LATERAL LOADING DISTRIBUTION BETWEEN THE ELEMENTS OF A THREE-DIMENSIONAL CIVIL STRUCTURE

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Abstract—The problem of the lateral loading distribution between the resistant elements of a three-dimensional civil structure is analyzed. The bracings (shear-walls and frames) are supposed to be axially undeformable and interconnected through floors undeformable in their planes, so that only three degrees-of-freedom per floor are considered.

A general formulation is presented and the internal loading transmitted to the single bracing is expressed through pre-multiplication of the external loading vector by a distribution matrix.

A numerical example is eventually shown, in order to illustrate the use of a FORTRAN computer program, which translates the algebraical formulation into a sequence of elementary operations.

1. INTRODUCTION

The problem of the lateral loading distribution between the resistant elements of a three-dimensional civil structure has been analyzed under its various aspects in recent years. Wynhoven and Adams [1] studied the reduction of the ultimate load carrying capacity of a structure when it is subjected to loads causing torsion. Coull and Irwin [2] presented a simple coefficient method for assessing the load distribution in three-dimensional multistory shear-wall structures. Heidebrecht and Stafford Smith proposed a simple approximate method of analysis for the behavior of open thin-walled shear-walls [3] and of tall wall-frame structures [4], subjected to torsional moments. Stamato and Mancini [5] and Glück and Krauss [6] used a “continuum medium technique” to analyze the three-dimensional interaction of walls and frames, whereas MacLeod and Hosny [7] proposed the use of a discrete matrix method and a frame computer program. More recently, Haris [8] presented an approximate matrix method to determine the lateral load distribution and the deformations in high-rise buildings due to wind loads. Haris considered only one degree-of-freedom per floor corresponding to lateral deformation.

The object of the present paper is the extension of the analysis by Haris [8] to the most general case, when three degrees-of-freedom per floor are considered. A general formulation of the problem is presented and the internal loading transmitted to the single bracing is expressed through pre-multiplication of the external loading vector by a distribution matrix. This was defined by Capurso for a wind-bracing system constituted by cantilevers of thin-walled open section in [9]. A numerical example is eventually shown, in order to illustrate the use of a FORTRAN computer program, which translates the algebraical formulation into a sequence of elementary operations.

2. GENERAL FORMULATION OF THE PROBLEM

A general formulation of the problem of the external lateral loading distribution between the bracings of a three-dimensional civil structure will be shown. The structure is idealized as consisting of NTOT bracings interconnected through floors undeformable in their planes and the axial deformations of bracings are not considered. With these hypotheses, the floor movement can be expressed by three displacements: translations in X- and Y-direction of the global coordinate system origin (Fig. 1) and floor rotation.

If N is the number of stories, the external load will be represented by a 3N-vector \( F \), whose elements are three elementary loads for each floor and, more exactly, two shears and the torsion moment. In the same way, the internal loading transmitted to the \( i \)th element will be represented by a 3N-vector \( S_i \) and obtained from the preceding \( F \) through a pre-multiplication by a distribution matrix.

Let \( p_i \) be the 2N-vector representing the shear-loadings, on the \( i \)th element in the global coordinate system \( XY \) (Figs. 1 and 2), and \( m_i \) the N-vector representing the torsion moments, so that

\[
S_i = \begin{bmatrix} p_i \\ m_i \end{bmatrix}.
\]

The internal loadings \( S_i \) transmitted to the \( i \)th bracing and related to the global coordinate system \( XY \) are connected with the same loadings \( S_i^* \) related to the local coordinate system \( U_iV_i \) (Fig. 1):

\[
p_i^* = N_i p_i,
\]

\[
m_i^* = m_i - \psi_i \sqrt{p_i \cdot u_z},
\]

where the superscript * is used to indicate the loadings in the local coordinate system \( U_iV_i \), \( N_i \) is the orthogonal matrix of transformation from the sys-
tem $XY$ to the system $U_iV_i$, $\psi_i$ is the coordinate-vector of the origin of the local system $U_iV_i$ in the global one $XY$, $u_i$ is the unit vector in the $Z$-direction (note that $\psi_i \wedge p_i \cdot u_i$ is a scalar triple product). The orthogonal matrix $N_i$ is

$$N_i = \begin{bmatrix} \cos \omega & \sin \omega \\ -\sin \omega & \cos \omega \end{bmatrix},$$

where each element represents a diagonal $N \times N$-matrix and $\omega$ is the angle between the $X$-axis and the $U_i$-axis (Fig. 1).

Equation (2) may be represented in the matrix form

$$S_i^* = A_iS_i,$$

where

$$A_i = \begin{bmatrix} N_i & 0 \\ -u_i \wedge \psi_i & I \end{bmatrix},$$

$I$ is the identity matrix and $O$ the null matrix.

The displacements $\alpha_i$ in the global coordinate system $XY$ are then connected with the displacements $\alpha_i^*$ in the local system $U_iV_i$:

$$\delta_i^* = N_i \delta_i,$$

$$\varphi_i^* = \varphi_i,$$

where $\delta_i$ represents the translations and $\varphi_i$ the rotations. Equation (6) may be represented in the matrix form

$$\alpha_i^* = B_i\alpha_i,$$

where

$$B_i = \begin{bmatrix} N_i & 0 \\ 0 & I \end{bmatrix}.$$
where each element is a diagonal $N \times N$-matrix and $(x_i, y_i)$ are the components of vector $\psi_i$. Equation (11) can be re-written

$$S_i = K_i \alpha_i$$

or

$$S_i = K_i^{-1} \alpha,$$  \hspace{1cm} (17) \hspace{1cm} (18)

where $K_i = K_i / T_i$ is the stiffness of the $i$th element with respect to the floor displacements. For the global equilibrium we have

$$\sum_{i=1}^{N} S_i = F = \sum_{i=1}^{N} K_i \alpha_i,$$ \hspace{1cm} (19)

or

$$F = \bar{K} \alpha,$$ \hspace{1cm} (20)

where $\bar{K} = \sum_{i=1}^{N} K_i$ is the global stiffness matrix of the rigid floors. Recalling eqns (18) and (20), we get

$$\alpha = \bar{K}^{-1} S_i = \bar{K}^{-1} F,$$ \hspace{1cm} (21)

and then

$$S_i = \bar{K} \bar{K}^{-1} F.$$ \hspace{1cm} (22)

Equation (22) solves the problem of the external loading distribution between the resistant elements of a building. It is formally analogous to the equation for the distribution of a force between different resistant elements in a plane problem. In fact, the distribution matrix $\bar{K} \bar{K}^{-1}$ is the product of the partial stiffness matrix by the inverse of the total stiffness matrix, as well as in the plane problem the distribution factor is the product of the partial stiffness by the inverse of the total stiffness. The sum of the distribution matrices is equal to the unit matrix.

### 3. COMPUTER PROGRAM “DISTRIB”

A FORTRAN program for the lateral loading distribution between the NTOT bracings of a three-dimensional N-stories building is presented, where NTOT $\leq 20$ and $N \leq 30$. The bracings are shear-walls (open or closed thin-walled cantilevers) and...

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**Fig. 4.** Equivalent shear-wall simulating a frame [11]: $E$ = elastic modulus (or Young modulus) of the material; $GEIB_i$ = flexural inertia of the $i$th beam; $GEIC_i$ = flexural inertia of the $i$th column.
frames. The open thin-walled cantilevers must be consisting of converging plane walls, so that the warping function vanishes. For example, \( L \), \( T \) or cruciform cross-sections are contemplated by the program.

The local coordinate system of the \( i \)th bracing is assumed with the origin in the center of twist \( \zeta_i \) and the \( U_i/V_i \) axes are parallel to the central ones (Fig. 3). Three degrees-of-freedom per floor are considered: translations in \( U_i \) and \( V_i \)-direction of the local system origin and bracing rotation \( \phi \) about the \( W_i \)-axis.

Since the external loadings on the building are supposed to be horizontal and acting at the floor levels, a condensation can be carried out [10] and eqn (13) can be transformed as follows:

\[
\begin{bmatrix}
K_{U,i,CON}^* & O & O \\
O & K_{V,i,CON}^* & O \\
O & O & K_{S,i,j}^*
\end{bmatrix}
\]

Each frame is simulated by an equivalent shear-wall (Fig. 4) [11], which only presents flexural and shear stiffness in the frame plane \( V-W \), i.e. \( K_{U,i,CON}^* \) and \( K_{S,i,j}^* \) are null matrices. Therefore, one shear-wall at least must be present in the considered building.

Then, the program transforms the condensed stiffness matrices from the local coordinate system to the global one and the obtained matrices are summed. In this way, the condensed stiffness matrix \( \bar{K} \) for the NTOT bracings in the global system is obtained (this matrix is called MATK in the program) and system (20) can be solved.

Recalling eqns (7) and (14), it is possible to obtain

\[
\alpha_i^* = B_i T_i \alpha_i,
\]

that is the displacements of the \( i \)th bracing. The product \( B_i T_i \) is called MATROT, while \( \alpha \) and \( \alpha_i^* \) are respectively called ALFA and ALFAAST in the program. Finally, the internal loadings \( S_i^* \) are computed for each bracing:

\[
S_i^* = K_{i,CON}^* \alpha_i^*;
\]

\( S_i^* \) and \( K_{i,CON}^* \) are respectively called SAST and KASTCON in the program.

The Flow Chart of the program "DISTRIB" is shown in Fig. 5, while the "INPUT Data Organization" and the "FORTRAN List" are reported in Appendices 1 and 2.

4. NUMERICAL EXAMPLE

A three-story building is analyzed; its plane is shown in Fig. 6. The building consists of four reinforced concrete bracings and the floor height is 300 cm.

Bracing 1 is a closed thin-walled cantilever with a 15 cm constant thickness. Bracing 2 is an open thin-walled cantilever with a 20 cm constant thickness. Bracing 3 is a two-bay frame: the column cross-section is \( 40 \times 40 \) cm for the upper story and \( 50 \times 50 \) cm for the two lower stories; the beam cross-section is \( 60 \times 24 \) cm. Bracing 4 is different from bracing 3 only because the beam span is 520 cm instead of 450 cm. All the sizes of the building and the global and local coordinate systems are shown in Fig. 6.

The external loading consists of four forces \( F = 15,000 \) kg, one for each floor (see Fig. 6).

The "INPUT Data Format" is shown in the table of Fig. 7 and the "RESULT PRINTOUT" is reported in Appendix 3. The displacements are measured in cm, the rotations in radians, the forces in kg, the moments in kg cm.

REFERENCES

Lateral loading distribution between elements of a three-dimensional civil structure

Fig. 5. Flowchart of the computer program DISTRIB.

Fig. 6. Plane of an example building.
![Table](https://example.com/table.png)

Fig. 7. INPUT Data Format for the considered example (see Fig. 6 and Appendix 1).
APPENDIX I

INPUT Data Organization

I. Master control card [312, F14.4].

<table>
<thead>
<tr>
<th>Columns</th>
<th>Variable</th>
<th>Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>N</td>
<td>Number of storeys</td>
</tr>
<tr>
<td>3-4</td>
<td>NUMS</td>
<td>Number of shear-walls (open or closed thin-walled cantilevers)</td>
</tr>
<tr>
<td>5-6</td>
<td>NUMF</td>
<td>Number of frames</td>
</tr>
<tr>
<td>7-20</td>
<td>H</td>
<td>Floor height</td>
</tr>
</tbody>
</table>

II. Shear-wall input data. Two cards must be supplied for each shear-wall.

(1) Shear-wall properties [F15.4, F5.3, 3 F15.4]

<table>
<thead>
<tr>
<th>Columns</th>
<th>Variable</th>
<th>Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-15</td>
<td>E</td>
<td>Elastic modulus of the material</td>
</tr>
<tr>
<td>16-20</td>
<td>PNI</td>
<td>Poisson ratio of the material</td>
</tr>
<tr>
<td>21-35</td>
<td>GEIU</td>
<td>Flexural inertia of the cross-section about the U-axis</td>
</tr>
<tr>
<td>36-50</td>
<td>GEIV</td>
<td>Flexural inertia of the cross-section about the V-axis</td>
</tr>
<tr>
<td>51-65</td>
<td>GEIT</td>
<td>Torsional inertia of the cross-section (Saint Venant's Theory)</td>
</tr>
</tbody>
</table>

(2) Local coordinate system for the shear-wall [3 F10.5]

<table>
<thead>
<tr>
<th>Columns</th>
<th>Variable</th>
<th>Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>X</td>
<td>X-coordinate (in the global system) of the local system origin</td>
</tr>
<tr>
<td>11-20</td>
<td>Y</td>
<td>Y-coordinate (in the global system) of the local system origin</td>
</tr>
</tbody>
</table>

III. Frame input data. Three card sets must be supplied for each frame.

(1) SC(I), where I = 1, N [8 F10.3]

\[ SC(I) = \sum_{i=1}^{M} \frac{E*GEIC_i}{H}, \]

where E, GEIC_i, and H are related to the M columns under the Ith floor (see Fig. 4).

(2) SB(I), where I = 1, N [8 F10.3]

\[ SB(I) = \sum_{i=1}^{Q} \frac{12*E*GEIB_i}{L_i}, \]

where E, GEIB_i, and L_i are related to the Q = M - 1 beams of the Ith floor (see Fig. 4).

(3) Local coordinate system for the frame [3 F10.5]

<table>
<thead>
<tr>
<th>Columns</th>
<th>Variable</th>
<th>Entry</th>
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<tbody>
<tr>
<td>1-10</td>
<td>X</td>
<td>X-coordinate (in the global system) of the local system origin</td>
</tr>
<tr>
<td>11-20</td>
<td>Y</td>
<td>Y-coordinate (in the global system) of the local system origin</td>
</tr>
</tbody>
</table>

IV. Vector F of the external forces and moments [8 F10.3]. The loads are applied to the global system origin; they are two shears (X-direction and Y-direction forces) and one torsion moment (Z-axis moment) for each floor. The input consists of 3N elements ordered as follows: N forces in X-direction, N forces in Y-direction, N Z-axis torsion moments.

APPENDIX 2

Fortran List

```
program distr(input, output, tape5=INPUT, tape6=output, tape1, tape2,
    tape3, tape4, tape7, tape8, tape9, tape10, tape11, tape12, tape13, tape14,
    tape15, tape16, tape17, tape18, tape19, tape20, tape21, tape23)

! NOTA BENE THE FOLLOWING DIMENSIONS ARE VALID FOR
nota bene ntot less or equal 20
n less or equal 30
```
REAL A(9C,9C),KAB(30,30),KAA(30,30),V(30),KUCON(30,30),KVC~(30,30)
10,3~),KVC~(30,30)
10,3~),MATK(9C,9C),KASTCON(90,90),MATROT(Q"QO),ALOAAST(90
2),SAST(90),SC(30),VX(20),VY(ZO),OMEGA(ZOl
122x661) DIMENSION ITAPE(ZO)
122x654) ITAPE(1)=1
122x647) ITAPE(3)=3
122x640) ITAPE(4)=4
123x625) ITAPE(5)=7
122x618) ITAPE(6)=8
122x611) ITAPE(7)=9
122x603) ITAPE(8)=10
122x596) ITAPE(9)=11
122x589) ITAPE(10)=12
122x582) ITAPE(11)=13
122x575) ITAPE(12)=14
122x568) ITAPE(13)=15
122x561) ITAPE(14)=16
122x554) ITAPE(15)=17
122x547) ITAPE(16)=18
122x540) ITAPE(17)=19
122x533) ITAPE(18)=20
122x526) ITAPE(19)=21
122x519) ITAPE(20)=22
C INPUT DATA PRINTOUT
WRITE(6,8)
8 FORMAT(1H1,45X,17(1H*),1,45X,1H*,15X,1H*,1,45X,174* INPUT DAT
$A *,45X,1H*,15X,1H*,45X,171H*1)
READ(5,10) N,NUMS,NUMF,4
10 FORMAT(3IZ,F14.4)
C INPUT DATA PRINTOUT
WRITE(6,12) N,NUMS,NUMF,H
12 FORMAT(1H1,45X,17(1H*),1,45X,1H*,15X,1H*,1,45X,174* INPUT DAT
$A *,15X,1H*,15X,1H*,45X,171H*1)
READ(5,14) E,PNI,GEIU,GEIV,GEIT
14 FORMAT(F15.4,F5.3,3F15.4)
GU=E*GEIU/(H**3)
GV=E*GEIV/(H**3)
GT=E*GEIT

I = 1/2(1+PNI)

C THE ELEMENTS OF THE MATRIX MATK ARE INITIALIZED
C MATK WILL BE UTILIZED AFTERWARDS (SEE SUBROUTINE KOTAT)
DO 13 J=1,NNN
DO 13 J=1,NNN
13 MATK(I,J)=0.
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Lateral loading distribution between elements of a three-dimensional civil structure

IS LOADED BY HORIZONTAL FORCES IN U-DIRECTION AT THE FLOOR LEVELS

SUBMATRIX A IS OBTAINED BY JOINING KBB AND KBA

SUBMATRIX A

SUBMATRIX KAB

SUBMATRIX KAA

KUCON = (E+GEIV((**3)) * (KAA-KAB*(((KBB)**(-1))**KBA))

I STEP 2 I ((KBB)**(-1))*KAA

GAUSSIAN REDUCTION IS APPLIED

CALL TRIANG(A+N,N,NN)

CONTINUE

CALL SOST(A+N,N,NN)

I STEP 2 I KAB*(((KBB)**(-1))*KBA)

THE RESULT IS MEMORIZED IN THE FIRST N COLUMNS OF KAB

CALL MULTIP(A+KAB+N)

I STEP 3 I (KAA-KAB*(((KBB)**(-1))*KBA))

THE RESULT IS MEMORIZED IN KAA

CALL SOTTR(KAA,KAB+N)

DO 100 J=1,N

100 KUCON(I,J)=GV*KAA(I,J)

AUTOMATIC ELEMENT GENERATION OF KVCON FOR THE GENERIC SHEARWALL

KVCON = CONDENSED STIFFNESS MATRIX IN THE LOCAL COORDINATE SYSTEM FOR THE GENERIC SHEARWALL WHEN THIS IS LOADED BY HORIZONTAL FORCES IN V-DIRECTION AT THE FLOOR LEVELS

I STEP 2 I KAA* KAB

I = STIFFNESS MATRIX IN THE LOCAL COORDINATE SYSTEM FOR THE GENERIC SHEARWALL WHEN THIS IS LOADED BY HORIZONTAL FORCES IN V-DIRECTION AT THE FLOOR LEVELS

DO 105 I=1,N

105 A(I,J)=0.

SUBMATRIX A IS OBTAINED BY JOINING KBB AND KBA

DO 110 I=1,N

110 KAB(I,J)=0.

CALL SOTTR(KAA,KAB+N)

DO 100 J=1,N
DO 115 J=1,N
 115 KAA(I,J)=0.
C     SUBMATRIX A
    A(I,I)=4.
    IF(N.EQ.1) GO TO 128
    DO 120 I=1,NL
       J=I+1
       A(I,J)=2.
 120 A(J,I)=2.
    DO 125 I=1,NL
       J=N+1
    125 A(I,I)=0.
    IF(N.EQ.1) GO TO 138
    DO 130 I=1,NL
       J=I+1
       KAB(I,J)=6.
    130 KAB(J,I)=6.
    IF(N.EQ.1) GO TO 147
    DO 140 I=2,NL
       J=I+1
       KAA(I,J)=12.
    140 KAA(J,I)=12.
C     SUBMATRIX KAB
    KAB(I,1)=0.
    IF(N.EQ.1) GO TO 147
    DO 140 I=1,NL
       J=I+1
    140 KAB(I,J)=6.
    IF(N.EQ.1) GO TO 157
    DO 155 I=2,NL
       J=I+1
       KAA(I,J)=12.
    155 KAA(J,I)=12.
C     SUBMATRIX KAA
    KCON = (E*GEIU/(E**3)) * (KAA-KAB*(KBB)**(-1))*KAA)
C
C CALL TRIANG(A,N,NN)
 157 CONTINUE
C CALL SOST(A,N,NN)
C CALL MQLTIP(A,KAB,V,N)
C CALL SOTTTR(KAA,KAB,N)
    DO 158 J=1,N
       DO 158 I=1,N
       KVCON(I,J)=GU*KAA(I,J)
    158 KVCON(I,J)=GU*KAA(I,J)

C-------------------------------------------------------------------------------
C AUTOMATIC ELEMENT GENERATION OF KETA FOR THE GENERIC SHEARWALL
C KETA = TORSIONAL STIFFNESS MATRIX FOR THE GENERIC SHEARWALL
C-------------------------------------------------------------------------------
DO 160 J=1,N
    KETA(I,J)=0.
    KETA(I,I)=GT*GPNI
    IF(N.EQ.1) GO TO 166
    DO 162 I=2,N
       J=I+1
       KETA(I,J)=GT*(-GPNI)
       KETA(J,I)=KETA(I,J)
    162 KETA(I,J)=GT*(-GPNI)
    164 KETA(I,J)=KETA(I,J)
    164 KETA(I,J)=KETA(I,J)

C-------------------------------------------------------------------------------
C KUCoN, KVCON AND KETA OF THE GENERIC SHEARWALL ARE MEMORIZED ON
C S (VECTORS OF FORCES AND MOMENTS FOR THE GENERIC BRACING) ARE
C COMPUTED FOR EACH BRACING
C-------------------------------------------------------------------------------
WRITE (KTAPE) (KUCON(I,M),L=1,N),
               (KVCON(L,M),L=1,N),
               (KETA(I,M),I=1,N)
C-------------------------------------------------------------------------------

C-------------------------------------------------------------------------------
C THE PROGRAM TRANSFORMS THE CONDENSED STIFFNESS MATRICES FROM THE
C LOCAL COORDINATE SYSTEM TO THE GLOBAL ONE. THEN THE OBTAINED
C MATRICES ARE SUMMED AND MATK IS OBTAINED AT THE END OF DO 185
C TEM FOR THE NUMS SHEARWALLS
C-------------------------------------------------------------------------------

C-------------------------------------------------------------------------------
C READ SOME QUANTITIES LOCATING THE LOCAL COORDINATE SYSTEM OF THE
C GENERIC SHEARWALL
C X,Y = COORDINATES (IN THE GLOBAL SYSTEM) OF THE LOCAL SYSTEM ORIGIN
C-------------------------------------------------------------------------------
Lateral loading distribution between elements of a three-dimensional civil structure

**LATERAL LOADING DISTRIBUTION BETWEEN ELEMENTS OF A THREE-DIMENSIONAL CIVIL STRUCTURE**

**OMEGA** = ANGLE THAT THE X-AXIS OF THE GLOBAL SYSTEM HAS TO ROTATE

**IN ORDER TO ACHIEVE THE U-AXIS OF THE LOCAL SYSTEM**

READ(5,100) VX(K),VY(K),MEGA(K)

180 FORMAT(3F10.5)
X=VX(K)
Y=VY(K)
SNUME=SIND(MEGA(K))
COSME=COSD(MEGA(K))

**INPUT DATA PRINTOUT**

WRITE(6,182) X,Y,MEGA(K)

182 FORMAT(3X,*COORDINATES OF THE LOCAL SYSTEM ORIGIN)
180 FORMAT(3X,*)

X=VX
Y=VY(K)
SINOMEG=SIND(MEGA)
COSOMEG=COSD(MEGA)

**INPUT DATA PRINTOUT**

WRITE(6,182) X,Y,MEGA(K)

182 FORMAT(3X,*)

**NUMS1=NUMS+1**

**KTAPE=KTAPE(K)**

READ THE SC(1) AND SB(1) FOR THE GENERIC FRAME, WHERE 1=1,N

SC1 = SUMMATION OF E*GEIC/H
(E*GEIC/H ARE RELATED TO THE M COLUMNS UNDER THE 1-TH FLOOR)

SB1 = SUMMATION OF 12*E*GEIL/L
(E*GEIL/L ARE RELATED TO THE Q BEAMS OF THE 1-TH FLOOR)

READS(180) SC1, SB1, 1=1,N

190 FORMAT(E10.3)
READ(5,190) SB1, 1=1,N

**INPUT DATA PRINTOUT**

WRITE(6,197) K

197 FORMAT(6(/),2X,3H3N=*,12*,*(FRAME),/2X,13(I1H-1),3X,*SC1), WHERE I=1,N

**I KAA I KAB I**

**KV* I **STIFFNESS MATRIX IN THE LOCAL COORDINATE SYSTEM FOR**

**I KBA I**

**I KAB I**

**I THE GENERIC FRAME (SIMULATED BY AN EQUVALENT SHEARWALL LOADED BY HORIZONTAL FORCES IN V-DIRECTION AT THE FLOOR LEVELS)**

DO 204 I=1,N
DO 264 J=1,NN
204 A(I,J)=.0

**SUBMATRIX A IS OBTAINED BY JOINING KBA AND KRA**

A = I KBA I KRA I

DO 267 I=1,N
DO 270 J=1,N
267 KAA(I,J)=.0

**SUBMATRIX A**

267 KAA(I,J)=.0

**A(I,J)=4*SC1+581**

IF(N.EQ.1) GO TO 225
DO 210 I=1,N
J=1
210 A(J,J)=4*SC1+4*SC(J)+581(J)
DO 220 I=1,N
J=1
220 A(I,J)=2*SC1

**A(I,J)=A(I,J)**

225 A(I,J)=6*SC1(I)/H

**IF(N.EQ.1) GO TO 255**

DO 230 I=1,N
J=1
230 A(I,J)=SC1(I)-SC1(J)/H

**DO 240 I=1,N**

240 A(I,J)=6*SC1(I)/H

**DO 250 I=2,N**
THE PROGRAM CALCULATES THE CONDENSED STIFFNESS MATRIX KCQN IN THE LOCAL COORDINATE SYSTEM FOR THE GENERIC FRAME WHEN THIS IS LOADED BY HORIZONTAL FORCES IN $V$-DIRECTION AT THE FLOOR LEVELS. THE FOLLOWING OPERATIONS ARE ANALOGOUS TO THOSE PREVIOUSLY DONE FOR THE SHKARWALLS. KCQN IS MEMORIZED IN THE SUBMATRIX KAA.

CALL TRIANG(A,N,NN)
CONTINUE
CALL SOLVE(A,N,NN)
CALL MULTIPлик(KAB,V,N)
CALL SOLTRКЕ(KAA,KAB,N)
DO 300 J=1,N
DO 300 I=1,N
KUCON(I,J)=0.
KTETA(I,J)=0.
300 CONTINUE
DO 500 I=1,N
DO 500 J=1,N
KUCON(I,J)*=KAA(I,J)
500 CONTINUE

The program transforms the condensed stiffness matrices from the local coordinate system to the global one. Then the obtained matrices are summed and matrix is obtained at the end of DO 900. In order to achieve the U-AXIS of the local system


READ(5,160) VX(K),VY(K),OMEGA(K)
X=VX(K)
Y=VY(K)
SIND=SIGND(OMEGA(K))
COSD=SIGND(OMEGA(K))
INPUT DATA PRINTOUT
WRITE(6,182) X,Y,OMEGA(K)
CALL ROTAT(SIND,COSD,X,Y,NN,MatK,KUCON,KCON,KTETA)
900 CONTINUE
910 CONTINUE
Lateral loading distribution between elements of a three-dimensional civil structure

---

C

THE SYSTEM MATK* ALFA = F IS SOLVED
C
MATK = CONDENSED STIFFNESS MATRIX IN THE GLOBAL COORDINATE SYSTEM
C FOR THE NTOT BRACINGS
C ALFA = VECTOR OF THE FLOOR DISPLACEMENTS IN THE GLOBAL COORDINATE
C SYSTEM (TRANSLATIONS OF THE GLOBAL COORDINATE SYSTEM ORIGIN
C AND FLOOR ROTATIONS)
C F = VECTOR OF THE KNOWN TERMS. IT IS MEMORIZED IN THE (1N+1)TH
C COLUMN OF THE MATRIX MATK
NNN+3*N+1
READ(5,1111) (MATK(I,J),NNNN),I=1,NNN
1111 FORMAT(8F10.3)
C INPUT DATA PRINTOUT
WRITE(6,1112) NTOT
1112 FORMAT(8X,VECTOR F OF THE KNOWN TERMS, I.E. EXTERNAL FORCES
SAND MOMENTS TO DISTRIBUTE BETWEEN THE *12# BRACING*12#
DO 1120 I=1,NTOT
WRITE(6,1113) I,MATK(I,NNNN)
1113 FORMAT(15X,3HFXC,I2,3HE12.5)
1120 CONTINUE

N+1 #
WRITE(6,1125) I,MATK(I,NNNN)
1125 FORMAT(15X,3HFYC,I2,3HE12.5)
N+1 #
WRITE(6,1135) I,MATK(I,NNNN)
1135 FORMAT(15X,3HM(C,I2,3HE12.5)
N+1 #
WRITE(6,1145)
1145 FORMAT(15X,130(1H))
C RESULT PRINTOUT
WRITE(6,1150)
1150 FORMAT(15X,45X,12,15H$)

C ALFAAST IS COMPUTED FOR EACH BRACING ALFAAS = MATROT * ALFA
C ALFAAS = ALFA ASTERISK = VECTOR OF THE DISPLA~EMENTS IN THE LOCAL
C COORDINATE SYSTEM (TRANSLATIONS OF THE LOCAL COORDINATE
C SYSTEM ORIGIN AND ROTATIONS)
C MATROT = ROTATION MATRIX
C
C SAST IS COMPUTED FOR EACH BRACING SAST = KASTCON* ALFAAS
C SAST = VECTOR OF THE FORCES AND MOMENTS IN THE LOCAL COORDINATE
C SYSTEM
C KASTCON = CONDENSED STIFFNESS MATRIX IN THE LOCAL COORDINATE
C SYSTEM FOR THE GENERIC BRACING
DO 4444 K=1,NTOT
WRITE(6,2000) K
2000 FORMAT(15X,15H$)

C THE ELEMENTS OF THE MATRIX KASTCON ARE INITIALIZED
DO 2215 J=1,NNNN
DO 2215 I=1,NNNN
2215 KASTCON(I,J)=0.

X=VX(K)
Y=VY(K)
SINOMEG=SIND(Omega(K))
COSOME=COSD(Omega(K))
WRITE(6,2222) X,Y,Omega(K)
2222 FORMAT(5X,5X,5X,5X,5X,$$F12.5,5X,5X,3H$)
CALL MATR0S(X,SINOMEG,COSOME,X,Y,MATROT)
CALL MULT(MATROT,MATK,ALFAAST,NNNN)
KTAPE=ITAPE(K)
READ KTAPE ((KÜCON(I,J)),I=1,N),J=1,N),((KVCÖN(I,J)),I=1,N),J=1,N)
$((KTÉTA(I,J)),I=1,N),J=1,N)
DO 2224 J=1,J
DO 2223 I=1,J
KASTCON(I,J)=KÜCON(I,J)
2223 CONTINUE
CALL MULT(KASTCON,ALFAAST,SAST,NNNN)
WRITE(6,3330) K
3330 FORMAT(15X,15H$)

C 3330 FORMAT(15X,15H$)
DO 3335 I=1,J
DO 3335 J=1,J
WRITE(6,3333) I,SAST(I)
3333 FORMAT(15X,$$F12.5,15H$)
3335 CONTINUE
DO 3344 J=1,J
J=J+1
WRITE(6,3338) I,SAST(I)
3338 FORMAT(1X,20X,3HSV(+,12,3H) =,E12.5)
3340 CONTINUE
      DO 3345 I=1,N
      J=I+NN
      WRITE(6,3343) I,SAST(J)
3343 FORMAT(/,20X,3H MI,12,3H) ·,EI7..5)
3345 CONTINUE
4444 CONTINUE
      GO TO 5000
C
4460 WRITE(6,4462)
4462 FORMAT(1H1,///,9X,*INPUT DATA ERROR*,9X,N IS GREATER THAN 20*)
4465 WRITE(6,4467)
4467 FORMAT(1H1,///,9X,*INPUT DATA ERROR*,9X,*NUMS = 0*,/,
5H34Y,*THE FRAMES ARE SIMULATED BY BRACINGS WITHOUT
6H34Y,*TORSIONAL STIFFNESS*,/34Y,*A
7H34Y,*END THEREFORE NUMS HAS TO BE DIFFERENT FROM 0*)
4466 WRITE(6,4468)
4468 FORMAT(1H1,///,9X,*INPUT DATA ERROR*,9X,*NTOT (TOTAL NUMBER OF BRA
5HCS) IS GREATER THAN 20*)
5000 CONTINUE
STOP
END
SUBROUTINE TRIANG(A,N,NN)
REAL A(90,91)
NZ=N-1
DO 1 K=1,N2
K1=K+1
DO 2 I=1,N
C=(I+K)/A(K,K)
2 CONTINUE
1 CONTINUE
RETURN
END
SUBROUTINE SOST(A,N,NN)
REAL A(90,91)
N1=N+1
N2=N-1
DO 10 J=N1,NN
A(N,J)=A(N,J)/A(N,N)
10 CONTINUE
DO 20 I=1,N
I1=I+1
DO 30 J=I1,N
A(I,J)-A(I,J)/A(I,I)
30 CONTINUE
20 CONTINUE
RETURN
END
SUBROUTINE SOTTR(KAA,KAB,N)
REAL KAA(30,30),KAB(30,30)
DO 1 I=1,N
DO 2 J=1,N
KAA(I,J)-KAA(I,J)+KAB(I,J)
2 CONTINUE
RETURN
END
SUBROUTINE ROTAT(SINOMEG,COSOMEG,X,Y,N,NN,MATK,KUCON,KVCON,KTETA)
REAL MATK(90,91),KUCON(30,30),KVCON(30,30),KTETA(30,30)
SINSIN=SINOMEG**2
COSCOS=COSOMEG**2
SINCOS=SINOMEG*COSOMEG
DO 10 J=1,N
10 CONTINUE
DO 20 I=1,N
MATK(I,J)-MATK(I,J)+SINCOS*KUCON(I,J)+SINSIN*KVCON(I,J)
20 CONTINUE
DO 30 J=1,N
M=J+N
DO 40 I=1,N
MATK(I,M)-MATK(I,M)+SINCOS*KUCON(I,J)+SINSIN*KVCON(I,J)
40 CONTINUE
30 CONTINUE
DO 50 J=1,N
M=J+N
DO 60 I=1,N
MATK(I,J)-MATK(I,J)+(SINCOS*X-COSCOS*Y)*KUCON(I,J)+(STCOS*X+SINS
1H)*KVCON(I,J)
60 CONTINUE
50 CONTINUE
DO 70 J=1,N
M=J+N
DO 80 I=1,N
L=I+N
70 CONTINUE
80 CONTINUE
RETURN
END
Lateral loading distribution between elements of a three-dimensional civil structure

120 MATK(L,M)*MATK(L,M)+SINSIN*KUCON(I,J)+COSCOS*KUCON(I,J)
130 CONTINUE
DO 160 J=1,N
M=N+NN
DO 150 I=1,N
L=I+NN
MATK(L,M)=MATK(L,M)+(SINSIN*X+COSCOS*Y)*KUCON(I,J)+(SINSIN*X+COSCOS*Y)*KVCN(I,J)
150 CONTINUE
160 CONTINUE
DO 180 J=1,N
M=N+NN
DO 170 I=1,N
L=I+NN
MATK(L,M)=MATK(L,M)+(X+SINOMEG*Y+COSOMEG*Z)*KUCON(I,J)+(X+COSOMEG*Y+SINOMEG*Z)*KVCN(I,J)+KTETA(I,J)
170 CONTINUE
180 CONTINUE
RETURN
END

SUBROUTINE SUBRTIN(A,N,M)
REAL A(90,91)
N1=N+1
N2=N-1
DO 100 J=N1,N
A(N,J)=A(J,N)
100 CONTINUE
DO 200 K=1,N2
I=N-K
II=I+1
DO 300 J=1,N
DO 400 K=1,N1
400 A(I,J)=A(I,J)+A(J,J)*A(K,J)
300 CONTINUE
DO 500 L=1,N1
500 A(I,J)=A(I,J)+A(I,J)*A(L,J)
500 CONTINUE
WRITE(6,700)
700 FORMAT(6(1,10X,VECTOR OF THE FLOOR DISPLACEMENTS IN THE GLOBAL COORDINATE SYSTEM*,10X,TRANSLATIONS OF THE GLOBAL COORDINATE SYSTEM ORIGIN AND FLOOR ROTATIONS,1*,/)
N1=N/3
N2=N1*2
DO 720 I=1,N3
WRITE(6,710) A(I,N3)
710 FORMAT(15X,TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER *,I2,5,2H4=EI2.5)
720 CONTINUE
DO 740 L=1,N3
J=I+N1
WRITE(6,730) A(J,N3)
730 FORMAT(15X,TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER *,I2,2H4=EI2.5)
740 CONTINUE
DO 760 L=1,N3
J=I+N32
WRITE(6,750) A(J,N32)
750 FORMAT(15X,ROTATION FOR THE FLOOR NUMBER *,I2,2H4=EI2.5)
760 CONTINUE
RETURN
END

SUBROUTINE MULRTP(A,KAB,V,N)
REAL A(90,91),KAB(30,30),V(30)
DO 3 J=1,N
DO 1 J=1,N
JN=N
3 CONTINUE
40 DO 2 K=1,N
2 KAR(I,K)=V(I)+KAB(K,J)*A(I,K)
2 CONTINUE
RETURN
END

SUBROUTINE MATROIN,SIN8MEG,COSOMEG,X,Y,MATROT)
REAL MATROT(90,90)
NN=NN+1
DO 10 J=1,NN
DO 15 I=1,NN
15 CONTINUE
10 CONTINUE
DO 20 J=1,NN
20 CONTINUE
DO 30 J=1,NN
30 CONTINUE
RETURN
END
APPENDIX 3

Result printout

Bracing Number 1

X = 600.000000  Y = 150.000000  OMEGA = 0.000000

VECTOR OF THE DISPLACEMENTS IN THE LOCAL COORDINATE SYSTEM
(TRANSLATIONS OF THE LOCAL COORDINATE SYSTEM ORIGIN AND ROTATIONS)

TRANSLATION IN U-DIRECTION FOR THE FLOOR NUMBER 1 • .79888E-04
TRANSLATION IN U-DIRECTION FOR THE FLOOR NUMBER 2 • .41241E-02
TRANSLATION IN U-DIRECTION FOR THE FLOOR NUMBER 3 • .61495E-03
TRANSLATION IN V-DIRECTION FOR THE FLOOR NUMBER 1 • .44895E-01
TRANSLATION IN V-DIRECTION FOR THE FLOOR NUMBER 2 • .26903E-01
TRANSLATION IN V-DIRECTION FOR THE FLOOR NUMBER 3 • .41910E-02
ROTATION FOR THE FLOOR NUMBER 1 • .51997E-04
ROTATION FOR THE FLOOR NUMBER 2 • .26940E-04
ROTATION FOR THE FLOOR NUMBER 3 • .79594E-05

VECTOR OF THE FORCES AND MOMENTS IN THE LOCAL COORDINATE SYSTEM FOR THE BRACING NUMBER 1

SUE 1 • 4.90001E+04
SUE 1 • 1.70315E+04
SUE 1 • 1.94609E+04
Lateral loading distribution between elements of a three-dimensional civil structure

VECTORS OF THE FORCES AND MOMENTS IN THE LOCAL COORDINATE SYSTEM FOR THE BRACING NUMBER 2

<table>
<thead>
<tr>
<th>SVI 1</th>
<th>SVI 2</th>
<th>SVI 3</th>
<th>MI 1</th>
<th>MI 2</th>
<th>MI 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10325E+04</td>
<td>0.28896E+04</td>
<td>0.32942E+04</td>
<td>-0.15077E+05</td>
<td>-0.3482E+04</td>
<td>-0.70054E+04</td>
</tr>
</tbody>
</table>

VECTORS OF THE DISPLACEMENTS IN THE LOCAL COORDINATE SYSTEM

<table>
<thead>
<tr>
<th>Translation in U-direction for the floor number 1</th>
<th>Translation in U-direction for the floor number 2</th>
<th>Translation in U-direction for the floor number 3</th>
<th>Translation in V-direction for the floor number 1</th>
<th>Translation in V-direction for the floor number 2</th>
<th>Translation in V-direction for the floor number 3</th>
<th>Rotation for the floor number 1</th>
<th>Rotation for the floor number 2</th>
<th>Rotation for the floor number 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10325E+04</td>
<td>0.28896E+04</td>
<td>0.32942E+04</td>
<td>-0.15077E+05</td>
<td>-0.3482E+04</td>
<td>-0.70054E+04</td>
<td>-0.51575E-04</td>
<td>-0.26696E-04</td>
<td>-0.15656E-05</td>
</tr>
</tbody>
</table>

VECTORS OF THE FORCES AND MOMENTS IN THE LOCAL COORDINATE SYSTEM FOR THE BRACING NUMBER 3

<table>
<thead>
<tr>
<th>SVI 1</th>
<th>SVI 2</th>
<th>SVI 3</th>
<th>MI 1</th>
<th>MI 2</th>
<th>MI 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

VECTORS OF THE DISPLACEMENTS IN THE LOCAL COORDINATE SYSTEM

<table>
<thead>
<tr>
<th>Translation in U-direction for the floor number 1</th>
<th>Translation in U-direction for the floor number 2</th>
<th>Translation in U-direction for the floor number 3</th>
<th>Translation in V-direction for the floor number 1</th>
<th>Translation in V-direction for the floor number 2</th>
<th>Translation in V-direction for the floor number 3</th>
<th>Rotation for the floor number 1</th>
<th>Rotation for the floor number 2</th>
<th>Rotation for the floor number 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>
VECTOR OF THE DISPLACEMENTS IN THE LOCAL COORDINATE SYSTEM

TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 1 = -44948E+09
TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 2 = -79990E+09
TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 3 = -91977E+09
TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 1 = -60792E+08
TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 2 = -41779E+09
TRANSLATION IN X-DIRECTION FOR THE FLOOR NUMBER 3 = -17491E+09

ROTATION FOR THE FLOOR NUMBER 1 = -55757E+04
ROTATION FOR THE FLOOR NUMBER 2 = -26678E+04
ROTATION FOR THE FLOOR NUMBER 3 = -75658E+05

VECTOR OF THE FORCES AND MOMENTS IN THE LOCAL COORDINATE SYSTEM FOR THE TRACING NUMBER 4

SU 1 = 0.
SU 2 = 0.
SU 3 = 0.
SVI 1 = -47003E+03
SVI 2 = -14075E+02
SVI 3 = -17952E+03
M1 1 = 0.
M2 1 = 0.
M3 1 = 0.

CONDENSED STIFFNESS MATRIX IN THE GLOBAL COORDINATE SYSTEM FOR THE NDST TRACTIONS (NDST = 4)

VECTORS OF THE FLOOR DISPLACEMENTS IN THE GLOBAL COORDINATE SYSTEM

TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 1 = -15773E+01
TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 2 = -74212E+02
TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 3 = -17974E+09
TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 1 = -60792E+08
TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 2 = -41779E+09
TRANSLATION IN Y-DIRECTION FOR THE FLOOR NUMBER 3 = -17491E+09

ROTATION FOR THE FLOOR NUMBER 1 = -55757E+04
ROTATION FOR THE FLOOR NUMBER 2 = -26678E+04
ROTATION FOR THE FLOOR NUMBER 3 = -75658E+05