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TECHNICAL NOTE

COMPUTER AIDED ANALYSIS OF REINFORCED CONCRETE COLUMNS SUBJECTED TO AXIAL COMPRESSION AND BENDING—I L-SHAPED SECTIONS

MALLIKARJUNA† and P. MAHADEVAPPA
Karnataka Regional Engineering College, Suratkal-574157, India

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Abstract—Numerical investigations on the strength of L-shaped short reinforced concrete columns subjected to combined axial load and bending were undertaken for the purpose of providing design aids for structural engineers. The use of a computer lends itself naturally to the solution of the problem which generally requires an iterative process. Therefore, an attempt has been made in this paper to computerize the analysis procedure for L-shaped sections and in the accompanying paper (part II)‡ for T-shaped column sections. The ACI-318, CP-110 and IS-456 codes presented design aids only for square/rectangular and circular columns. Apparently this study constitutes the first to present the interaction curves for L-shaped and T-shaped column sections with the limit state analysis.

INTRODUCTION

The analysis and design of L-shaped corner columns are complicated and cumbersome. Next to rectangular and circular shapes, L-sections may be the most frequently encountered reinforced concrete columns, since they can be used at outside and re-entrant building corners. Nevertheless, information for their analysis and design is not generally available to structural engineers, either in working stress or ultimate strength theories. There are some design approaches in which the design effort is reduced by approximated shape of strength envelopes (e.g. Bresler [2], Parme *et al.* [3], CP-110 [4], ACI-318 [5] and IS-456 [6, 7]), and the use of simplifying approximations (e.g. the method of superposition [8] and the method of equivalent uniaxial eccentricity [8]). Ramamurthy [9] developed simple equations to closely represent the load contours in square and rectangular columns. He also illustrated how they can be used to determine the appropriate interaction diagram for given eccentricities of the load. Although several noteworthy articles [2, 3, 8–17] on biaxial bending of square/rectangular column sections, which contributed greatly to the understanding of this subject, have appeared in recent years, significant gaps in the area of design aids for biaxial bending still exist. To lessen these gaps, a number of comprehensive design aids are presented in the present investigation.

This paper deals with the limit state analysis of L-shaped reinforced concrete (R.C.) columns. The aim of limit state design is to achieve acceptable probabilities that the structure will not become unfit for the use for which it is intended, that is, that it will not reach a limit state. To ensure the above objectives, the design should be based on characteristic values for material strengths and applied loads, which takes into account the variations in the material strengths and in the loads to be supported.

ASSUMPTIONS AND MATERIAL PROPERTIES

In the analysis, the following assumptions [6], which are almost the same as those codified in CP-110 [4], are made:

(a) the strain distribution in the concrete in compression and the strain in the reinforcement, whether in tension or compression, are derived from the assumption that plane sections normal to the axis remain plane after bending, and that there is no bond-slip between the reinforcement and the concrete,
(b) the tensile strength of concrete is ignored,
(c) the relationship between stress–strain distribution in concrete is assumed to be parabolic as shown in Fig. 1. The maximum compressive stress is equal to $0.67 f_{ck}/1.5$ (see Fig. 2),
(d) the stresses in reinforcement are derived from the representative stress–strain curve for the type of steel used. Typical curves are shown in Figs 3 and 4,
(e) the maximum compressive strain in concrete in axial compression is taken as 0.002,
(f) the maximum compression strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending, but when there is no tension on the section, is taken as 0.0035 minus 0.75 times the strain at the least compressed extreme fibre (see Fig. 2a),
(g) the maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending, when part of the section is in tension, is taken as 0.0035 (see Fig. 2b). In the limiting case, when the neutral axis lies along one edge of the section, the strain varies from 0.0035 at the highly compressed edge to zero at the opposite edge.

METHOD OF ANALYSIS

The criteria generally proposed for determining the ultimate strength of R.C. members subjected to axial compression combined with bending are based on limiting the maximum strain (or stress) in the concrete to some prescribed value. The load-carrying capacities discussed

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† Present address: Engineering Mechanics and Design Group, Department of Mechanical Engineering, University of Toronto, Toronto M5S 1A4, Canada.

‡ See ref. [1].

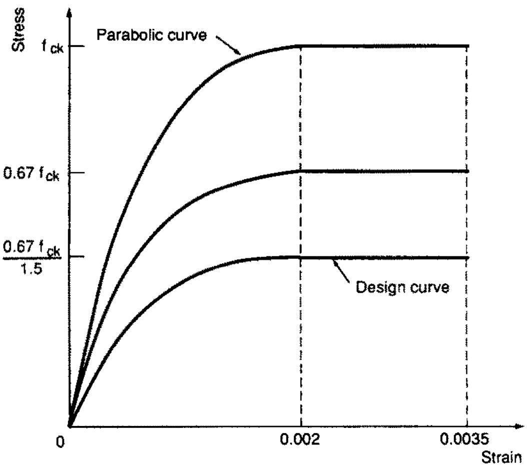
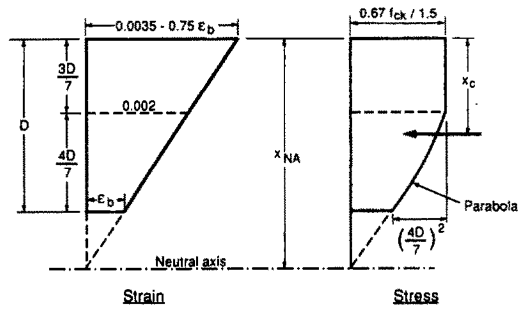


Fig. 1. Idealized stress–strain curve for concrete.

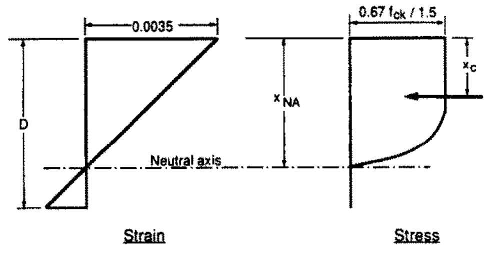
here apply to relatively short columns for which the effect of lateral deflections on the magnitude of bending moments is negligible. Also effects of sustained load and reversal of bending moments are not considered.

In the present investigation, a square section of size $B \times B$ is considered. If a small square of size $B_l \times B_l$ ($B_l < B$) is removed from the corner of a original square section then it will become a symmetric L-section as shown in Fig. 5. For different values of B_l the L-sections of various sizes can be obtained. If $B_l = 0.0$, the L-section becomes square section. Since the ratio of B_l/B for all practical purposes varies from 0.3 to 0.6, the present work is limited to the ratios of B_l/B equal to 0.3, 0.4, 0.5 and 0.6. The parameters considered are symmetric L-shaped column sections and reinforcement is assumed to be uniformly distributed as a thin strip along all the sides with effective cover to depth ratio (B'/B) as 0.1.

Design charts for combined axial compression and bending are obtained in the form of interaction diagrams in which curves for $P_u/f_{ck}B^2$ versus $M_u/f_{ck}B^3$ are plotted for different values of p/f_{ck}. When bending moments are acting in addition to axial load, the points for plotting the interaction diagrams are obtained by assuming different positions of neutral axis. For each position of the neutral axis, the strain distribution across the section and the stress block parameters are determined. The stresses in the reinforcement are also calculated from the known strains. Thereafter the resultant axial force and the moment about the centroid of the section are calculated as follows.



a) neutral axis outside the section.



b) neutral axis inside the section.

x_{NA} = depth of neutral axis

Fig. 2. Stress and strain diagrams.

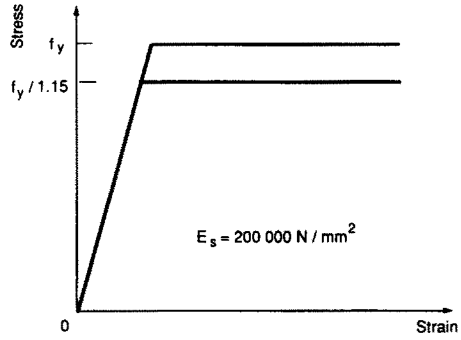


Fig. 3. Idealized stress–strain curve for mild steel bars.

To find the forces and moments due to concrete in the L-section subjected to axial compression and bending (both uniaxial and biaxial bending with equal eccentricities $e_x = e_y = e$), the following procedure is used in the analysis. The stress block (see Fig. 2) is divided into number of strips. First the width of each strip is calculated. This strip width is multiplied by corresponding width of the section and depth of the strip, which gives the force in that strip of concrete. The algebraic sum of all such elemental forces gives the total force in concrete. This force in concrete multiplied by the distance between centroid of the stress block and centroid of the section gives the moment due to concrete. The forces and moments due to reinforcement (both for uniaxial and biaxial bending) are determined as follows:

$$\text{force in the reinforcement} = \sum_{i=1}^{n} (f_{si} - f_{ci}) p_i A_c / 100 \quad (1a)$$

moment of resistance

$$\text{with respect to steel} = \sum_{i=1}^{n} (f_{si} - f_{ci}) p_i A_c y_i / 100 \quad (1b)$$

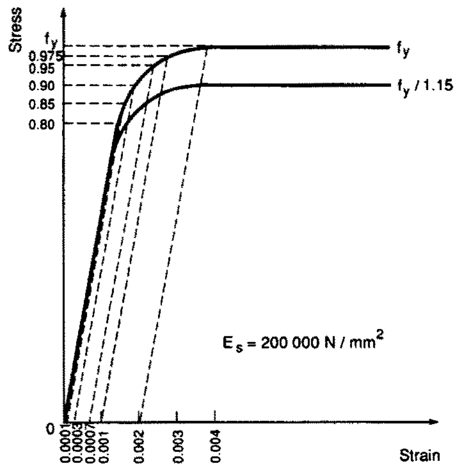


Fig. 4. Idealized stress–strain curve for high yield strength deformed bars.

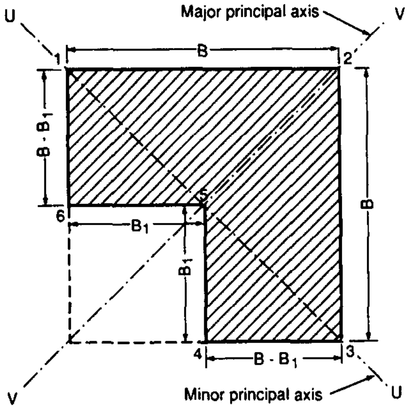


Fig. 5. L-shaped column section.

in which n is the number of rows of reinforcement, but in the present work, since the reinforcement is assumed to be distributed uniformly as thin strip along all sides of the L-section, the notation n here refers to the number of unit length of the reinforcement strip at which the stresses in steel and concrete (at that level) are to be determined, f_{si} is the stress in the ith row of steel (compression being positive and tension negative), f_{ci} is the stress in concrete at the level of the ith row of reinforcement, A_c is the area of concrete, may be taken equal to the gross area, $p_i = (A_{si}/A_c)100$ is the percentage of steel in the ith row, A_{si} is the area of reinforcement in the ith row, y_i is the distance of the ith row of reinforcement measured from the centroid of the section. It is positive towards the highly compressed edge and negative towards the least compressed edge.

INTERACTION DIAGRAMS

Because of symmetry, in a square section, the eccentricity on either side of the centre of gravity makes no difference in the approach to interaction curves except when steel is not symmetric, whereas, in the case of L-shaped column sections the same is not true. For the L-shaped section considered here, the minor principal axis U–U and major principal axis V–V are shown in Fig. 5, and the interaction curves have been prepared by considering the axis of bending as explained below:

Case 1. Uniaxial bending parallel to edge 1–2, by treating edge 1–2 in compression.
Case 2. Uniaxial bending parallel to edge 1–2, by treating edge 1–2 in tension.
Case 3. Biaxial bending with equal eccentricities treating corner 2 in compression.
Case 4. Biaxial bending with equal eccentricities treating corner 2 in tension.

The four computer programs, namely UNIAX1, UNIAX2, BIAX1, and BIAX2 for the above-mentioned cases 1–4, respectively, are developed by using FORTRAN and are presented in the Appendix. These programs were used to obtain the ultimate bload (P_u) and moment (M_u) as

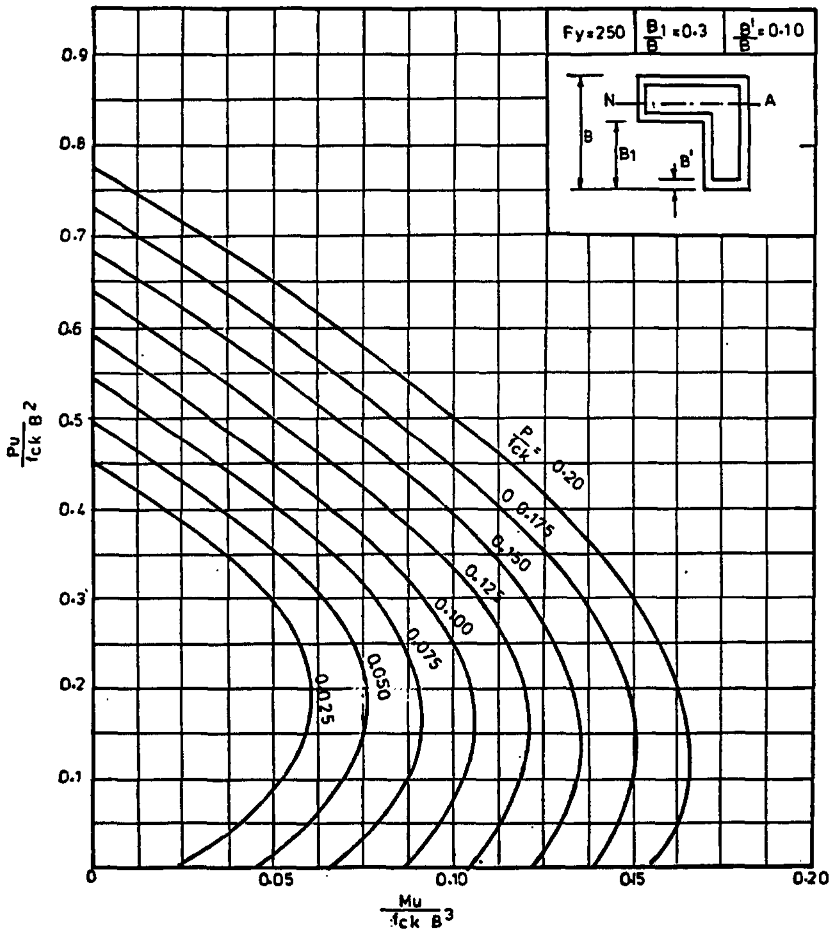


Fig. 6. Axial compression with uniaxial bending.

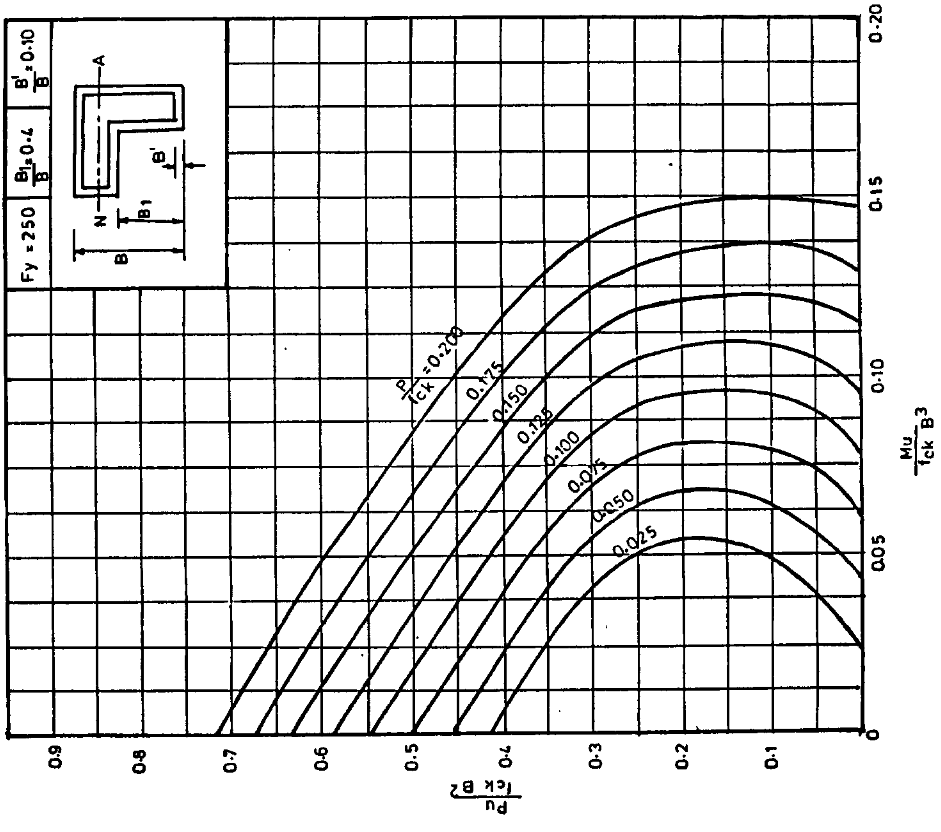


Fig. 7. Axial compression with uniaxial bending.

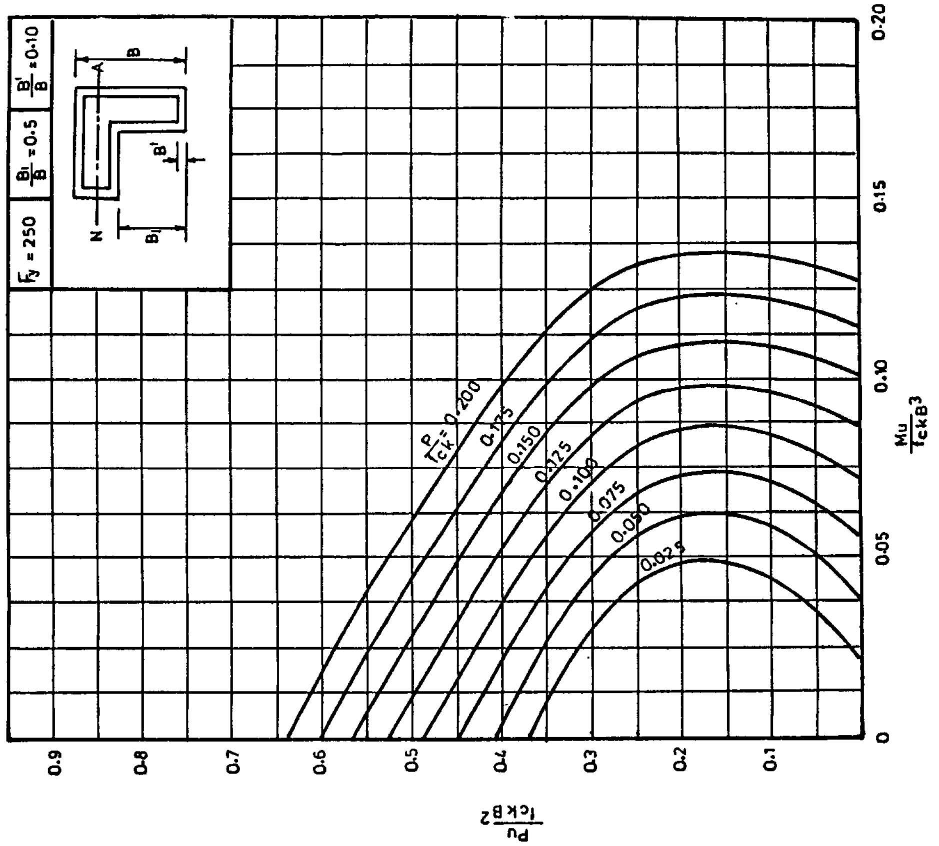


Fig. 8. Axial compression with uniaxial bending.

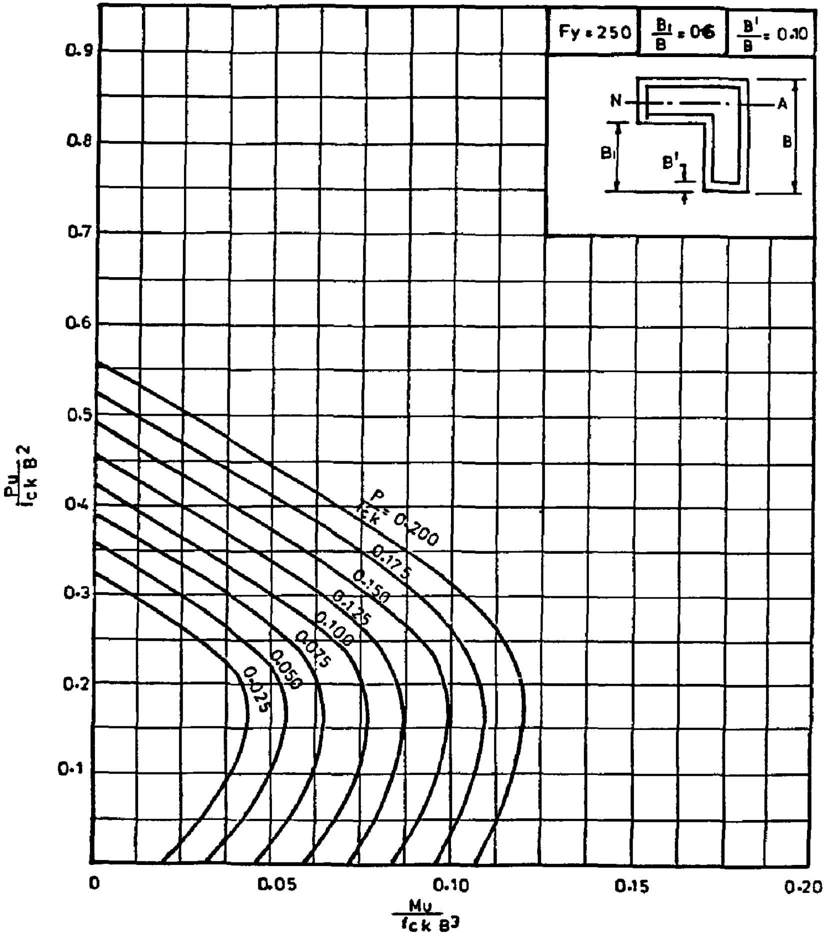


Fig. 9. Axial compression with uniaxial bending.

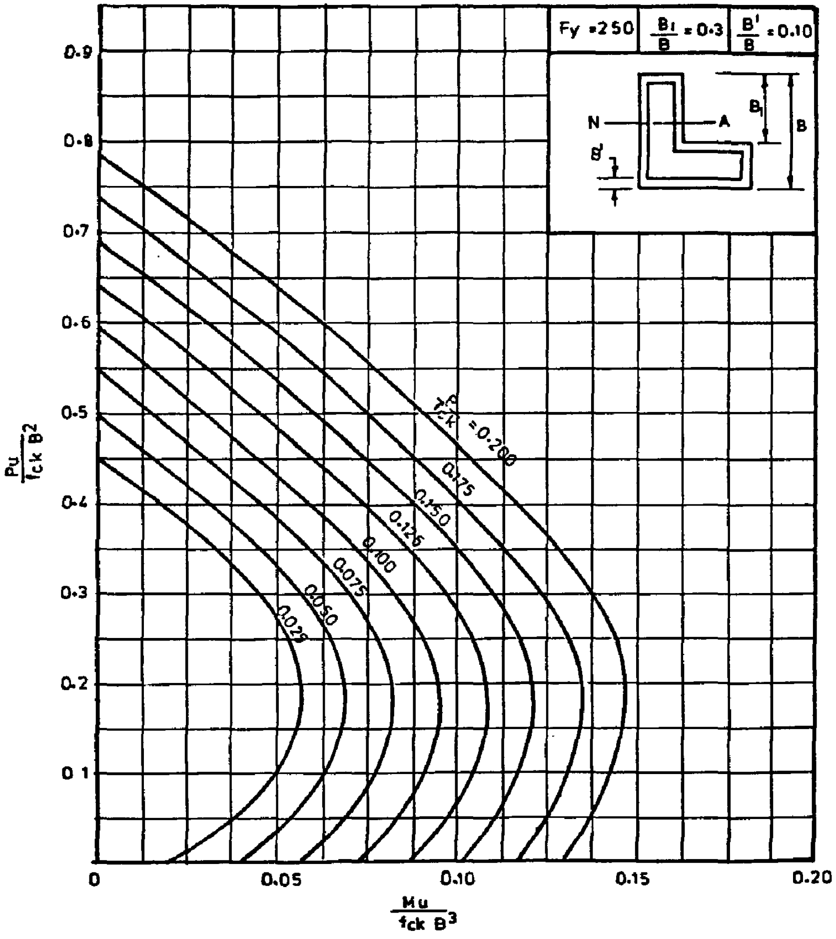


Fig. 10. Axial compression with uniaxial bending.

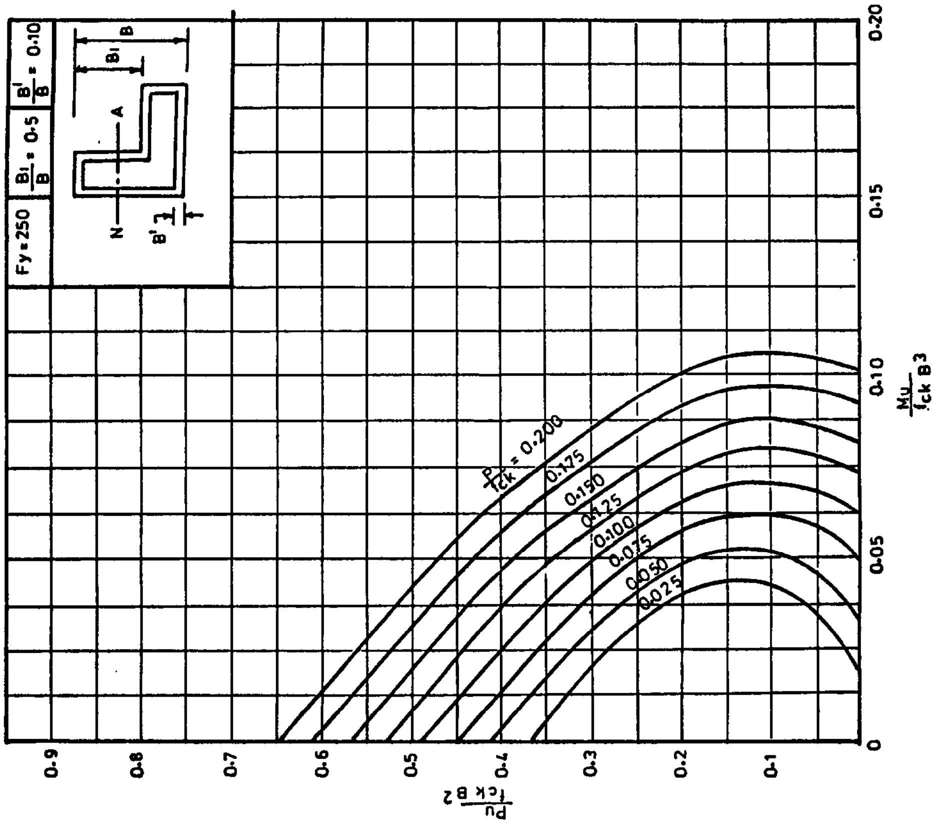


Fig. 12. Axial compression with uniaxial bending.

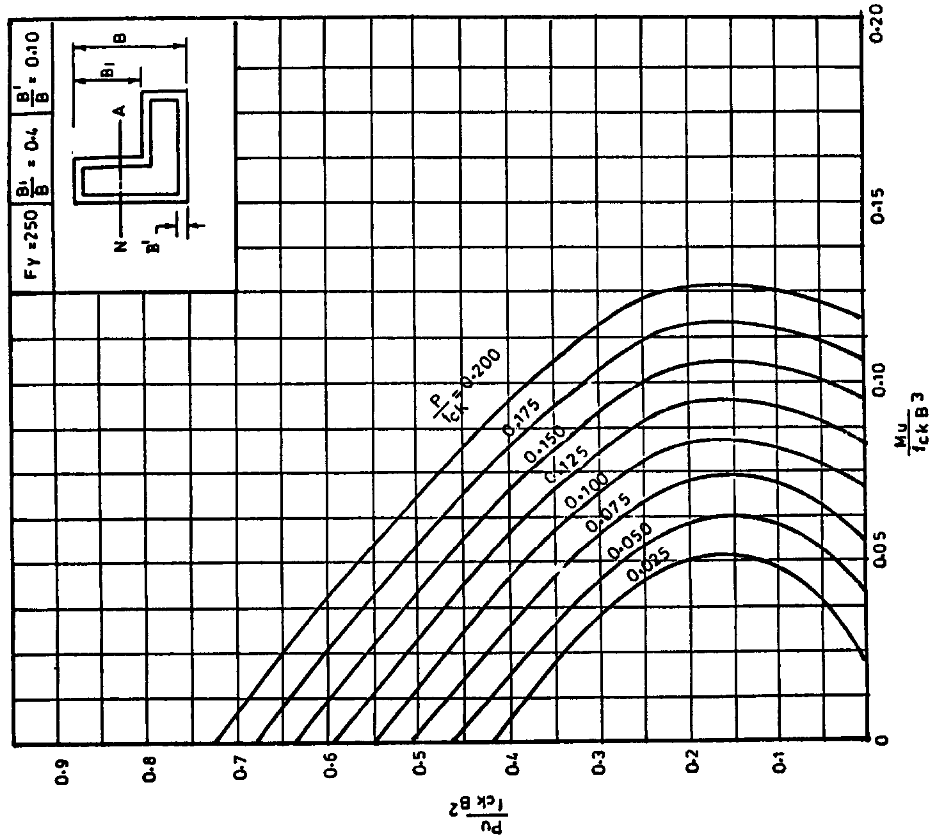


Fig. 11. Axial compression with uniaxial bending.

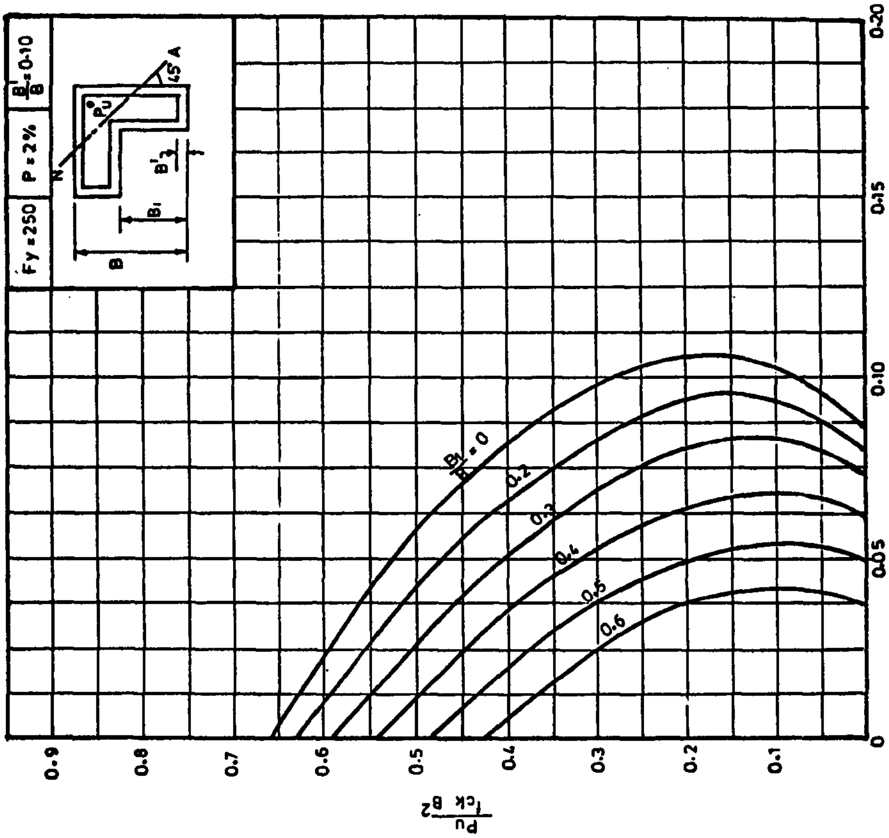


Fig. 14. Axial compression with biaxial bending.

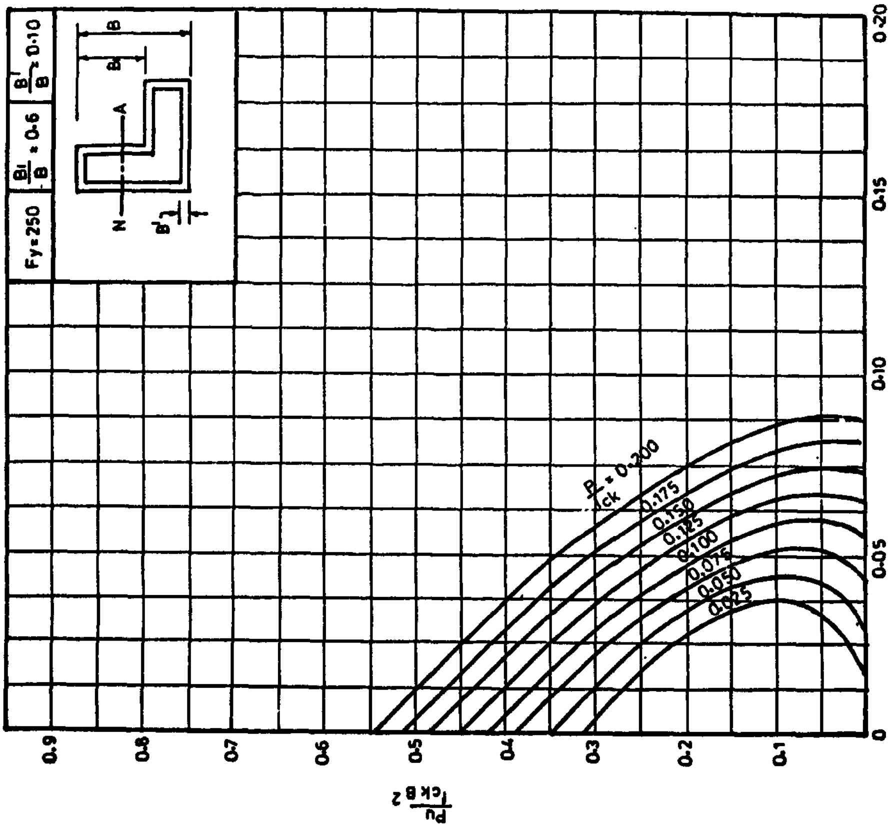


Fig. 13. Axial compression with uniaxial bending.

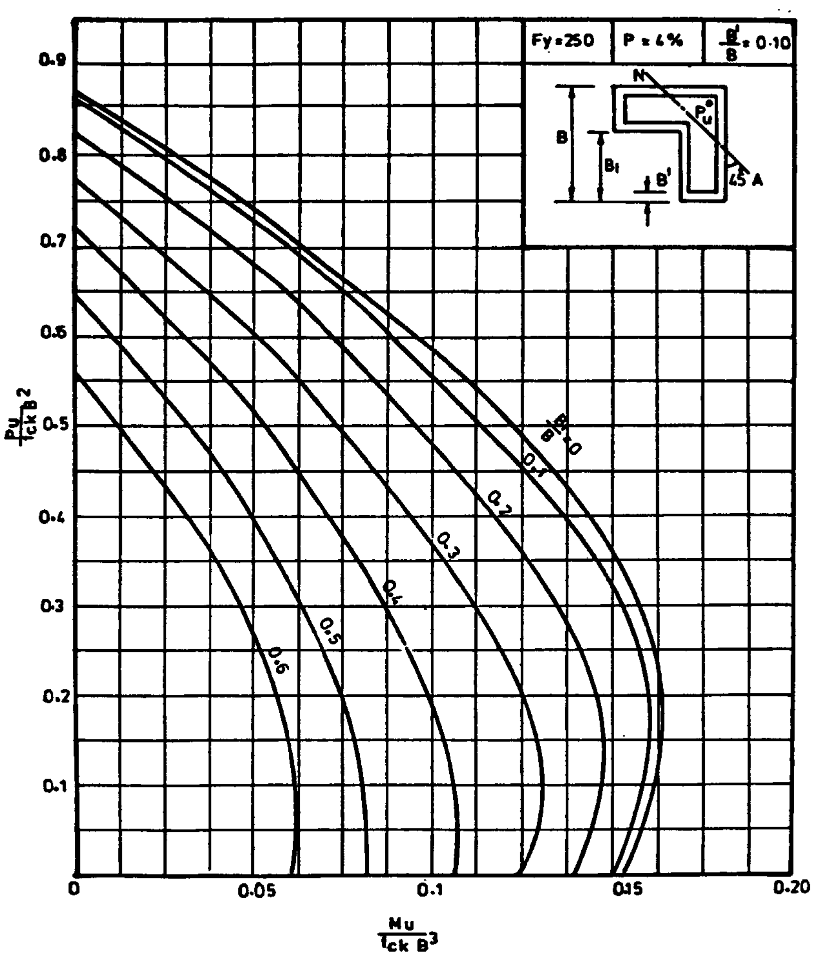


Fig. 15. Axial compression with biaxial bending.

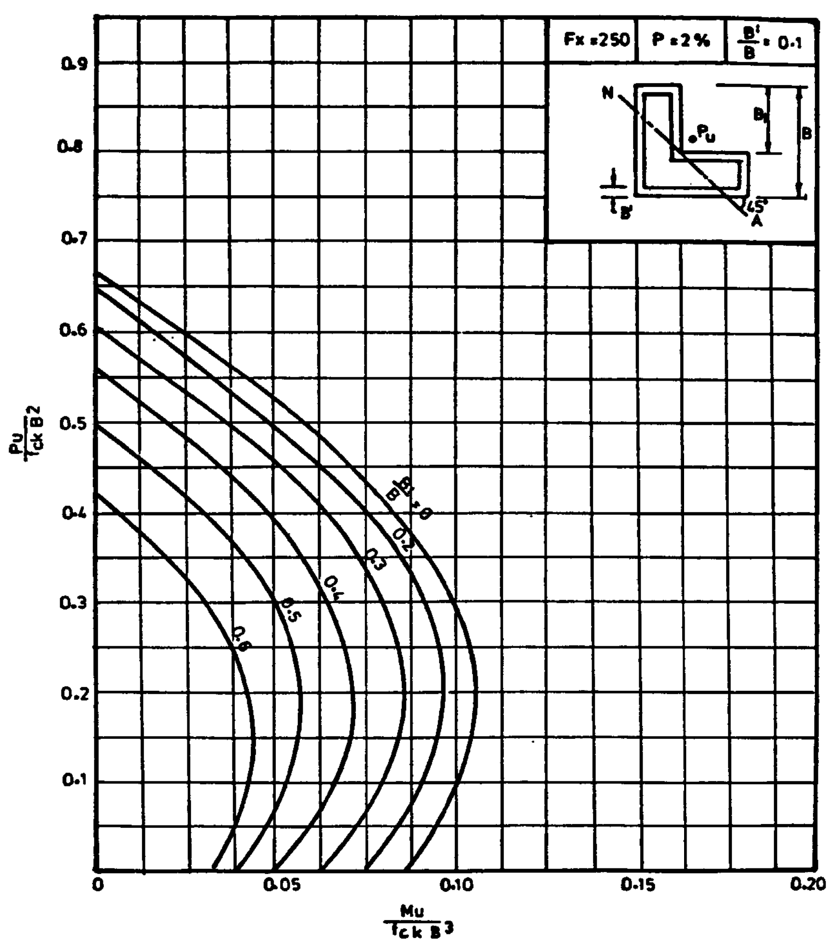


Fig. 16. Axial compression with biaxial bending.

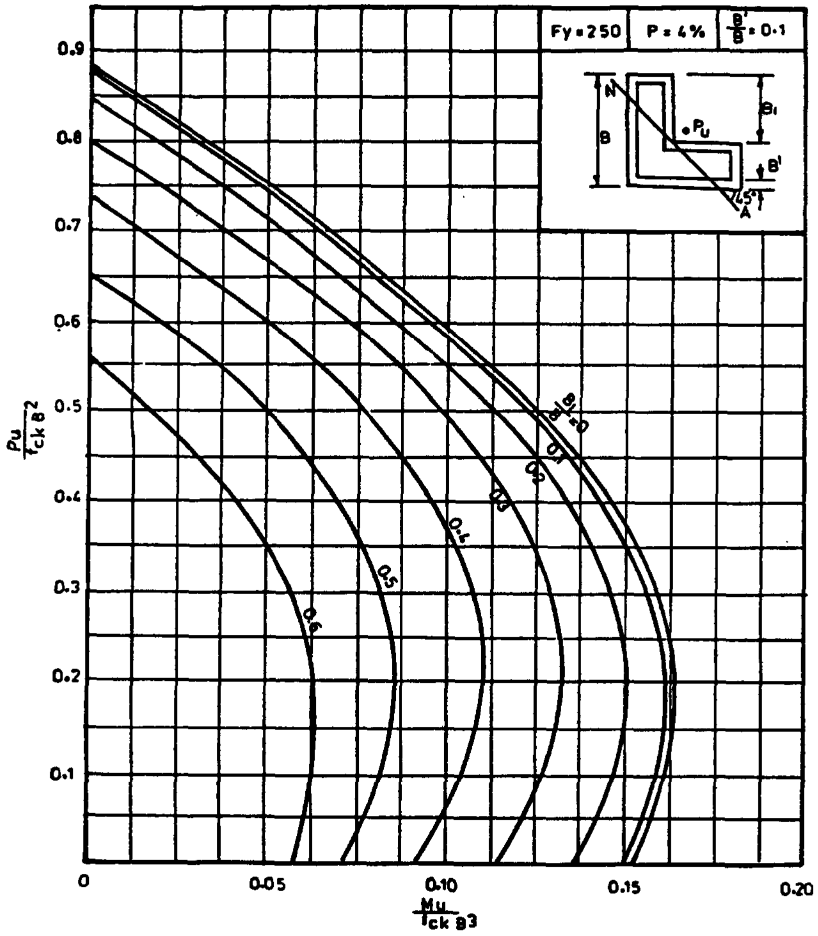


Fig. 17. Axial compression with biaxial bending.

output for different positions of neutral axes. The input data consists of the square size (B_1) of the removed portion from the original square section, depth (B) of the section, cover depth (B'), characteristic strength of the concrete (f_{ck}) and steel (f_y), and modulus of elasticity of steel (E_c). All the loads and moments so obtained are graphically represented in terms of non-dimensional parameters ($P_u/f_{ck}B^2$ versus $M_u/f_{ck}B^3$) and are shown in Figs 6–17.

LIMITATIONS

The number of variables considered in this paper are restricted as there was limited space. In the present investigation, the following parameters were considered:

(i) symmetric L-shaped column sections with reinforcement as a thin strip along all sides,
(ii) effective cover to depth ratio (B'/B) is taken as 0.1 in all the cases,
(iii) B_1/B ratios are 0.0, 0.3, 0.4, 0.5 and 0.6,
(iv) the modulus of elasticity of mild steel is taken equal to 200 kN/mm^2.

CONCLUSIONS

The analysis of reinforced concrete L-shaped column sections subjected to axial compression and bending (uniaxial and biaxial) has been computerized. Interaction curves for L-shaped column sections under axial compression and uniaxial bending for two cases are presented in Figs 6–9 and Figs 10–13. For columns under axial compression and biaxial bending with equal eccentricities, the curves for two cases are shown in Figs 14–15 and Figs 16–17. It is hoped that the charts which are included in this paper, will be useful aids for designers and also will bring some attention to the particular form of resistance exhibited by these cross-sections. It offers the possibility of economizing and can complement the existing design procedures.

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APPENDIX

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C****************************************************************
C      ANALYSIS OF L-SHAPED COLUMN SECTIONS UNDER AXIAL
C      COMPRESSION AND UNIAXIAL BENDING (See Figs. 6-9)
C****************************************************************
        OPEN(5,FILE='UNIAX1.DAT')
        OPEN(6,FILE='UNIAX1.OUT',STATUS='NEW')
        DO 299 I=1,10
        READ(5,5,END=300)B1,B,DC,FCK,FY,ES
  5     FORMAT(5F6.2,F10.2)
        P=0.0
  7     P=P+0.5
        XU=DC
  8     XU=XU+5.0
        FK=0.446*FCK
        Y1=(0.5*B*(B-B1)+B1*(B-0.5*B1))/(B+B1)
        A=B*(B-B1)+B1*(B-B1)
        AS=P*A/100.0
        RL=4.0*B-8.0*DC
        TS=AS/RL
C       DETERMINATION OF FORCES DUE TO CONCRETE
        IF(XU-B) 10,10,20
  10    X1=3.0*XU/7.0
        X2=4.0*XU/7.0
        GO TO 30
  20    X1=3.0*B/7.0
        X2=4.0*B/7.0
  30    PC=0.0
        AMC=0.0
        B5=(B-B1)
        IF(X1-B5) 40,70,70
  40    C1=B*X1*FK
        BMC1=C1*(Y1-0.5*X1)
        X=0.0
  45    X=X+1.0
        B6=B-B1-X1
        IF(X-B6)50,50,60
  50    F=FK-FK*X*X/((XU-X1)*(XU-X1))
        PC1=B*F
        AMC1=PC1*(Y1-(X1+X))
        GO TO 65
  60    F=FK-FK*X*X/((XU-X1)*(XU-X1))
        PC1=(B-B1)*F
        AMC1=PC1*(Y1-(X1+X))
  65    PC=PC+PC1
        AMC=AMC+AMC1
        IF(X.LT.X2) GO TO 45
        TPC=PC+C1
```

```
      TAMC=AMC+BMC1
      GO TO 80
 70   C1=(B-B1)*B*FK
      BMC1=C1*(Y1-0.5*(B-B1))
      C2=(B-B1)*(X1-(B-B1))*FK
      AMC2=C2*(Y1-(0.5*X1-0.5*(B-B1)))
      X=0.0
 75   X=X+1.0
      F=FK-FK*X*X/((XU-X1)*(XU-X1))
      PC1=(B-B1)*F
      AMC1=PC1*(Y1-(X1+X))
      PC=PC+PC1
      AMC=AMC+AMC1
      IF(X.LT.X2) GO TO 75
      TPC=C1+C2+PC
      TAMC=BMC1+AMC2+AMC
C     DETERMINATION OF FORCES IN COMPRESSION
C     REINFORCEMENT
 80   B7=B-DC
      IF(XU-B7) 90,160,160
 90   PSC=0.0
      AMSC=0.0
      PSC1=0.0
      AMSC1=0.0
      D=0.0
 95   D=D+1.0
      EC=0.0035*D/XU
      IF(FY.EQ.250.0)GO TO 96
      IF(EC.GE.0.0038) GO TO 96
      IF(EC.LE.0.00145) GO TO 96
      FC=FY/1.15-12831145.0*(0.0038-EC)*(0.0038-EC)
      GO TO 97
 96   FC=EC*ES
      F1=FY/1.15
      IF(FC.GE.F1) FC=F1
 97   B8=XU-(B-B1-DC)
      IF(D-B8) 110,100,110
 100  PSC1=B1*TS*(FC-FK)
      AMSC1=PSC1*(Y1-(XU-D))
      GO TO 115
 110  PSC2=2.0*TS*(FC-FK)
      AMSC2=PSC2*(Y1-(XU-D))
      PSC=PSC+PSC2
      AMSC=AMSC+AMSC2
      B9=XU-DC
 115  IF(D.LT.B9) GO TO 95
      PSC3=(B-2.0*DC)*TS*(FC-FK)
      AMSC3=PSC3*(Y1-(XU-D))
      TPSC=PSC+PSC1+PSC3
      TAMSC=AMSC+AMSC1+AMSC3
C     DETERMINATION OF FORCES DUE TO TENSILE REINFORCEMENT
      Z1=(B-DC-XU)
      PST=0.0
      AMST=0.0
      PST1=0.0
      AMST1=0.0
      Z=0.0
 116  Z=Z+1.0
      ET=0.0035*Z/XU
      IF(FY.EQ.250.0) GO TO 117
      IF(ET.GE.0.0038) GO TO 117
      IF(ET.LE.0.00145) GO TO 117
      FT=FY/1.15-12831145.0*(0.0038-ET)*(0.0038-ET)
      GO TO 118
 117  FT=ET*ES
      F1=FY/1.15
      IF(FT.GE.F1) FT=F1
 118  Z2=(B-B1-DC-XU)
      IF(Z-Z2) 120,130,120
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```
  130   PST1=-B1*TS*FT
        AMST1=PST1*(Y1-(XU+Z))
        GO TO 125
  120   PST2=-2.0*TS*FT
        AMST2=PST2*(Y1-(XU+Z))
        PST=PST+PST2
        AMST=AMST+AMST2
  125   IF(Z.LT.Z1) GO TO 116
        PST3=-(B-2.0*DC)*TS*FT
        AMST3=PST3*(Y1-(XU+Z))
        TPST=PST+PST1+PST3
        TAMST=AMST+AMST1+AMST3
        GO TO 200
  160   FT=0.0
        PSC=0.0
        AMSC=0.0
        PSC2=0.0
        AMSC2=0.0
        D1=(XU-(B-DC))
        D=D1-1.0
  165   D=D+1.0
        EC=0.002*D/(XU-X1)
        IF(FY.EQ.250.0) GO TO 168
        IF(EC.GE.0.0038) GO TO 168
        IF(EC.LE.0.00145) GO TO 168
        FC=FY/1.15-12831145.0*(0.0038-EC)*(0.0038-EC)
        GO TO 169
  168   FC=EC*ES
        F1=FY/1.15
        IF(FC.GE.F1)FC=F1
  169   IF(D-D1) 166,167,166
  167   PSC3=(B-B1-2.0*DC)*TS*(FC-FK)
        AMSC3=PSC3*(Y1-(XU-D))
        GO TO 165
  166   B11=XU-(B-B1-DC)
        IF(D-B11) 170,180,170
  180   PSC2=B1*TS*(FC-FK)
        AMSC2=PSC2*(Y1-(XU-D))
        GO TO 175
  170   PSC4=2.0*TS*(FC-FK)
        AMSC4=PSC4*(Y1-(XU-D))
        PSC=PSC+PSC4
        AMSC=AMSC+AMSC4
        B12=XU-DC
  175   IF(D.LT.B12) GO TO 165
        PSC1=(B-2.0*DC)*TS*(FC-FK)
        AMSC1=PSC1*(Y1-(XU-D))
        TPSC=PSC+PSC1+PSC2+PSC3
        TAMSC=AMSC+AMSC1+AMSC2+AMSC3
        TPST=0.0
        TAMST=0.0
  200   TF=TPSC+TPST+TPC
        TM=TAMSC+TAMST+TAMC
        E=TM/TF
        XC=TM/(FCK*B*B)
        YC=TF/(FCK*B)
        P1=P/FCK
        WRITE(6,6) XU,P1,FT,XC,TC
  6     FORMAT(5X,'XU=',F5.1,5X,'P1=',F5.4,5X,'FT=',F5.1,
        5X,'XC=',F5.4,5X,'YC=',F5.4/)
        XUMAX=2.0*B
        IF(XU.LE.XUMAX) GO TO 8
        IF(P.LT.4.0) GO TO 7
  299   CONTINUE
  300   STOP
        END
C--------------------------------------------------------------
```

```
C******************************************************************
C       ANALYSIS OF L-SHAPED COLUMN SECTIONS UNDER AXIAL
C       COMPRESSION AND UNIAXIAL BENDING (See Figs. 10-13)
C******************************************************************
        OPEN(5,FILE='UNIAX2.DAT')
        OPEN(6,FILE='UNIAX2.OUT',STATUS='NEW')
        DO 299 I=1,10
        READ(5,5,END=300)B1,B,DC,FCK,FY,ES
  5     FORMAT(5F6.2,F10.2)
        P=0.0
  7     P=P+0.5
        XU=DC
  8     XU=XU+5.0
        FK=0.446*FCK
        A=B*(B-B1)+B1*(B-B1)
        Y1=B-(0.5*B*(B-B1)+B1*(B-0.5*B1))/(B+B1)
        AS=P*A/100.0
        RL=4.0*B-8.0*DC
        TS=AS/RL
C       DETERMINATION OF FORCES DUE TO CONCRETE
        IF(XU-B) 10,10,20
  10    X1=3.0*XU/7.0
        X2=XU-X1
        GO TO 30
  20    X1=3.0*B/7.0
        X2=B-X1
  30    TPC=0.0
        TAMC=0.0
        X=0.0
  35    X=X+1.0
        IF(X-X1)40,40,50
  40    F=FK
        GO TO 60
  50    F=FK-FK*(X-X1)*(X-X1)/(XU-X1)/(XU-X1)
  60    IF(X-B1) 70,100,100
  70    W=B-B1
        GO TO 130
  100   W=B
  130   PC=W*F
        AMC=PC*(Y1-X)
        TPC=TPC+PC
        TAMC=TAMC+AMC
        B5=X1+X2
        IF(X.LT.B5) GO TO 35
C       DETERMINATION OF FORCES IN COMPRESSION REINFORCEMENT
        TPSC=0.0
        TAMSC=0.0
        B6=B-DC
        IF(XU-B6)140,150,150
  140   D=0.0
        GO TO 160
  150   D=XU-B6-1.0
  160   D=D+1.0
        EC=0.002*D/(XU-X1)
        IF(FY.EQ.250.0) GO TO 168
        IF(EC.GE.0.0038) GO TO 168
        IF(EC.LE.0.00145) GO TO 168
        FC=FY/1.15-12831145.0*(0.0038-EC)*(0.0038-EC)
        GO TO 169
  168   FC=EC*ES
        F1=FY/1.15
        IF(FC.GE.F1) FC=F1
  169   B7=XU-B+DC
        B8=XU-B1-DC
        B11=XU-DC
        IF(D.EQ.B7) GO TO 180
        IF(D.EQ.B11) GO TO 200
        IF(D.EQ.B8) GO TO 190
        WS=2.0*TS
```

```
        GO TO 210
  180   WS=(B-2.0*DC)*TS
        GO TO 210
  190   WS=B1*TS
        GO TO 210
  200   WS=(B-B1-2.0*DC)*TS
  210   PSC=WS*(FC-FK)
        AMSC=PSC*(Y1-(XU-D))
        TPSC=TPSC+PSC
        TAMSC=TAMSC+AMSC
        IF(D.LT.B11) GO TO 160
C       DETERMINATION OF FORCES IN TENSION STEEL
        FT=0.0
        TPST=0.0
        TAMST=0.0
        IF(XU.GE.B6)GO TO 265
        Z=0.0
  215   Z=Z+1.0
        ET=0.002*Z/(XU-X1)
        IF(FY.EQ.250.0) GO TO 216
        IF(ET.GE.0.0038) GO TO 216
        IF(ET.LE.0.00145) GO TO 216
        FT=FY/1.15-12831145.0*(0.0038-ET)*(0.0038-ET)
        GO TO 217
  216   FT=ET*ES
        F1=FY/1.15
        IF(FT.GE.F1) FT=F1
  217   B12=B1+DC-XU
        B14=B-DC-XU
        IF(Z.EQ.B12) GO TO 230
        IF(Z.EQ.B14) GO TO 240
        WS=2.0*TS
        GO TO 260
  230   WS=B1*TS
        GO TO 260
  240   WS=(B-2.0*DC)*TS
  260   PST=-WS*FT
        AMST=PST*(Y1-(XU+Z))
        TPST=TPST+PST
        TAMST=TAMST+AMST
        IF(Z.LT.B14) GO TO 215
  265   TF=TPC+TPSC+TPST
        TM=TAMC+TAMSC+TAMST
        E=TM/TF
        P1=P/FCK
        XC=TM/(FCK*B*B*B)
        YC=TF/(FCK*B*B)
        WRITE(6,6) XU,P1,FT,XC,TC
  6     FORMAT(5X,'XU=',F6.1,5X,'P1=',F5.4,5X,'FT=',F5.1,
        5X,'XC=',F6.4,5X,'YC=',F6.4/)
        XUMAX=2.0*B
        IF(XU.LT.XUMAX) GO TO 8
        IF(P.LT.4.0) GO TO 7
  299   CONTINUE
  300   STOP
        END
C-------------------------------------------
C*******************************************************************
C       ANALYSIS OF L-SHAPED COLUMN SECTIONS SUBJECTED TO AXIAL
C       COMPRESSION AND BIAXIAL BENDING WITH EQUAL ECCENTRICITIES
C       (See Figs.14 and 15)
C*******************************************************************
        OPEN(5,FILE='BIAX1.DAT')
        OPEN(6,FILE='BIAX1.OUT',STATUS='NEW')
        DO 299 I=1,10
        READ(5,5,END=300)B1,B,DC,FCK,FY,ES
  5     FORMAT(5F6.2,F10.2)
        P=0.0
  7     P=P+0.5
```

```
      XU=DC
    8 XU=XU+5.0
      FK=0.446*FCK
      A=B*(B-B1)+B1*(B-B1)
      Y1=(B*B*B*0.707-B1*B1*B1*0.707-B1*B1*(B-B1)*1.414)/A
      AS=P*A/100.0
      RL=4.0*B-8.0*DC
      TS=AS/RL
C     DETERMINATION OF FORCES DUE TO CONCRETE
      B2=(2.0*B-B1)*0.707
      IF(XU-B2) 10,10,20
   10 X1=3.0*XU/7.0
      X2=XU-X1
      GO TO 30
   20 X1=3.0*B2/7.0
      X2=B2-X1
   30 TPC=0.0
      TAMC=0.0
      X=0.0
   35 X=X+1.0
      IF(X-X1)40,40,50
   40 F=FK
      GO TO 60
   50 F=FK-FK*(X-X1)*(X-X1)/(XU-X1)/(XU-X1)
   60 B3=1.4142*(B-B1)
      B4=0.707*B
      IF(X-B3) 70,70,100
   70 IF(X-B4) 80,80,90
   80 W=2.0*X
      GO TO 130
   90 W=2.0*(1.4142*B-X)
      GO TO 130
  100 IF(X-B4) 110,110,120
  110 W=2.0*1.4142*(B-B1)
      GO TO 130
  120 W=(2.0*B-B1-X*1.4142)*2.0*1.4142
  130 PC=W*F
      AMC=PC*(Y1-X)
      TPC=TPC+PC
      TAMC=TAMC+AMC
      B5=X1+X2
      IF(X.LT.B5) GO TO 35
C     DETERMINATION OF FORCES IN COMPRESSION REINFORCEMENT
      TPSC=0.0
      TAMSC=0.0
      B6=(2.0*B-B1-2.0*DC)*0.7071
      IF(XU-B6)140,150,150
  140 D=0.0
      GO TO 160
  150 D=XU-B6-1.0
  160 D=D+1.0
      EC=0.002*D/(XU-X1)
      IF(FY.EQ.250.0) GO TO 168
      IF(EC.GE.0.0038) GO TO 168
      IF(EC.LE.0.00145) GO TO 168
      FC=FY/1.15-12831145.0*(0.0038-EC)*(0.0038-EC)
      GO TO 169
  168 FC=EC*ES
      F1=FY/1.15
      IF(FC.GE.F1) FC=F1
  169 B7=B*0.7071
      B8=(B-B1-DC)*1.4142
      B9=XU-B7
      B10=XU-B8
      B11=XU-1.4142*DC
      IF(D-B10) 180,180,190
  180 WS=4.0*TS*1.4142
      GO TO 210
```

```
  190   WS=2.0*TS*1.414
  210   PSC=WS*(FC-FK)
        AMSC=PSC*(Y1-(XU-D))
        TPSC=TPSC+PSC
        TAMSC=TAMSC+AMSC
        IF(D.LT.B11) GO TO 160
C       DETERMINATION OF FORCES IN TENSION STEEL
        FT=0.0
        TPST=0.0
        TAMST=0.0
        IF(XU.GE.B6)GO TO 265
        Z=0.0
  215   Z=Z+1.0
        ET=0.002*Z/(XU-X1)
        IF(FY.EQ.250.0) GO TO 216
        IF(ET.GE.0.0038) GO TO 216
        IF(ET.LE.0.00145) GO TO 216
        FT=FY/1.15-12831145.0*(0.0038-ET)*(0.0038-ET)
        GO TO 217
  216   FT=ET*ES
        F1=FY/1.15
        IF(FT.GE.F1) FT=F1
  217   B12=-B9
        B13=-B10
        B14=B6-XU
        IF(Z-B13) 230,230,240
  230   WS=2.0*TS*1.4142
        GO TO 260
  240   WS=4.0*TS*1.4142
  260   PST=-WS*FT
        AMST=PST*(Y1-(XU+Z))
        TPST=TPST+PST
        TAMST=TAMST+AMST
        IF(Z.LT.B14) GO TO 215
  265   TF=TPC+TPSC+TPST
        TM=TAMC+TAMSC+TAMST
        E=TM/TF
        P1=P/FCK
        XC=TM/(FCK*B*B*B)
        YC=TF/(FCK*B*B)
        WRITE(6,6) XU,P1,XC,TC
  6     FORMAT(5X,'XU=',F7.1,5X,'P1=',F8.5,
        5X,'XC=',F6.4,5X,'YC=',F6.4/)
        XUMAX=1.5*B
        IF(XU.LT.XUMAX) GO TO 8
        IF(P.LT.4.0) GO TO 7
  299   CONTINUE
  300   STOP
        END
C-------------------------------------------------------------
C**********************************************************
C    ANALYSIS OF L-SHAPED COLUMN SECTIONS SUBJECTED TO
C    AXIAL COMPRESSION AND BIAXIAL BENDING WITH EQUAL
C    ECCENTRICITES (See Figs.16 and 17)
C**********************************************************
        OPEN(5,FILE='BIAX2.DAT')
        OPEN(6,FILE='BIAX2.OUT',STATUS='NEW')
        DO 299 I=1,10
        READ(5,5,END=300)B1,B,DC,FCK,FY,ES
  5     FORMAT(5F6.2,F10.2)
        P=0.0
  7     P=P+0.5
        XU=DC
  8     XU=XU+5.0
        FK=0.446*FCK
        A=B*(B-B1)+B1*(B-B1)
        Y1=(B*B*B*0.707-B1*B1*B1*0.707-B1*B1*(B-B1)*1.414)/A
        AS=P*A/100.0
```

```
      RL=4.0*B-8.0*DC
      TS=AS/RL
C     DETERMINATION OF FORCES DUE TO CONCRETE
      B2=(2.0*B-B1)*0.707
      Y2=B2-Y1
      IF(XU-B2) 10,10,20
   10 X1=3.0*XU/7.0
      X2=XU-X1
      GO TO 30
   20 X1=3.0*B2/7.0
      X2=B2-X1
   30 TPC=0.0
      TAMC=0.0
      X=0.0
   35 X=X+1.0
      IF(X-X1)40,40,50
   40 F=FK
      GO TO 60
   50 F=FK-FK*(X-X1)*(X-X1)/(XU-X1)/(XU-X1)
   60 B3=1.4142*(B-B1)
      B4=0.707*B
      B31=B2-B3
      B41=B2-B4
      IF(X-B31) 70,70,100
   70 IF(X-B41) 80,80,90
   80 W=4.0*X
      GO TO 130
   90 W=(B-B1)*1.4142*2.0
      GO TO 130
  100 IF(X-B41) 110,110,120
  110 W=(1.4142*B-B2+X)*2.0
      GO TO 130
  120 W=(B2-X)*2.0
  130 PC=W*F
      AMC=PC*(Y2-X)
      TPC=TPC+PC
      TAMC=TAMC+AMC
      B5=X1+X2
      IF(X.LT.B5) GO TO 35
C     DETERMINATION OF FORCES IN COMPRESSION REINFORCEMENT
      TPSC=0.0
      TAMSC=0.0
      B6=(2.0*B-B1-2.0*DC)*0.7071
      IF(XU-B6)140,150,150
  140 D=0.0
      GO TO 160
  150 D=XU-B6-1.0
  160 D=D+1.0
      EC=0.002*D/(XU-X1)
      IF(FY.EQ.250.0) GO TO 168
      IF(EC.GE.0.0038) GO TO 168
      IF(EC.LE.0.00145) GO TO 168
      FC=FY/1.15-12831145.0*(0.0038-EC)*(0.0038-EC)
      GO TO 169
  168 FC=EC*ES
      F1=FY/1.15
      IF(FC.GE.F1) FC=F1
  169 B7=B*0.7071
      B8=(B-B1-DC)*1.4142
      B9=XU-B7
      B10=XU-B2+B8
      B11=XU-1.4142*DC
      IF(D-B10) 180,180,190
  180 WS=2.0*TS*1.4142
      GO TO 210
  190 WS=4.0*TS*1.414
  210 PSC=WS*(FC-FK)
      AMSC=PSC*(Y2-(XU-D))
      TPSC=TPSC+PSC
```

```
      TAMSC=TAMSC+AMSC
      IF(D.LT.B11) GO TO 160
C     DETERMINATION OF FORCES IN TENSION STEEL
      FT=0.0
      TPST=0.0
      TAMST=0.0
      IF(XU.GE.B6)GO TO 265
      Z=0.0
  215 Z=Z+1.0
      ET=0.002*Z/(XU-X1)
      IF(FY.EQ.250.0) GO TO 216
      IF(ET.GE.0.0038) GO TO 216
      IF(ET.LE.0.00145) GO TO 216
      FT=FY/1.15-12831145.0*(0.0038-ET)*(0.0038-ET)
      GO TO 217
  216 FT=ET*ES
      F1=FY/1.15
      IF(FT.GE.F1) FT=F1
  217 B12=-B9
      B13=B2-B8-XU
      B14=B6-XU
      IF(Z-B13) 230,230,240
  230 WS=4.0*TS*1.4142
      GO TO 260
  240 WS=2.0*TS*1.4142
  260 PST=-WS*FT
      AMST=PST*(Y2-(XU+Z))
      TPST=TPST+PST
      TAMST=TAMST+AMST
      IF(Z.LT.B14) GO TO 215
  265 TF=TPC+TPSC+TPST
      TM=TAMC+TAMSC+TAMST
      E=TM/TF
      P1=P/FCK
      XC=TM/(FCK*B*B*B)
      YC=TF/(FCK*B*B)
      WRITE(6,6) XU,P1,XC,YC
    6 FORMAT(5X,'XU=',F7.1,5X,'P1=',F8.5,
      5X,'XC=',F6.4,5X,'YC=',F6.4/)
      XUMAX=1.5*B
      IF(XU.LT.XUMAX) GO TO 8
      IF(P.LT.2.0) GO TO 7
  299 CONTINUE
  300 STOP
      END
C-----------------------------------------------------------
```