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OPTIMUM DESIGN OF STATICALLY INDETERMINATE FRAMES BY MEANS OF NON–LINEAR PROGRAMMING (PROGRAM DESCRIPTION)

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Optimum Design
of
Statically Indeterminate Frames
by Means of
Nonlinear Programming

(Program Description)

by

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LIST OF CONTENT

1. INTRODUCTION

This report contains a description of the program which was prepared in connection with the study described in the following report

Moe, J.:
"Optimum Design of Statically Indeterminate Frames by Means of Nonlinear Programming", Department of Ship Structures, The Technical University of Norway. Meddelelse SKB II/M12, Trondheim, 1968.

This report is in the following referred to as "reference |1|".

2. PROGRAM DESCRIPTION

A. Description of the Main Program

The main program contains the following three alternative branches (see flowchart in Fig. 1).

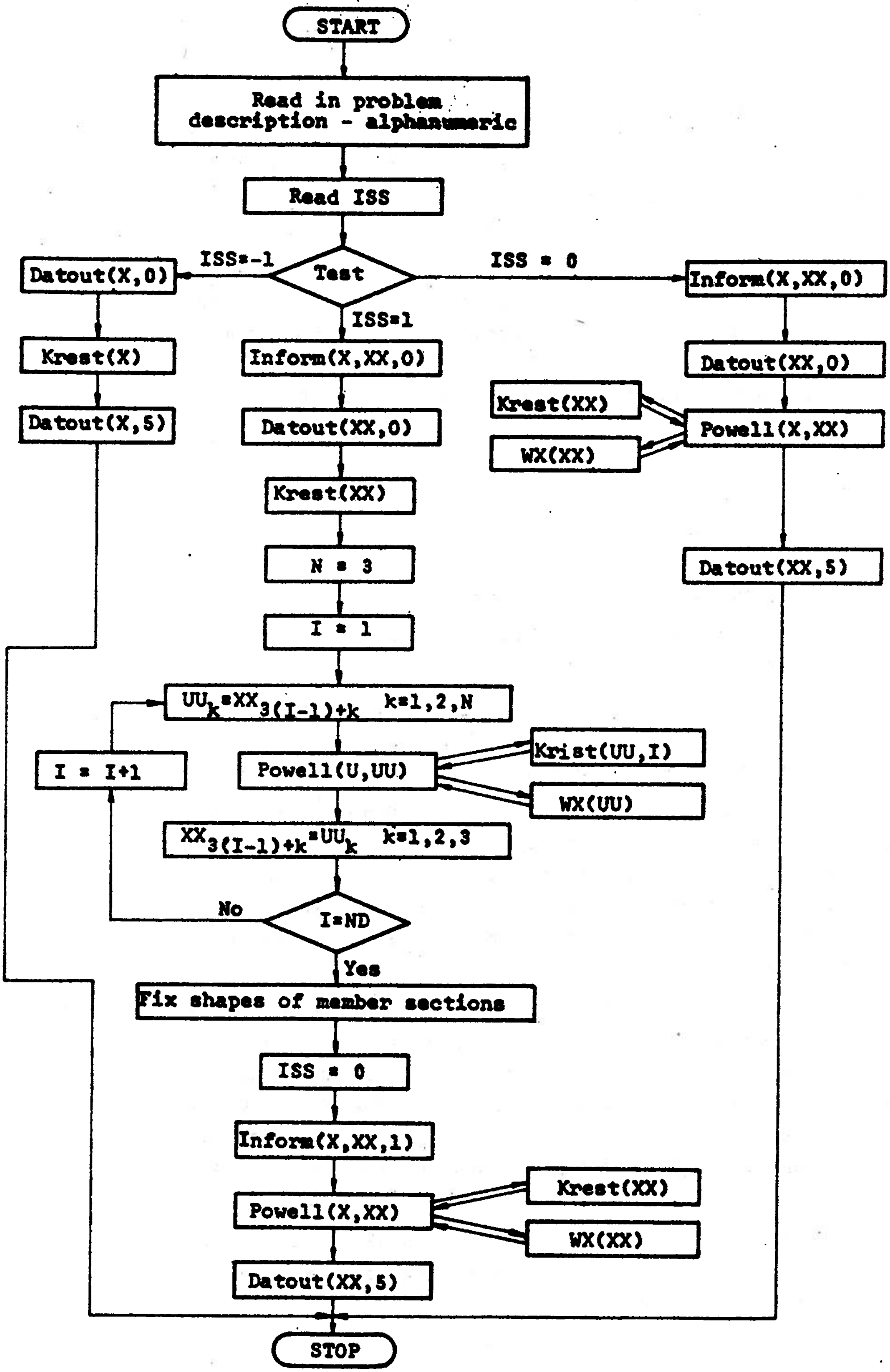
A. Ordinary frame analysis (ISS = -1, see flowchart)
B. Frame optimization - normal mode (ISS = 0)
C. Frame optimization - two-stage mode (ISS = 1)

The program handles two-dimensional frames with three degrees of freedom at each node (k = 3) as well as continuous beams on fixed supports with one degree of freedom at each node (k = 1). In the latter case the angular displacements of the beams at the supports are treated as the unknowns in the analysis.

In branch B all of the variables are optimized simultaneously through the entire search process. This approach tends to require much computer time when the number of design variables is, say, more than ten. Branch C represents a procedure which more nearly corresponds to the approach taken by an experienced designer, and involves the following steps:

a) First a set of initial values for all of the design variables is read in. (This is also done in the two other branches.)

Fig. 1 Flowchart for Main Program



b) A complete frame analysis is carried out.

c) A series of suboptimizations are now performed, in which the variable cross-sectional properties for each of the member types are optimized without changing the force distribution.

d) The cross-sectional shape of each member is next fixed, and only one quantity representing the size of the cross-section is maintained as variable in the final search for optimum, which involves reanalyses of the structure whenever required, see Section B.

In the following the functions of each of the subroutines shown in Fig. 1 are briefly described.

Inform — is reading in the information related to the search for the optimum as explained in Section 4.

Datout (X,0) — reads in the necessary information about the structure to be optimized (or analyzed) and its loadings. A special subroutine (Loadin) is called by Datout to process member load input. If the second argument (zero) is replaced by a positive integer, this routine performs the output of problem-related results, such as dimensions, stresses, etc. Information related to the searching process are written by Powell, see below.

Krest (X) — This routine is described in detail in Section B. Its function is to perform the required analyses of the structure and compute the current values of the constraints.

Krist(UU,I) — replaces Krest when the search for local optima is performed, i.e. during the optimization of the member cross-sections. The second argument (I) denotes which member type is currently being optimized. Krist computes the constraint values for all members of type I while disregarding changes in the force distribution caused by changes in the variables.

Powell(X,XX) is the subroutine which performs the search for optimum by means of Powell's method of direct search.

W(X) is a function subprogram which evaluates the object function. In the present case the object function is simply portraying the weight of the structure. The effect of web stiffeners has been included qualitatively.

B. Description of Subroutine Krest(X)

This subroutine performs the required analyses of the structure and calculates the values of the restrictions (g_i). A flowchart for this subroutine is shown in Fig. 2. In the following we shall present a short description of each of the subroutines used by Krest(X).

Assign

This routine produces the following member properties matrices

Flange areas	AF(I)	I = 1, ... M
Web areas	AW(I)	I = 1, ... M
Beam heights	HL(I)	I = 1, ... M

where

M = total number of beams.

An assignment vector JM is used during the derivation of the above mentioned properties from the vector (X) of design variables.

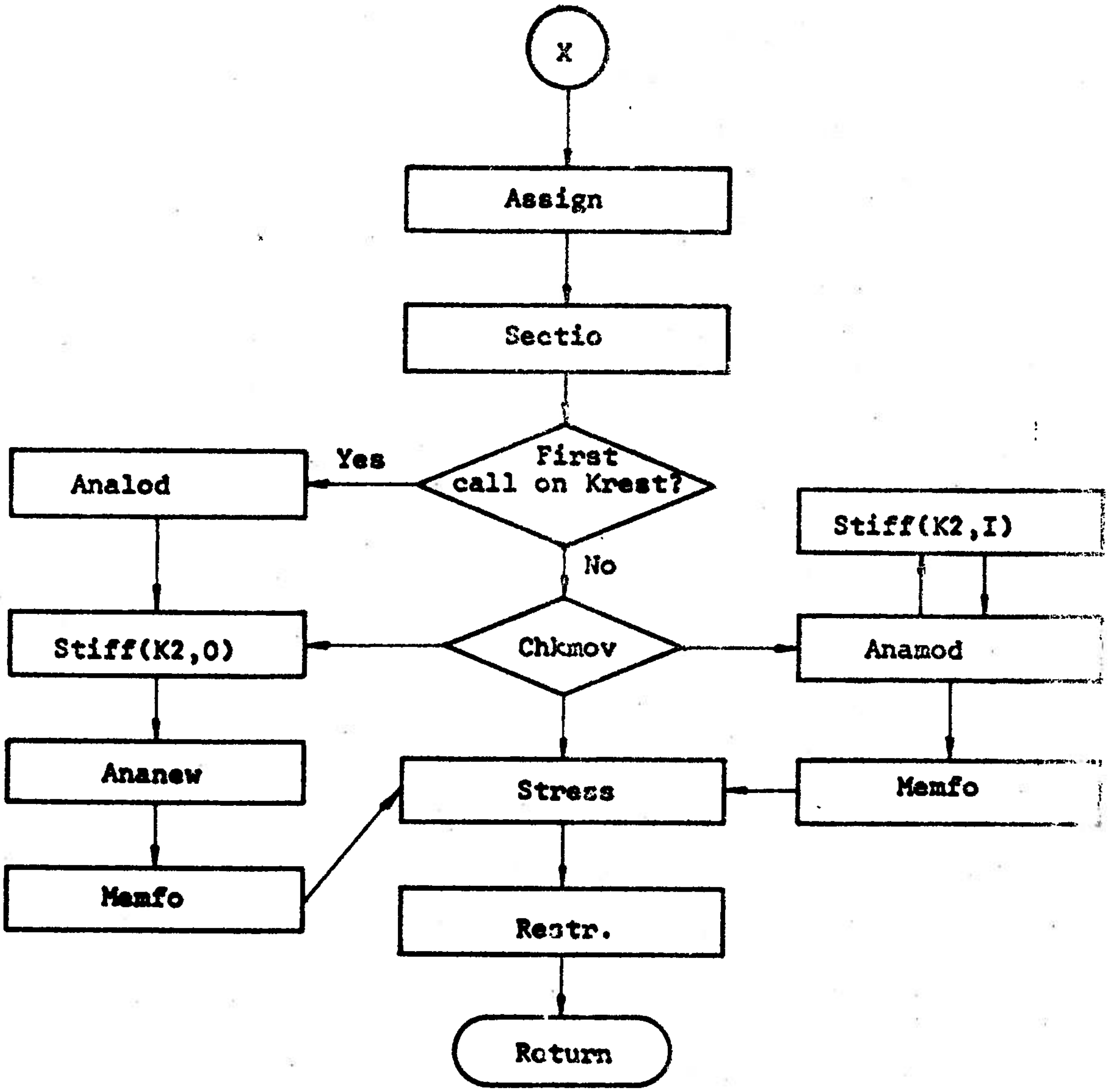
Sectio

This routine produces areas, moments of inertia and section moduli for all of the beams and places these member properties in Common.

Analod

This routine, which is only called during the first

Fig. 2 Flowchart for
Subroutine Krest(X)



call on Krest, transforms fixed end forces (calculated in subroutine Loadin) into unbalanced nodal point loads and adds these to the direct loads on the nodal points.

<u>Chkmov</u>

This routine directs a branching between three alternative routes of redesign, involving

a) Complete reanalysis including new inversion of the stiffness matrix K_r (Ananew).

b) Approximate reanalyses of the structure without new inversion of the stiffness matrix (Anamod).

c) No reanalysis of the statically indeterminate system (direct move to Stress).

The values of the design variables at the time of the previous complete analysis are stored in the array OLANAL while the current values are stored in X.

Ananew is called if one of the following three conditions are met:

1) A new response surface has just been selected

2) STEP(I) = $|\{X(I)-OLANAL(I)\}/OLANAL(I)| > \varepsilon_1$ for any one value of I, where I = 1, 2, ... N

3) $\sum_{I=1}^{N} STEP(I)^2 > \varepsilon_2$

Controll is transfered directly to Stress if

$$|STEP(I)| < \varepsilon_3 \quad \text{for all I,} \quad I = 1, \ldots N$$

In all cases except those listed above Anamod is called.

A list is created of all the members for which at least one of the design variables has been changed more than ε_3. This list is stored in Common (Array JK).

<u>Stiff</u>(K2,IK)

This routine calculates the stiffnesses of the frame members and produces the stiffness matrix k_i.

If k = 1 (the value K2 will then be 2), the k_i-matrix will be of dimension 2x2 corresponding to the case of a beam on fixed supports with no axial loads considered.

If k = 3 (K2 = 6), the k_i-matrix will be 6x6, and correspond to the general case in two-dimensional frame analysis.

Shear deflections have not been included. All beams have been assumed to be prismatic with uniform cross-sections.

If IK = 0, the stiffness matrices for all of the frame members are calculated and placed in Common (SKI).

If IK > 0, only the stiffness matrix of member number IK is calculated.

Ananew

This routine assembles the main stiffness matrix K from the member stiffness matrices k_i by the procedure indicated by Eq. (I.18) of reference |1|. The stiffness matrix is next rearranged to take into account the support conditions, reduced and inverted. The nodal point displacements are computed by means of Eq. (I.25) and the array of nodal point displacements is rearranged again as outlined in Appendix I of reference |1|. The displacement array (DISPL) is placed in Common.

All matrix operations are performed by means of System/360 Scientific Subroutine Package (360 A-CM-03X) Version II. This applies also to the matrix inversion.

Anamod

This routine calculates the changes (dk_i) in the stiffness matrices of all members that are listed in the JK-array (see under Chkmov). Next, the change (dK) in the main stiffness matrix is evaluated by means of a procedure similar to that outlined for the generation of K. But the summation of contributions to dK only includes those members which have been changed.

The matrix dK is rearranged to account for support conditions, and an approximate value for $(K + dK)^{-1}$ is calculated by means of the formula (12) of reference |1|. A new displacement vector is finally derived as outlined for Ananew.

<u>Memfo</u>

This routine calculates the resulting member end forces by means of Eqs. (I.27 and 28) of reference |1|.

<u>Stress</u>

Axial stresses (σ_x) due to bending combined with axial forces are calculated for six different points of each member, as shown in Fig. 3. Tensile stresses are positive. The position x_o is taken at the point of zero shearing force if the beam is transversely loaded, otherwise $x_o = \ell/2$. If the axial force is not equal in magnitude at both ends of the member it is assumed to vary linearly. Shearing stresses are calculated at both ends of each member. The following approximate formula is used

$$\tau = Q/A_w$$

For each member the maximum positive and negative axial stress as well as the numerically largest shearing stress are found, considering all loading cases. These values are stored in the arrays SIGMAX, SIGMIN and TAUMAX, respectively.

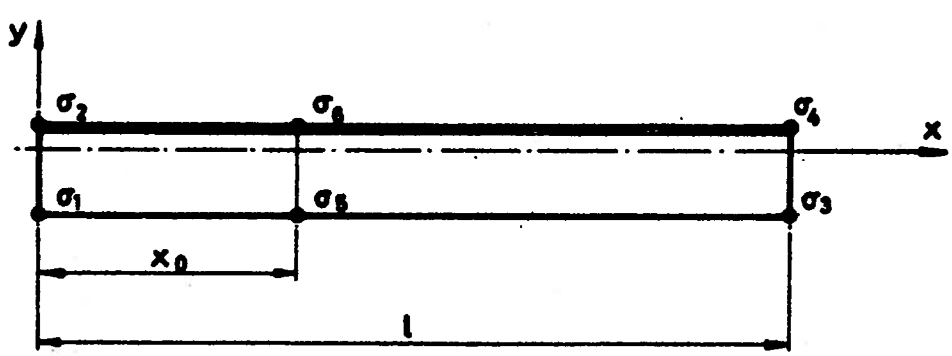


FIG. 3 Locations of points at which stresses are checked

Restr

The following stress related restrictions are imposed.

$$\text{Rest}\ (J) = (1 - \sigma_{max}/\sigma_{all\cdot t})_J$$

$$\text{Rest}\ (J+M) = (1 - \sigma_{min}/\sigma_{all\cdot c})_J$$

$$\text{Rest}\ (J+2M) = (1 - \tau_{max}/\tau_{all})_J$$

where

J = 1, ... M

$\sigma_{all\cdot t}$ = maximum allowable stress in tension

$\sigma_{all\cdot c}$ = maximum allowable stress in compression

τ_{all} = maximum allowable stress in shear

In addition an upper limit on the ratio of height to thickness (H/t_w) of the web may be imposed. This upper limit may be specified in the input, but is otherwise by default set equal to 100.

3. INPUT MANUAL AND EXAMPLE

A. Two-Stage Mode of Optimization

The following description covers the input for the two-stage mode of optimization described in Section 2. At the end of this section is a list of the modifications required if one of the other two branches in the main program is used.

Read by Main Program

Cards 1, 2 — Format (20A4)
Title cards with alphanumeric text, to be stated at the top of the output (NB! 2 cards)

Card 3 — Format (I5)
Parameter ISS directing branching in the main

program:
-1 ordinary frame analysis
 1 two-stage mode of optimization
 0 normal mode of optimization

Read by Inform

Card 4 Format (16I5)
Information concerning the optimization procedure.

Col. 1- 5 Total number of free variables (N = 3ND)

6-10 Total number of inequality constraints (NC = 3M+ND+N).
The following columns of this card concern the local optimization of the cross-sections of the different member types:

11-15 Number of response surfaces (NOPT)

16-20 Maximum number of search cycles for the first response surface (NMAX). After completing the search along the first surface, NMAX is automatically divided by 2.

21-25 Maximum number of search for minimum along each direction (Fibonacci-mode)(NGOLD).

26-30 Control parameter for desired amount of output (MA)

Parameter:	Output:
13	Only final minimum point together with values of object function and restrictions in this point.
11	The values listed above for each response surface.
9	In addition: Starting values of the variables and the object function for each cycle.
7	In addition: Number of trials in boxing-process as well as Fibonacci search.(Golden Section Search).
6,4,2,1	Increasing amount of output.

Col.31-35 Number of equality constraints.

36-40 Decides whether the search is to be performed with built in parameters (INNL).

0: Built in parameters as listed in Section D of this chapter. In this case columns 11-15 should contain a number < 5

1: Search parameters are to be read in.

-1: Also the initial search vector is to be read in.

41-45 Parameter that controls search for feasible starting point (MM).

-1: Computation stops if starting point is unfeasible.

0: Search for feasible starting point is automatically performed.

K: In the search for feasible starting point the K-th restriction is made positive first.

46-50 Parameter that makes it possible to jump from one to the following response surface if the object function increases while the total function is minimized (NRED).

1: If the object function has increased after the first cycle, the starting point is maintained while the response factor is reduced one step.

0: Such increase in the object function causes no interference with the regular search.

51-55 Some of the variables may be fixed during the search for optimum.

0: All of the variables are free. Data card 6 is omitted.

NA: Total number of variables including those which have fixed values.

56-60 Parameter (IS) that decides whether the search is to be started out along

0: the coordinate axes, or

1: along the vector SS and vectors orthogonal to SS. The vector SS is in the program put equal to {1,1 ... 1} except when read in (-1 in col. 36-40 og this card). In the latter case SS must not be selected as a unit vector along any one of the coordinate axes.

Card 5 — Format (8F10.2)
Vector SS along which to start the search (read only if col. 36-40 on card 4 contains -1).

Card 6 — Format (60I1)
Vector listing fixed and free variables. In columns 1-NA is written
0: for every free variable
1: for every fixed variable.
This card is read only if NA>N (see card 4).

Card 7 — Format (8Flo.2)
Starting values of the variables are read in the following sequense: $(AW, AF, HL)_1$, $(AW, AF, HL)_2$ .... $(AW, AF, HL)_{ND}$

Card 8[x)] — Format (8F10.2)
Scaling factors for the variables, one for each free variable. If this card contains the same numerical values as the previous card, the scaled variables will all become 1.0 at the starting point.

Card 9[x)] — Format (8F10.2)
Initial step lengths (LAMX) in the search procedure, one value for each free variable.

Card 10[x)] — Format (8F10.2)
Initial convergency criteria GAMMA, one for each variable, applies to the first response surface.

[x)] This card is only read if INNL = 1, see columns 36-40 on card 4.

Card 11[x)] Format (8E10.2)

Col. 1-10 Convergency criterium for Golden Search (EPI)

11-20 Minimum acceptable value for each constraint (E1).

21-30 Coefficient that sharpens the convergency criterion for each new response surface (RED).

31-40 Coefficient that reduces the initial step length for each new response surface (REDL)

Card 12[x)] Format (8F10.2)

Coefficients by which the response factor is reduced for each new response surface. If the values read in are a_1, a_2, a_3... the response values will be $r_1 = 1/a_1$, $r_2 = r_1/a_2$, $r_3 = r_2/a_3$... respectively.

Read by Datout and Loadin

Card 13 Format (10I4)

Col. 1- 4 Number of members in the frame ($M \leq 30$)

5-8 Number of joints in the frame ($JO \leq 30$)

9-12 Degrees of freedom for each joint ($k \leq 3$)

13-16 Number of different beam cross-section types ($ND \leq 13$)

17-20 Index controlling analysis of loadings, should always be 0 (IP = 0).

21-24 Number of nonzero terms (IQ) in the a-matrix, see Eq. (I.11).

25-28 Number of separate loading conditions ($LL \leq 5$)

29-32 Number of zero displacement conditions at supports ($LLS \leq 20$).

33-36 Number of cards (NLB) with information about lateral loads on the frame member, see following.

37-40 Number of cards (NLNP) with information about nodal point loads (see following).

[x)] See footnote previous page.

Cards 14→K_1 (K_1=M+13) — Format (2I4, F10.3, I4, 2F10.3, 2I4)
For each member of the frame one card with the following information is required:

Col. 1- 4 Member number

5-8 Type number of the cross-section

9-18 Length of member

19-22 Index describing cross-sectional form (See Fig. I.3 of reference |1|)

-1: Unsymmetric cross-section with plate area on the negative side of the neutral axis.

0: Symmetric cross-section

1: Unsymmetric cross-section with plate flange on the positive side.

23-32 Area of plate flange (set to zero for symmetric cross-sections).

33-42 Maximum permissible ratio of beam height (H) to thickness of the web (t_w). If no value is stated explicitly the ratio H/t_w is required to be less than 100.

43-46 Number of node at member start

47-50 Number of node at member end.

Cards (K_1+1)→K_2 — All nonzero elements in the a-matrix (Eq. I.11 of reference |1|) are read in by means of a namelist statement. The name-list name is DAT.

1) The first card in this group should have the four characters "&DAT" in columns 2-5

2) Next follows the necessary number of cards to contain all the nonzero elements of a, which are listed as follows:
$A(i_1, j_1, k_1)$ =n.nn, $A(i_2, j_2, k_2)$=m.mm
and so forth, where
i = member displacement number. (See Fig. I.1 of reference |1|).
j = node displacement number
k = member number

Note that the node displacements must be numbered as described in Appendix I of reference |1|. Each card may contain as many elements of the matrix as space permits.

3) The last card in this group contains only the four characters "&END", which are punched in columns 2-5.

Card K_2+1 — Format (20I4)

This card contains the vector of zero displacement conditions (ISUP(I)). Note that this vector must be ordered as a row of decreasing numbers: ISUP(1) > ISUP(2) >...

Card K_2+2 — Format (3F8.3, 3F8.0)

Col. 1- 8	Maximum relative change in any one design variable without requiring complete new analysis (ε_1). (See description of Chkmov in Section 2).
9-16	Maximum relative change in the vector of variables without requiring complete new analysis (ε_2).
17-24	Maximum admissible relative change in variables without reevaluating force distribution (ε_3).
25-32	Maximum allowable tensile stress.
33-40	Maximum allowable compressive stress (negative).
41-48	Maximum allowable ahearing stress.

Card (K_2+3)+K_3 (K_3=(K_2+2)+NLB) — Format (4I4, 8F8.2)

These cards (NLB in number, see card number 13) supply all data concerning loads on the members. (Joint loads are treated separately below.) Each card is prepared as follows:

Col. 1- 4	Member number (MEM)
5- 8	Loading condition number (LOC)
9-12	Code denoting type of loading. (See Table I.1 of reference |1| (IND)).

Col.13-16 Number of load values specified on this card. (See Table I.1 of reference |1| (NOL)).

17-24 First load value

25-32 Second load value if more than one has to be stated. (See Table I.1 of reference |1|).

33-40

41-48 Following all load values eventually comes the list of abscissae, describing load positions according to Table I.1 of reference |1|. One separate datacard is required for each loading condition and for every member which is loaded. Each member may only be loaded by one of the loading types indicated in Table I.1 of reference |1| for each loading condition.

Cards $(K_3+1)\rightarrow K_4$ $(K_4=K_3+NLNP)$

Format (2I4, F8.0)

These cards (NLNP in number, see card 13) supply all data concerning joint loads. Joint loads are designated in the same way as the joint displacements.

Col. 1- 4 Number of force. (Must correspond to the numbering of joint displacements. (NOFOR))

5- 8 Loading condition (NOLOD)

9-16 Magnitude of applied force (VAL)

Read in by Inform

Card K_4+1

Format (16I5)

This card is prepared exactly as card 4, but now all the data read in will apply to the global optimization, which is carried out after each cross-sectional shape has been fixed. If column 40 is zero, this will be the last data card and the search will be performed by means of built in parameters (see separate section). If column 40 is 1, cards corresponding to 8-12 should also be included, with data applicable to the global search. If -1 is punched in column 40 a card corresponding to 5 should also be inserted immediately after this card. Cards corresponding to 6 and 7 should in no case be included.

B. Normal Mode of Optimization

In this case a 1 should be punched in column 5 of card 3, as mentioned under Section A. In addition, the following changes should be made in the scheme outlined in Section A:

Card 4	All of the information on this card is now related to the global optimization.
Card K_4	This is the last data card.

C. Ordinary Frame Analysis

In this case a -1 should be punched in columns 4-5 of card 3 as explained in Section A. In addition the following changes should be made in the scheme outlined in Section A:

Card 4		Format (I5, F6.3)
	Col. 1- 5	Total number of free variables (N=3ND)
	6-11	Punch 1.0 here. The rest of this card is blank.
Card 7		Format (8F10.2) This card and if necessary additional cards following immediately after, lists the sectional properties corresponding to the variables.

Cards 5-6 and 8-12 Omitted

Card K_4 This is the last card.

D. Built-in Parameters in the Search Procedure

The following values are used if a zero is punched in column 40 of card 4.

a) Scaling factors are set equal to the initial values of the variables. Hence the scaled values of all of the variables are 1.0 at the starting point.

b) Initial step lengths (LAMX) are set to

   1) 0.01 in the global search mode
   2) 0.02 in the local search mode

c) Initial convergency criteria (GAMMA) are set to

   1) 0.002 in the global search mode
   2) 0.01 in the local search mode

d) Convergency limit on the Golden Search EP1 = 10^{-5}

e) Minimum acceptable value for each constraint E1 = 10^{-8}

f) Coefficient that sharpens the convergency criterion for each new response surface RED = 0.4.

g) Coefficient that reduces the initial step length for each new response surface REDL = 0.4.

h) Coefficients by which the response factor is reduced, CC(I) = 1, 20, 20, 20, 20.

E. Example - FRAME 1

At the end of this report the input and some of the output concerning a two-stage mode of design of the frame shown in Fig. 4a is presented. Frame members 1 and 3 are required to have identical shapes. All of the frame members are required to have symmetrical cross-section. Fig. 4b shows member type numbering and selected local as well as global coordinate systems. Figs. 4c and d show the two independent loading cases to be considered.

Altogether 25 data cards have to be prepared for this problem. Each line on the data sheets contains the data to be punched on one of these cards. Following the list of input are eight pages of selected output.

Notice from the output that the derived optimum design

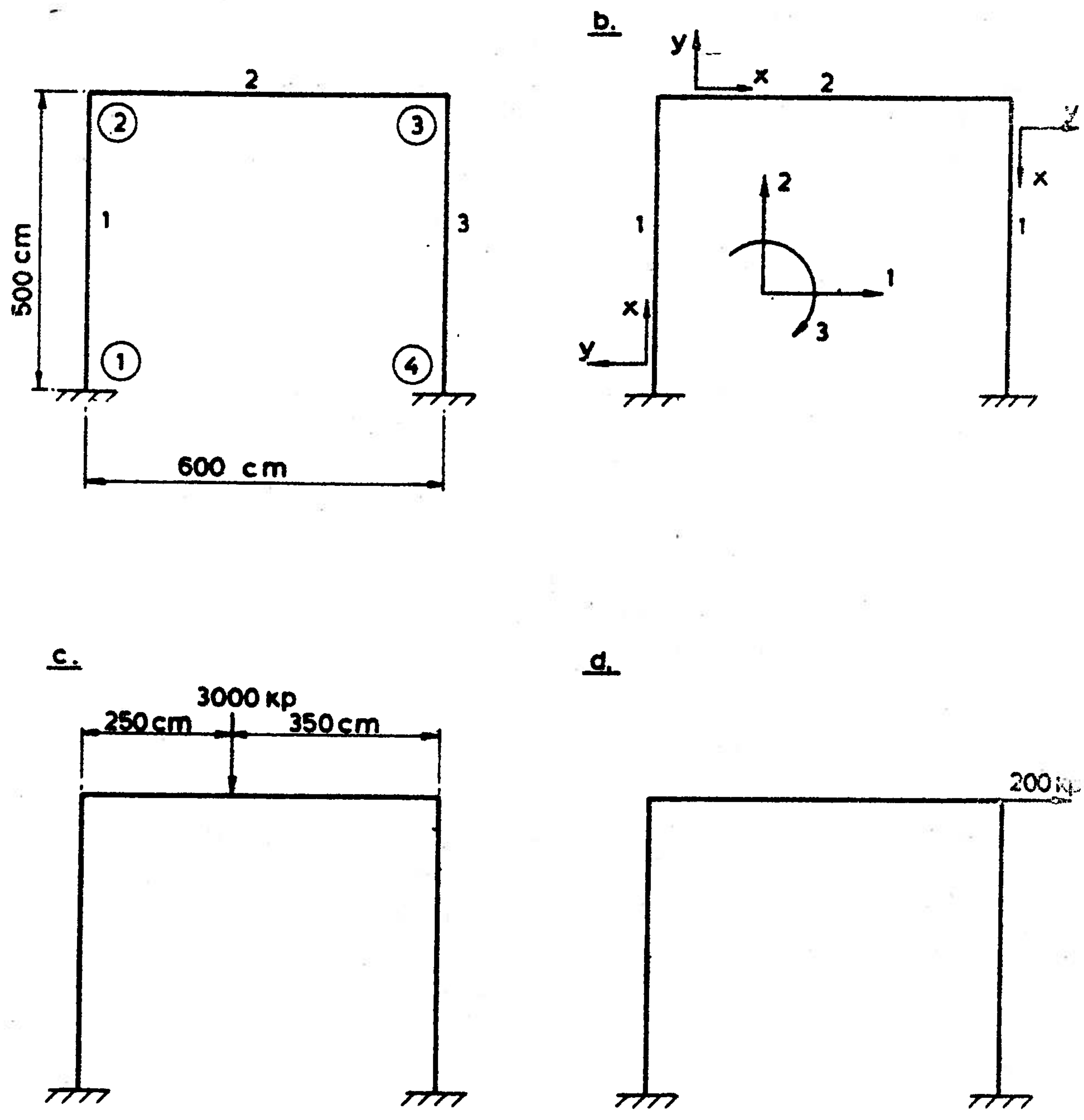


FIG. 4 Outline of Frame and Loadings.

does not yield a H/t_w-ratio equal to the maximum permissible value of 60, as one would expect. This is due to a slightly different problem formulation used at the time of execution. The output shows that the optimum in this case corresponds to a fully stressed design, which one would expect since buckling and displacement limitations are not included.

4. DATA STORAGE AND DEFINITIONS

COMMON/LOAD/:

- LL = Number of loading conditions (maximum of 5)
- LLS = Number of zero displacement conditions for supports (maximum of 20)
- ISUP( )= Array of zero joint displacements, listed such that ISUP(1) > ISUP(2) ... > ISUP(LLS)
- R = Matrix of nodal point loads
- SF = Matrix of fixed end reactions caused by member loads
- ALLOW = Array of allowable stresses: σ_{tens}, $\sigma_{compr.}$, τ ($\sigma_{compr.}$ must be negative)
- SFO = Matrix of maximum midspan moments caused by the external loads in simply supported conditions
- XO = Abscissa along member for point of zero shear
- OLANAL = Array of variables for which the last preceding complete analysis was performed
- OLC = Response value at last preceding complete analysis

COMMON/FRAME 1/:

- M = Number of members in frame (maximum of 30)
- JO = Number of joints in frame (maximum of 30)
- k = Degrees of freedom at each joint (3 for plane frames, 1 for beams)
- ND = Number of different member types with respect to cross-sectional properties of the variables (maximum of 10)

AL = Array of member lengths
JM = Array of member types, length equal to M
A = Matrix of frame geometry
IP = Control integer, to be read in as zero
EPSI = Array of three branching parameters (See description of Chkmov.)

COMMON/FRAME 2/:

AF = Array of flange areas (length = M)
AW = Array of web areas (length = M)
HL = Array of beam heights (length = M)
SKI = Matrix containing stiffness matrices for all of the members
JK = Array of members that have been changed sufficiently to warrent new computations of stiffness
IN = Total number of members listed in JK
NONEW = Counter of number of complete analyses
NOMOD = Counter of number of approximate analyses
NONO = Counter of steps without analysis

COMMON/FRAME 3/:

ZERO = Null-matrix
BIGINV= Matrix for storage of the inverse of the main stiffness matrix
RFI = Array for one-dimensional storage of the fixed end generalized forces
DISPL = Array mode of storage for node (joint). displacements

COMMON/FRAME 4/:

ENDFOR= Matrix for storage of generalized member end forced
AMAXMO= Matrix for storage of maximum moments in the spans
SIGMAX= Array of maximum tensile stress in each member

TAUMAX = Array of maximum shearing stress in each member

Q01 = Matrix of shearing forces at the start of each member

Q02 = Matrix of shearing forces at the end of each member

SIGMIN = Array of maximum compressive stress (negative) in each member

COMMON/FRAME 5/:

JS = Array of codes for cross-sectional shapes of each member

MOIN = Array of moments of inertia for each member

PLAREA = Array of plate flange areas (zeros in positions representing members with no plate flange)

AREA = Array of total cross-sectional areas for each member

SEMOP = Array of section moduli for each member with respect to the positive flange

SEMON = Array of section moduli with respect to the negative flange side

SIGMA = Matrix of combined stresses due to bending and axial forces

TAU = List of shearing stresses

COMMON/CONSTR/:

RATIO = Array of maximum admissible ratios of height-to-thickness for webs of each of the members

COMMON/COINS/:

NSTART = Array of nodal point number for start of each member

NEND = Array of nodal point number for end of each member

FRAME OPTIMIZATION

FRAME 1

MOE

1

DATA

```
                                                                        CARD NO
OPTIMIZATION OF FRAME NO 1 - TWO-STEP MODE                                    1
NEW STARTING POINT                                                            2
 1                                                                            3
 6   17    4    4    3    7    0    1                                         4
     3.0       8.0       7.0       6.0       10.0      35.0                   5
     3.0       8.0       7.0       6.0       10.0      35.0                   6
     .02       .02       .02       .02       .02       .02                    7
     .008      .008      .008      .008      .008      .008                   8
    .1E-03    .1E-07    .4E 00    .4E 00                                      9
     10.       20.       20.       20.                                       10
3   4   3   2   0   18   2   6   1   1                                       11
1   1     500.   0        0       60.   1   2                                12
2   2     600.   0        0      150.   2   3                                13
3   1     500.   0        0       60.   3   4                                14
&DAT                                                                         15
A(1,2,1)=1.0, A(2,1,1)=-1.0, A(3,3,1)=1.0, A(4,5,1)=1.0,                     16
A(5,4,1)=-1.0, A(6,6,1)=1.0, A(1,4,2)=1.0, A(2,5,2)=1.0,                     17
A(3,6,2)=1.0, A(4,7,2)=1.0, A(5,8,2)=1.0, A(6,9,2)=1.0,                      18
A(1,8,3)=-1.0, A(2,7,3)=1.0, A(3,9,3)=1.0, A(4,11,3)=-1.0,                   19
A(5,10,3)=1.0, A(6,12,3)=1.0,                                                20
&END                                                                         21
 12   11   10   3   2   1                                                    22
```

FRAME OPTIMIZATION
FRAME 1

MDE
2

DATA

								CARD NO
0.04	0.04	0.005	1600.	-1500.	1000.			23
2	1	1	1	-3000.	250.			24
7	2	200.						25

PTIMIZATION OF BEAM TYPE 1

```
                 RESPONSE SURFACE NUMBER  1           RESPONSE FACTOR  0.1000E 00

AMBDA   0.200E-01 0.200E-01 0.200E-01
AMMA    0.800E-02 0.800E-02 0.800E-02
  1      STARTING VALUE OF TOTAL FUNCTION  0.828981E 01      NET FUNCTION  0.700000E 01
T.PT.    1.00000E 00    1.00000E 00    1.00000E 00
        3  6  4  2
        3  3  4  3
  2      STARTING VALUE OF TOTAL FUNCTION  0.580271E 01      NET FUNCTION  0.442576E 01
T.PT.    1.10789E 00    2.75520E-01    1.37584E 00
        3  1  2  0
        3  1  3  0
  3      STARTING VALUE OF TOTAL FUNCTION  0.564880E 01      NET FUNCTION  0.418078E 01
T.PT.    1.05367E 00    2.54945E-01    1.31488E 00
        2  2  2  0
        3  2  3  0
  4      STARTING VALUE OF TOTAL FUNCTION  0.552241E 01      NET FUNCTION  0.396127E 01
T.PT.    9.86846E-01    2.50183E-01    1.30145E 00
        2  3  2  4
        2  2  3  2
AMMA    0.800E-02 0.800E-02 0.800E-02
AMBDA   0.200E-01 0.200E-01 0.200E-01

                 RESPONSE SURFACE NUMBER  1           RESPONSE FACTOR  0.1000E 00

                 RESPONSE SURFACE NUMBER  2           RESPONSE FACTOR  0.5000E-02

AMBDA   0.800E-02 0.800E-02 0.800E-02
AMMA    0.320E-02 0.320E-02 0.320E-02
  1      STARTING VALUE OF TOTAL FUNCTION  0.355074E 01      NET FUNCTION  0.245655E 01
T.PT.    8.65536E-01    2.59986E-01    1.33327E 00
        4  3  4  0
        3  2  4  0
  2      STARTING VALUE OF TOTAL FUNCTION  0.286525E 01      NET FUNCTION  0.265091E 01
T.PT.    4.42221E-01    1.70621E-01    1.28373E 00
        2  2  3  5
        2  2  1  2
[illegible]
[illegible]
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                    RESPONSE SURFACE NUMBER  3            RESPONSE FACTOR  0.2500E-03

LAMBDA  0.320E-02 0.320E-02 0.320E-02
GAMMA   0.128E-02 0.128E-02 0.128E-02
   1       STARTING VALUE OF TOTAL FUNCTION  0.252213E 01      NET FUNCTION  0.250379E 01
ST.PT.     5.32814E-01   2.25493E-01   1.43778E 00
          4  4  3  2
          4  3  1  1
   2.      STARTING VALUE OF TOTAL FUNCTION  0.242911E 01      NET FUNCTION  0.237689E 01
ST.PT.     4.85230E-01   2.28311E-01   1.47287E 00
          1  3  2  6

          2  1  1  3
GAMMA   0.128E-02 0.128E-02 0.128E-02
LAMBDA  0.320E-02 0.320E-02 0.320E-02

                    RESPONSE SURFACE NUMBER  3            RESPONSE FACTOR  0.2500E-03

                    RESPONSE SURFACE NUMBER  4            RESPONSE FACTOR  0.1250E-04

LAMBDA  0.128E-02 0.128E-02 0.128E-02
GAMMA   0.512E-03 0.512E-03 0.512E-03
   1       STARTING VALUE OF TOTAL FUNCTION  0.234932E 01      NET FUNCTION  0.234614E 01
ST.PT.     4.34221E-01   2.59206E-01   1.56693E 00
          3  1  4  2
          2  1  1  1
   2       STARTING VALUE OF TOTAL FUNCTION  0.233810E 01      NET FUNCTION  0.233031E 01
ST.PT.     4.25226E-01   2.61966E-01   1.57551E 00
          1  4  2  6
          1  1  1  2
GAMMA   0.512E-03 0.512E-03 0.512E-03
LAMBDA  0.128E-02 0.128E-02 0.128E-02

                    RESPONSE SURFACE NUMBER  4            RESPONSE FACTOR  0.1250E-04

 THE FUNCTION FX WAS CALCULATED    243 TIMES

LOCAL OPTIMUM
      UU(1)             UU(2)             UU(3)
 0.120478E 01   0.222114E 01   0.113681E 02
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OPTIMIZATION OF [illegible] TYPE   2
CONST.  -0.117[illegible]  -[illegible]985 00   1.77495E 00   0.22440E 00   0.60000E 01   0.10010E 02   0.35000E 02
THE STARTING POINT IS NOT ACCEPTABLE
  2       STARTING VALUE OF TOTAL FUNCTION  0.116021E 02      NET FUNCTION  0.109980E 00
ST.PT.    1.00000E 00   1.00000E 00   1.[illegible]E 00

                  RESPONSE SURFACE NUMBER  1            RESPONSE FACTOR  C.1000E 00

LAMBDA  C.200E-01 C.200E-01 C.200E-01
GAMMA   0.800E-02 0.800E-02 0.800E-02
  1       STARTING VALUE OF TOTAL FUNCTION  0.107592E 03      NET FUNCTION  0.179660E 02
ST.PT.    1.05724E 00   1.05724E 00   1.05724E 00
        3  3  3  C
        4  2  2  0
  2       STARTING VALUE OF TOTAL FUNCTION  0.219551E 02      NET FUNCTION  0.180051E 02
ST.PT.    1.13953E 00   1.15416E 00   1.03837E 00
        2  2  2  4
        3  2  2  2
  3       STARTING VALUE OF TOTAL FUNCTION  0.204747E 02      NET FUNCTION  0.182416E 02
ST.PT.    1.27995E 00   1.32502E 00   9.68884E-01
        2  1  1  1
        1  1  1  1
  4       STARTING VALUE OF TOTAL FUNCTION  0.204189E 02      NET FUNCTION  0.184264E 02
ST.PT.    1.30141E 00   1.28940E 00   9.80321E-01
        1  1  1  3
        1  1  1  1
GAMMA   0.800E-02 0.800E-02 0.800E-02
LAMBDA  0.200E-01 C.200E-01 0.200E-01

                  RESPONSE SURFACE NUMBER  1            RESPONSE FACTOR  0.1000E 00

                  RESPONSE SURFACE NUMBER  2            RESPONSE FACTOR  0.5000E-02

LAMBDA  0.800E-02 0.800E-02 0.800E-02
GAMMA   0.320E-02 0.320E-02 0.320E-02
  1       STARTING VALUE OF TOTAL FUNCTION  0.184849E 02      NET FUNCTION  0.183837E 02
ST.PT.    1.36332E 00   1.20932E 00   9.55703E-01
        4  5  5  0
        1  3  1  0
  2       STARTING VALUE OF TOTAL FUNCTION  0.176275E 02      NET FUNCTION  0.172716E 02
ST.PT.    1.30608E 00   1.16232E 00   9.02124E-01
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        1   1   1   1
AMMA    0.320E-02 0.320E-02 0.320E-02
AMBDA   0.800E-02 0.800E-02 0.800E-02

                    RESPONSE SURFACE NUMBER  2          RESPONSE FACTOR  0.5000E-02

                    RESPONSE SURFACE NUMBER  3          RESPONSE FACTOR  0.2500E-03

AMBDA   0.320E-02 0.320E-02 0.320E-02
AMMA    0.128E-02 0.128E-02 0.128E-02
  1        STARTING VALUE OF TOTAL FUNCTION  0.172323E 02      NET FUNCTION  0.172153E 02
T.PT.      1.31002E 00    1.07401E 00    9.15447E-01
        5   5   5   2
        3   1   1   1
  2        STARTING VALUE OF TOTAL FUNCTION  0.170048E 02      NET FUNCTION  0.169329E 02
T.PT.      1.32268E 00    1.02220E 00    8.93252E-01
        5   3   2   4
        1   1   1   1
AMMA    0.128E-02 0.128E-02 0.128E-02
AMBDA   0.320E-02 0.320E-02 0.320E-02

                    RESPONSE SURFACE NUMBER  3          RESPONSE FACTOR  0.2500E-03

                    RESPONSE SURFACE NUMBER  4          RESPONSE FACTOR  0.1250E-04

AMBDA   0.128E-02 0.128E-02 0.128E-02
AMMA    0.512E-03 0.512E-03 0.512E-03
  1        STARTING VALUE OF TOTAL FUNCTION  0.169216E 02      NET FUNCTION  0.169178E 02
.PT.       1.26766E 00    1.07442E 00    9.15990E-01
        7   5   7   4
        2   1   1   1
  2        STARTING VALUE OF TOTAL FUNCTION  0.168856E 02      NET FUNCTION  0.168730E 02
.PT.       1.21641E 00    1.12200E 00    9.34383E-01
        6   3   2   4
        1   1   1   1
AMMA    0.512E-03 0.512E-03 0.512E-03
AMBDA   0.128E-02 0.128E-02 0.128E-02

                    RESPONSE SURFACE NUMBER  4          RESPONSE FACTOR  0.1250E-04

HE FUNCTION FX WAS CALCULATED   226 TIMES
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GOAL OPTIMUM
    UU(1)           UU(2)           UU(3)
0.754511E 01   0.107674E 02   0.320892E 02

LOCAL OPTIMIZATION STARTS HERE

                    RESPONSE SURFACE NUMBER  1          RESPONSE FACTOR  0.2500E-01

AMBDA   0.100E-01 0.100E-01
AMMA    0.600E-02 0.600E-02
  1        STARTING VALUE OF TOTAL FUNCTION  0.242094E 02      NET FUNCTION  0.215054E 02
T.PT.      3.01195E-01    1.25752E 00
           2  2  0
           4  4  0
  2        STARTING VALUE OF TOTAL FUNCTION  0.234119E 02      NET FUNCTION  0.220818E 02
T.PT.      3.28228E-01    1.26488E 00
           2  1  0
           4  4  0
  3        STARTING VALUE OF TOTAL FUNCTION  0.234097E 02      NET FUNCTION  0.217481E 02
T.PT.      3.19877E-01    1.25402E 00
           2  1  0
           4  2  0
  4        STARTING VALUE OF TOTAL FUNCTION  0.232814E 02      NET FUNCTION  0.220679E 02
T.PT.      3.23969E-01    1.26806E 00
           1  1  0
           4  4  0
AMMA    0.600E-02 0.600E-02
AMBDA   0.100E-01 0.100E-01

                    RESPONSE SURFACE NUMBER  1          RESPONSE FACTOR  0.2500E-01

                    RESPONSE SURFACE NUMBER  2          RESPONSE FACTOR  0.1250E-02

AMBDA   0.400E-02 0.400E-02
AMMA    0.240E-02 0.240E-02
  1        STARTING VALUE OF TOTAL FUNCTION  0.221117E 02      NET FUNCTION  0.220450E 02
T.PT.      3.24435E-01    1.26636E 00
           4  1  0
           3  2  0
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2        STARTING VALUE OF TOTAL FUNCTION  0.214363E 02      NET FUNCTION  0.212494E 02
ST.PT.     2.991275E-01   1.24591E 00
           2  2  1
           3  4  1
GAMMA    0.240E-02 0.240E-02
LAMBDA   0.400E-02 0.400E-02

                 RESPONSE SURFACE NUMBER  2           RESPONSE FACTOR  0.1250E-02

                 RESPONSE SURFACE NUMBER  3           RESPONSE FACTOR  0.6250E-04

LAMBDA   0.160E-02 0.160E-02
GAMMA    0.960E-03 0.960E-03
1        STARTING VALUE OF TOTAL FUNCTION  0.211310E 02      NET FUNCTION  0.211200E 02
ST.PT.     3.01835E-01    1.23520E 00
           3  3  1
           1  3  1
2        STARTING VALUE OF TOTAL FUNCTION  0.210760E 02      NET FUNCTION  0.210506E 02
ST.PT.     3.06532E-01    1.22690E 00
           3  2  4
           1  1  3
GAMMA    0.960E-03 0.960E-03
LAMBDA   0.160E-02 0.160E-02

                 RESPONSE SURFACE NUMBER  3           RESPONSE FACTOR  0.6250E-04

                 RESPONSE SURFACE NUMBER  4           RESPONSE FACTOR  0.3125E-05

LAMBDA   0.640E-03 0.640E-03
GAMMA    0.384E-03 0.384E-03
1        STARTING VALUE OF TOTAL FUNCTION  0.209386E 02      NET FUNCTION  0.209372E 02
ST.PT.     2.93940E-01    1.23200E 00
           4  4  0
           2  3  0
2        STARTING VALUE OF TOTAL FUNCTION  0.208736E 02      NET FUNCTION  0.208714E 02
ST.PT.     2.91568E-01    1.23041E 00
           3  3  0
           2  3  0
GAMMA    0.384E-03 0.384E-03
LAMBDA   0.640E-03 0.640E-03

                 RESPONSE SURFACE NUMBER  4           RESPONSE FACTOR  0.3125E-05
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THE FUNCTION FX WAS CALCULATED 167 TIMES

OPTIMUM DIMENSIONS

BEAM NO	FLANGE AREA	WEB AREA	WEB HEIGHT
1	0.115859E 01	0.213598E 01	0.109323E 02
2	0.738125E 01	0.105336E 02	0.313922E 02
3	0.115859E 01	0.213598E 01	0.109323E 02

WXX= 0.208373E 05

STRESSES

LOADING CONDITION 1

BEAM NO	SIGMA 1	SIGMA 2	SIGMA 3	SIGMA 4	SIGMA 5	SIGMA 6
1	-0.991316E 02	-0.684291E 03	-0.100108E 04	0.216959E 03	-0.550107E 03	-0.234016E 03
2	-0.363857E 02	0.340184E 02	-0.354969E 02	0.331296E 02	0.148930E 04	-0.149167E 04
3	-0.873495E 03	0.313736E 03	0.294624E 02	-0.588221E 03	-0.422516E 03	-0.137242E 03

BEAM NO	TAU 1	TAU 2
1	-0.139836E 02	-0.139836E 02
2	0.166175E 03	-0.118623E 03
3	0.139837E 02	0.139837E 02

LOADING CONDITION 2

BEAM NO	SIGMA 1	SIGMA 2	SIGMA 3	SIGMA 4	SIGMA 5	SIGMA 6
1	-0.145911E 04	0.149628E 04	0.148366E 04	-0.144649E 04	0.122765E 02	0.248987E 02
2	0.907467E 02	-0.828404E 02	-0.828575E 02	0.907638E 02	0.394464E 01	0.396172E 01
3	-0.148396E 04	0.144478E 04	0.145941E 04	-0.149659E 04	-0.122730E 02	-0.249022E 02

BEAM NO	TAU 1	TAU 2
1	0.456241E 02	0.456241E 02
2	-0.787864E 01	-0.787864E 01
3	0.456333E 02	0.456333E 02

VALUES OF RESTRICTIONS

0.247711E-02	0.713366E-02	0.270593E-01	0.272604E-01	0.555539E-02	0.227588E-02
0.954376E 00	0.833825E 00	0.954267E 00	0.115859E 01	0.738125E 01	

NUMBER OF COMPLETE FRAME ANALYZES 78
NUMBER OF FRAME MODIFICATIONS 118
NUMBER OF SEARCHES WITHOUT FRAME ANALYSIS 241
IHC002I STOP 0 ***** RESTART AT LOCATION 103D22
EXECUTION TERMINATED