FCPM
FINDB
FINDE
FINDM
FIX
FIY
FES
FUMXY
LIMIT
PHI
RECX
RECY
RECZ
REINF
REINS
REINT
RST
SABC
SENDL
SUMRY
UNCPM
UNSPM

The source deck is followed by a blank card and the data cards for two sample problems. A copy of the input form and the printed output from two sample problems is included elsewhere in the write up.

6.2 Loading the Source Program into Disk

The disk into which the program is to be loaded must contain the IBM Monitor System Version 2, Modification Level 7, or higher.

To load the program into an IBM 1130 computer simply place the appropriate "Cold-Start" card before the source deck and run this through the card-reader, following the usual procedure for storing programs in disk, after placing deck in hopper, press START button in card reader, and then successively press the IMM STOP, RESET and PROGRAM LOAD buttons on the console. (The procedure for loading on an IBM 360 computer may be slightly different from that described here.) This will store the program from the working storage into the user's area of the disk. Note that if a specific disk is being used for this program, then the appropriate user area identification must appear on all the *STORE cards of the source deck. Note also that if a printer other than an IBM 1132 printer is being used for this program, then the appropriate printer identification must appear on all the *IOCS cards of the source deck.

6.3 Execution of the Program PCAUC

After storage of the program on the disk, the user should execute the sample problem data. The sequence of cards needed are as follows:

[// JOB]
[// XEQ PCAUC] - Monitor Control Cards

[Input data for one compression member] - Data Cards

[** or blank] - End Cards

Note that the monitor control cards may be different for an IBM 360 computer. The end card bearing '**' in c. c. 1-2 allows for the batch running of several columns, while a ' ' (i. e. blank) in c. c. 1-2 transfers control to the Monitor supervisor after the CALL EXIT operation.

6.4 Error Messages

During the input phase of the program certain illegal information in some of the input cards will cause the following message to be printed: "INPUT ERROR."

Under such conditions, the monitor supervisor should abort the job. The problem with the revised input data should then be reprocessed as a new job.

PORTLAND CEMENT pca ASSOCIATION

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