COMPUTER PROGRAM CRANE

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TABLE OF CONTENTS

Introduction

In a large industrial complex such as Stelco, one of the major and most important elements of structural design is the overhead crane runway. At the Hilton Works plant there are about 25 miles of crane runway supporting some 360 cranes. These numbers are steadily increasing as the plant is developed.

Since these cranes are the heart of a mill, it is essential that the runway system be precisely designed. It is a certainty that the design loads will be attained, if not sometimes surpassed.

The aspect of design varies for the engineer. It may be a completely new runway system to be developed. Or it may be that an existing installation must be checked for a newer, heavier crane, and perhaps have to be reinforced. Quite often an existing runway may have to be drastically modified to suit new plant facilities. Alternate schemes must be evaluated.

In all cases, the design must adhere to strict tolerances regarding allowable stresses and deflections. Also, the criteria for minimizing fatique effects must be satisfed. Notwithstanding these parameters, the engineer must produce an economical design in a reasonably short time. In many cases, a decision is required within hours.

To fulfill these demands, the engineer requires a tool that is fast, accurate, and readily available. Until the development of this computer program CRANE, such service was not always provided.

Even the design of simply supported girders can become tedious and time consuming. Although there is an accurate analytical method for determining the maximum bending moments, the process bogs down as the girder span and number of wheel loads increases. It should be remembered that several analyses are needed, e.g. one crane with impact or two cranes, no impact. Also, the spans in a runway may vary, and a separate girder may have to be designed. Influence lines are used as well. Having obtained single maximum values, it is still necessary to combine the effect of all wheels to form envelopes of bending and shear. The maximum deflection is usually approximated by placing the loads in the center of the girder, and calculating the resulting displacement at that point.

For runway systems incorporating trusses and continuous beams, the task of analysis is greatly compounded. In addition to truss action and local bending (because of wheel loads between panel points), secondary bending due to joint deflections must be accounted for. The most common approach is to make simplifying assumptions, use approximations, apply "rule-of-thumb", and rely on experience. The top chord of trusses is often analysed as a continuous beam. The loads are placed at several discrete locations, and the system is analysed, either by manual methods or by a computer program for static loading. The more locations that are investigated, the more complete the solution.

The results of these methods is a design that is generally conservative (to account for some of the uncertainties and assumptions), and hence not the most economical. In some cases the assumptions may be quite invalid, particularly on indeterminate structures.

A full "picture" of the response of the structure to the passing loads is seldom achieved. Areas of stress reversal and zones of low or high bending and shear are not readily identified. This data is required for splicing, cut-outs, spacing of stiffeners, and welding of attachments. These methods are time consuming, and experienced designers are kept from exploring alternate schemes.

The development of the computer program CRANE has successfully remedied these problems. The solution is based on a stiffness matrix analysis. The displacements at each joint are calculated, and these in turn are used to calculate the bending, axial, and shear forces.

No simplifying assumptions are required. The entire series of loads is moved across the runway in increments of one foot. Thus, a total picture is achieved. Structures of varying complexity are analysed with equal ease.

The inter-relationship of forces is shown. The top chord of a truss must be designed as a beam-column, and the maximum bending and concurrent axial force are calculated. In a girder, the stresses due to bending and shear in the tension flange must be checked concurrently. This data is available from the computer output.

Single maximum values are easily located. Also, envelopes are easily obtained from the printout. Maximum vertical deflectionsof the joints of the top chord are calculated. A full description of the analysis is given later in the Scope.

Equally important, the program can be run on "time-sharing" facilities right in the design office. The format is design orientated, with a minimum emphasis on computer knowledge.

The method of analysis, conventions, units, method of coding, and sample problems are discussed in the report. The actual use of computer hardware is not discussed, nor is the mode of communicating on the terminal. These subjects vary considerably according to the computer system being used, and are best learned from the appropriate manuals. The program is written in FORTRAN IV, and the sample problems were run on HP's time sharing system.* A listing is given in the Appendix.

The example problems supplement the documentation of the program. They serve as teaching tools for coding. They also demonstrate the versatility, and comprehensiveness of the program. They also allow for some discussion of the analysis. From this basis, more complicated structures can be tackled. The results of the first three examples have been verified by independent methods.

* HEWLETT PACKARD 3000 SERIES COMPUTER SYSTEM.

Scope of Analysis

General

The program CRANE will analyze any given planar structure (simple girder, truss, continuous beam, trestle, etc.) that is subjected to a series of moving loads. No restriction is placed on the magnitude or the spacing of the loads. Springs, or elastic supports, can be incorporated as required.

The analysis is in two parts: that of the chord, i.e., the member directly supporting the moving loads, and that of the web members and bottom chord. In a girder, the web members and bottom chord would not be applicable. The chord is assumed to be continuous and horizontal.

Chord Analysis

The chord analysis yields the following:

(1) both the maximum positive and negative bending moments, at one foot intervals, along with the associated axial and shear forces, i.e. those forces acting simultaneously with the maximum bending moments.

(2) maximum axial force (per panel), along with the associated bending moments at one foot intervals

(3) the maximum absolute shear force, at one foot intervals.

Web and Bottom Chord Analysis

The web member analysis yields the following:

(1) maximum tensile force and the absolute value of the associated bending moment.

(2) maximum compressive force, and associated bending moment.

(3) maximum value of absolute shear force.

(4) length of members, as calculated from center line working points

Also, the maximum vertical deflection of the chord panel points is calculated.

A printout of member and joint data is optional.

Size Limitations

There are, for practical reasons, a number of restrictions. The maximum number of chord panels is 10, with a maximum panel length of 25 ft. The total number of joints must not exceed 25, nor the total number of members 40. Maximum number of wheels is 15. These values can be altered somewhat to suit a particular problem. On a larger computer system than that usually associated with a time-sharing service, these size limitations can usually be eliminated.

Panel lengths, as well as wheel load spacing, must be integer values. All loads must be vertical.

Springs

Springs can be added to any joint. They can be used to represent the effects of settling foundations, or actual structural spring supports. The effects of full or partial restraint of the end rotation of a crane girder can be studied.

The designer must determine the spring constant that would apply to his specific application.

Eccentricity

The effects of any joint eccentricity would be added manually to the computer printout. However, it is general design practice to have the center lines of all members of a joint intersect at one point, thereby eliminating eccentricity.

Interpretation of Analysis

The values of bending moment, axial and shear forces generated by the program enable an experienced engineer to perform a complete and accurate design. The inter-relationship of the forces are known, and the effects of combined stresses can be investigated.
See Example No. 3, p. 44 for further details.

Not only are the maximum points of stress identified, but the envelopes of maximums can be plotted. Thus a graphical representation can show the zones of high or low stresses. This has been done in the example problems.

Areas of stress reversal can also be identified.

Secondary bending due to joint deflection is automatically incorporated in the analysis.

The joint deflections reflect the stiffness of the members and the effect of either pin or moment connections.

The data generated allows the engineer to make the most economical use of the material, to pin-point potential trouble areas, and to place cut-outs and splices in the optimum locations.

Coding Format

The coding of the data must be in accordance with the format described. If the joint or member data does not follow this format, an error message will be printed, and the run is aborted. Further, the error printout, "STRUCTURE IS UNSTABLE", will be given if, for any reason, the three states of equilibrium are not satisfied for the structure as a whole, or for any of its members or joints.

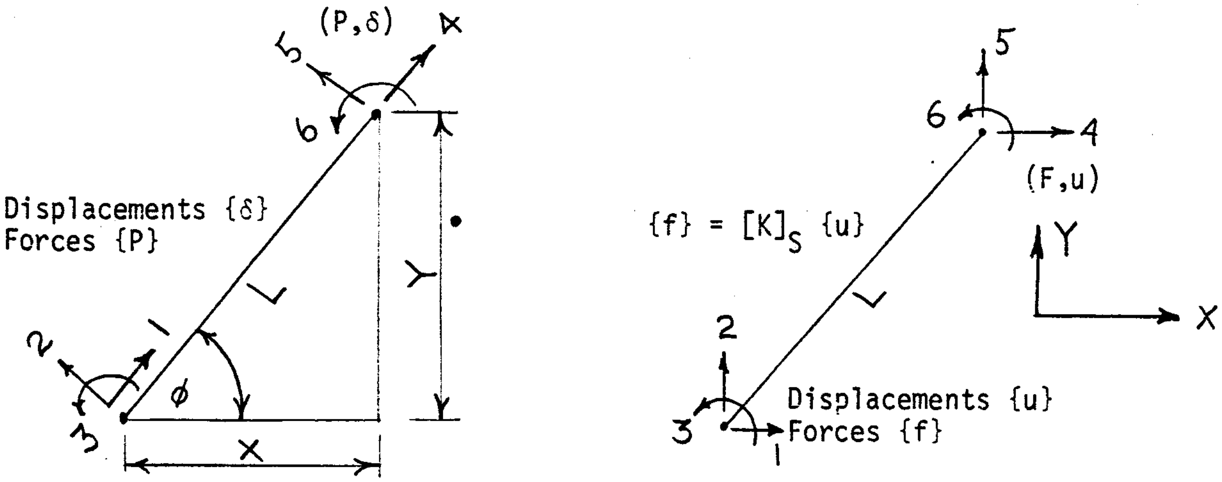
This means that proper joint restraints must be defined to satisfy equilibrium requirements of simple statics. No inference is made to the actual "stability" of any particular member.

Method of Analysis

The solution is based on a stiffness matrix analysis: a system of linear force-displacement equations for the total structure is solved by the Choleski method. The displacements (horizontal, vertical, and rotational) of each joint are calculated, and, using these values, the forces (shear, axial, and bending moment) of each member are then determined. Elastic theory is used. An outline of the analysis is given in the following pages.

Co-ordinate Systems

A stiffness matrix $[K]_S$ for each member, relative to a set of proper reference system co-ordinates, is established. A relationship exists between the reference system co-ordinates and the local member co-ordinates. This is shown in Figure A. There are six displacements/ forces for each member. In the member co-ordinates, the vectors are parallel and perpendicular to the member, rather than the main co-ordinate system.



Member Co-ord.

System Co-ord.

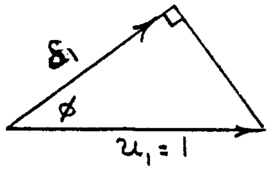
Figure A

Compatibility

The compatibility of the co-ordinate systems is given by:

$$\{\delta\} = [B]\ \{u\}$$

where [B] is the displacement transformation matrix, i.e. it reflects the effect on the array of member displacements {δ} by unit movements in the array of system displacements {u}. For example, if in Figure A, u_1 is equal to one, then $\delta_1 = \text{Cos}\ \phi$ (see diagram below).



This procedure is repeated for each displacement, building the transformation matrix. The analysis is referenced to the <u>system</u> co-ordinates.

Constitutative Relationship

The constitutive relationship is given by:

$$\{P\} = [K]_m \{\delta\}$$

where $[K]_m$ is the member stiffness matrix relative to member co-ordinates.

It reflects the effect on the array of member forces {P} by unit movements of member displacements $\{\delta\}$. For example, if in Figure A, δ_1 is equal to one, then $P_1 = \frac{AE}{L}$.

Pin-Pin Member

The transformation matrix for a pin-pin member as shown in Figure A is given by:

$$[B] = \begin{bmatrix} \ell & m & 0 & 0 & 0 & 0 \\ -m & \ell & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \ell & m & 0 \\ 0 & 0 & 0 & -m & \ell & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad \begin{matrix} \ell = \text{Cos } \phi \\ m = \text{Sin } \phi \end{matrix}$$

The corresponding member stiffness matrix is given by:

$$[K]_m = \frac{AE}{L} \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Now, the member stiffness matrix re the system co-ordinates for axial deformations can be calculated. The relationship is given by $[K]_{s\ AXIAL} = [B]^T [K]_m [B]$.

$$[K]_s\ \text{AXIAL} = \frac{AE}{L^3} \begin{bmatrix} X^2 & XY & 0 & -X^2 & -XY & 0 \\ XY & Y^2 & 0 & -XY & -Y^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -X^2 & -XY & 0 & X^2 & XY & 0 \\ -XY & -Y^2 & 0 & XY & Y^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The stiffness matrix to reflect bending is done in a similar manner, and can be combined with the axial matrix to give $[K]_s$ for fix-fix, fix-pin, and pin-fix conditions.

Total Stiffness Matrix

The joints and members are coded (Figure B), as well as the structure displacements {a} (Figure C),

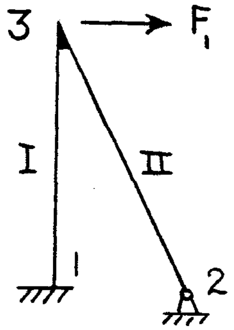


Figure B

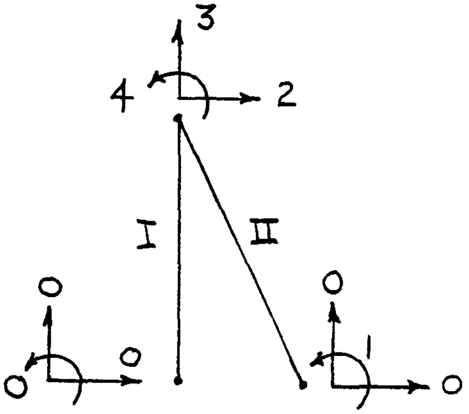
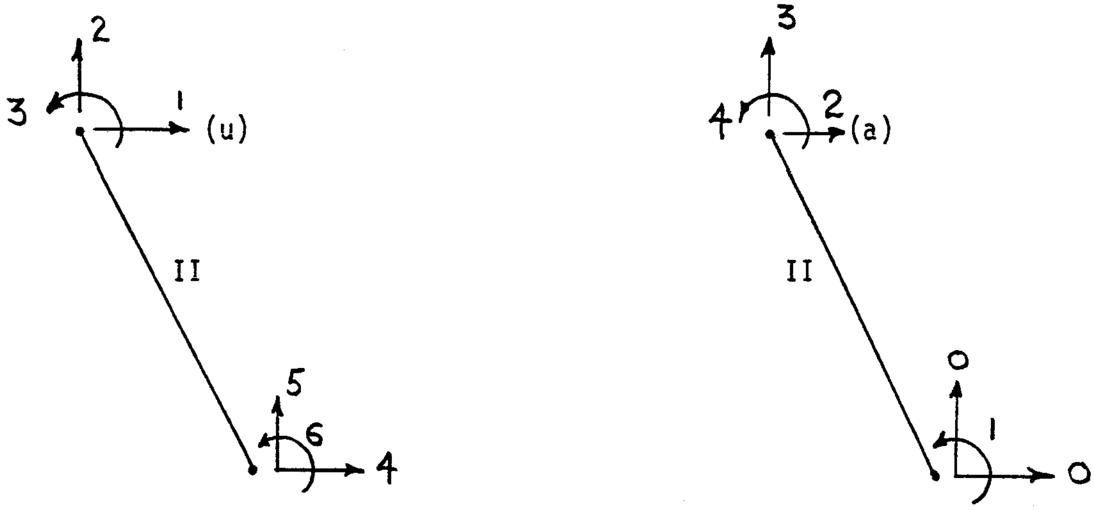


Figure C

The structure displacements, a total of four, are the unknowns that must be solved. They are referenced to system co-ordinates. At joint no. 1, there is no movement and thus no unknowns; at joint no. 2, movement is possible in all three modes and three unknowns (a_2, a_3, a_4) must be determined; at joint no. 3, only the rotation is unknown (a_1).

The correlation between the member system displacements and the structure system displacements is shown in Figure D.



Member Code

Structure Code

Figure D

Thus, structure displacement no. 2 is in effect the member displacement no. 1 for member II. The total such relationship can be summarized in chart form:

		1	2	3	4	5	6	} member displacement code
member numbers	1	0	0	0	2	3	4	structure displacement code
	2	2	3	4	0	0	1	

At this point, a stiffness matrix for the whole structure can be generated from the individual member matrices. This then would represent the actual system of linear force-displacement equations which must be solved:

$$\{F\} = [K]_{s_{TOTAL}} \{a\}$$

where $\{F\}$ is the array of externally applied forces, having the same code numbers and sense as the structure displacements $\{a\}$. In Figure B, this array would be: $\{F\}^T = \{0 \quad F_1 \quad 0 \quad 0\}$

$[K]_{TOTAL}$ represents the effect on the whole structure to unit movement by $\{a\}$. For example, if a unit displacement a_2 is applied, then the resulting corresponding force F_2 would be the sum of f_4 (member I) and f_1 (member II).

In other words, K_{22} (TOTAL) = K_{44} (member I) + K_{11} (member II).

In like fashion, the total stiffness matrix is generated.

The structure displacements can now be determined, and these values are back-substituted into the individual member stiffness matrices, giving the member forces as shown in Figure E. These forces are then resolved into the familiar components of axial and shear. Bending moments are the same for both systems (except for sign convention).

The member forces are resolved into components as shown below:

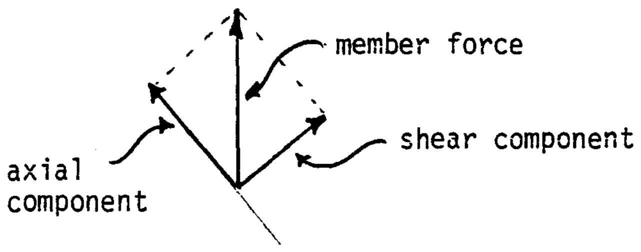


Figure E

Summary of Symbols

$[K]_s$ - member stiffness matrix relative to system co-ordinates

$[B]$ - displacement transformation matrix, relating member displacements to system displacements

L - member length

X - horizontal component of member length, relative to system co-ordinates

Y - vertical component of member length

δ - member displacement, member co-ordinates

P - member forces, member co-ordinates

u - member displacement, system co-ordinates

f - member forces, system co-ordinates

$[K]_m$ - member stiffness matrix relative to member co-ordinates

$[K]_{s_{TOTAL}}$ - stiffness matrix of whole structure

F - externally applied loading

a - joint displacements of the structure

Band Matrix

In this particular program, the total stiffness matrix was assembled in a band formation [Rubenstein, p. 165], which is better suited to computer applications. The algorithm[†] for this

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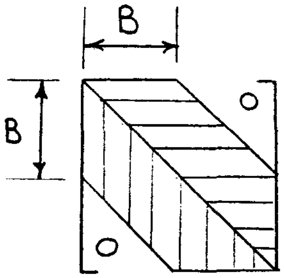
[†] Algorithm and subroutine BAND were obtained from lecture notes by Dr. Emery, McMaster University, 1972.

is located in lines 238-254 inclusive of the program. The subroutine BAND is used to solve this matrix.

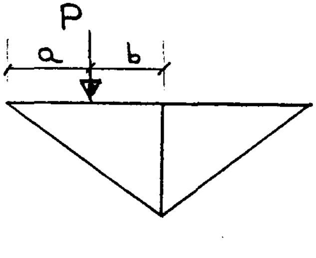
In effect, the band matrix excludes all zero components, and is stored in the computer as a one dimensional array (DIMENSION Z, Line 120 in program): the total size is the product of the band with times the number of unknowns.



Band matrix of width B.

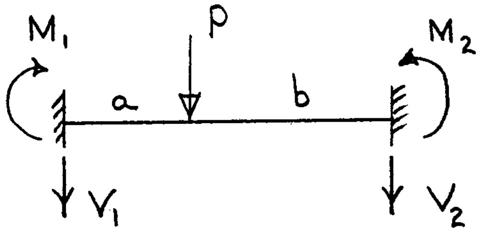
Application of Loads

The formulae and methods described have been set up to accommodate external loads applied only at the nodes, or joints. In the actual design problem (moving a series of loads across a structure), the loads are only infrequently located at an actual panel point. In the truss shown below, the load P is on the panel.

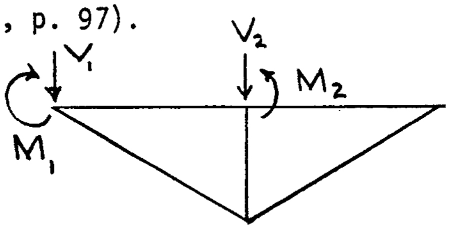


One solution is to "create" node points (joints) at one foot intervals, coinciding with the load movements: the shear and axial forces, as well as bending moments, would be calculated directly. However, this method entails an extremely increased amount of tedious coding, and, because each such node introduces an additional 3 unknowns, the size of the matrices is greatly increased. Thus, to reduce coding requirements and to keep the size of the program within the restrictions of time-sharing facilities, an alternative approach was taken.

The panel loads are accommodated by calculating the fixed end moments and shears, and applying these as external loads at the two adjacent panel joints (Rubenstein, p. 97).



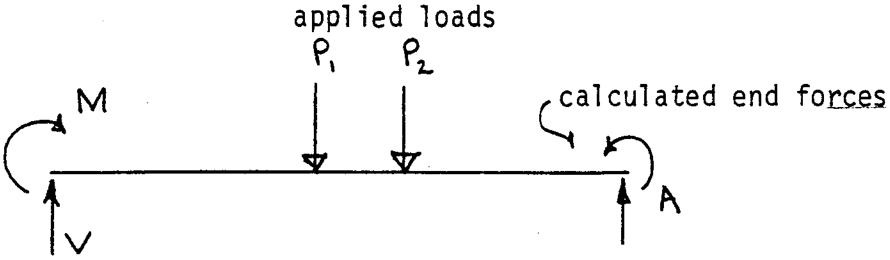
Fixed-end Forces



Equivalent Loading

When the member forces are later calculated, the shears, axial, and bending moments must be reduced by the value of these fixed-end forces. Any external load which is actually located at a joint is analysed in the normal fashion.

Once the end forces of each panel have been established by matrix analysis, the intermediate values of bending and shear (M and V in diagram below) are calculated, at one foot intervals, by statics, taking moments about point A (right panel joint).



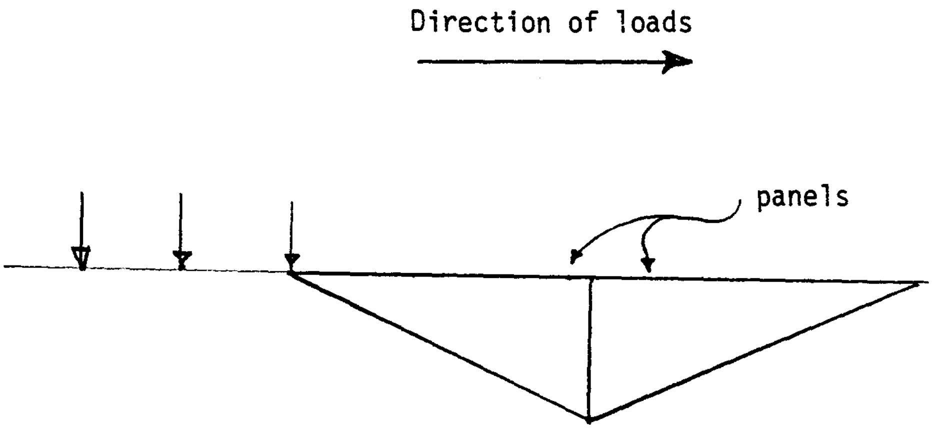
Springs

Spring constants are added directly to the total stiffness matrix at the required joints: they can be in the horizontal or vertical sense (assimilating elastic supports), or in the torsional sense (to effect semi-rigid joints).

Movement of Loads

The wheel loads are moved from left to right, one foot at a time, across the chord. The first wheel is set at the zero foot mark. All loads directly on a joint are analysed as such. All other loads are treated as panel forces: accordingly, the number and location of loads on each panel are tabulated constantly.

A structural analysis is done after each advancement of the loads. The values immediately obtained are compared to the previous ones, and the higher ones saved. This procedure is repeated until all loads are off the structure.



Experience has shown that a one foot increment in load movement gives results that have a negligible difference from a truly continuous movement. The same is true for determining the forces at one foot intervals. The accuracy is better than the value of the design loads.

Data Input

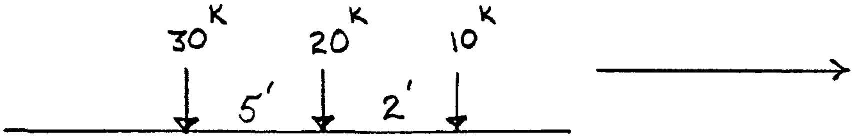
Input is achieved both by stored data files and "on-line" terminal communications. The bulk of the data (structure geometry and member properties) is stored in one of five data files: FIRST, SECND THIRD, FORTH and FIFTH. In response to the terminal request, "FILE NO. REQ'D.", the appropriate number, e.q. "1" for FIRST is typed. Free field format is used.

The program will then proceed, requiring the additional terminal input in turn:

a) Number of loads

b) Wheel loads (magnitude)

c) Wheel spacing, (first wheel at zero)



The data for the above arrangement is given by:

a) Wheel loads: 10, 20, 30

b) Wheel spacing: 0, 2, 5

Note: wheel spacing must be integer values.

If a printout of the structure data is required, then type in the word "YES" when requested. Otherwise type "NO".

The remaining data is stored in the independent files. A typical data sheet is as shown.

Data Variables

The variables are listed in the order and sequence required in the data file. The line numbers have not been shown.

NP

JNTC

NNN

NJ, NM, E, NR, NSP

JN, X, Y (one line for each joint)

JNR, NR1, NR2, NR3 (one line for each joint restrained)

MN, JNL, JNG, A, B (one line for each member)

NP - number of panels in top chord

JNTC - joint numbers of the chord, left to right

NNN - JOB DESCRIPTION

NJ - total number of joints

NM - total number of members

E - modulus of elasticity

NR - number of joints with deflection restraints

NSP - number of springs, use "0" (zero) if none

JN - joint number

X,Y - horizontal and vertical joint co-ordinates respectively.

JNR - joint number of restrained joint

NR1 - joint degree of freedom (either 1 or 0) in horizontal

NR2 - joint degree of freedom (either 1 or 0) in vertical

NR3 - joint degree of freedom (either 1 or 0) in rotation

MN - member number (chord members must be numbered from left to right, the first member being no. 1)

JNL - lower joint number

JNG - greater joint number

A - cross sectional area of member

B - moment of inertia of member

Generally, the structure is described by locating the joints with the co-ordinates, and describing the member by identifying its joint numbers. The area and inertia of each member is also given. The degree of freedom and member fixity completes the description.

JOINT RESTRAINT AND MEMBER FIXITY

Degrees of Freedom: Any given joint has three degrees of freedom, i.e. freedom to move in the x-direction, the y-direction, and to rotate. It is necessary to *describe* the three degrees of freedom for each joint in a structure.

If a joint is restrained from movement in one of these directions, that degree of freedom is set to zero (0). Otherwise, it is set to one (1), signifying *no restraint*.

Joint restrained	0
Joint *not* restrained	1

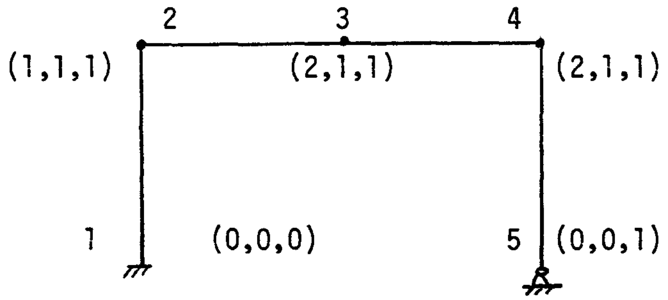
It is also possible to set the deflection of one joint equal to that of any other joint.

All joints are assumed to have three degrees of freedom; only those joints that have some degree of restraint need be specified.

Member Fixity: Member fixity describes the end connection of the member, whether it is a continuous (moment) connection, or a pinned (shear) connection. If a connection is assumed to be fully continuous no coding is required.

If a pin connection is required, special coding is needed. This is accomplished by placing, in the member data, a minus sign before that joint number where no moment is to be transferred.

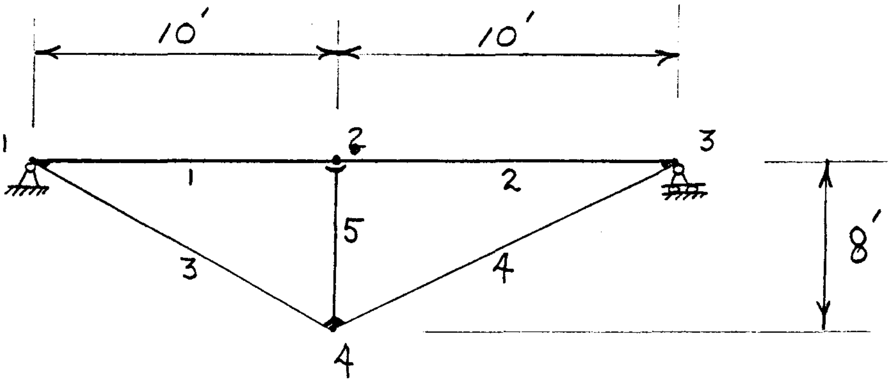
Note: The chord directly supporting the loads is continuous.



The x,y, and rotational degrees of freedom of the joints in the above frame are given in the brackets. Joint no. 1 is restrained completely; joint no. 5 is restrained in the x and y directions, but is able to rotate. Joint no. 3 is an optional joint (it may be deleted) to allow direct computation of stress and deflections at that point. Joint #2 has no external restraint. Joint 3 and 4 are free to rotate and to move freely in a vertical direction, but have been forced to have the same horizontal deflection as joint #2. This is achieved by coding a "2" for the X-direction restraint. It is important to note that a "1" always denotes freedom from external restraint (see example data sheet on page 26).

Example Data Sheet

The data file for a simple truss is given below. The left support point has been taken as the origin.



Data File:

```
100  2
110  1, 2, 3
120  SAMPLE DATA FOR TRUSS
130  4, 3, 29000, 3, 0
140  1, 0, 0
150  2, 10, 0
160  3, 20, 0
170  4, 10. -8
180  1, 0, 0, 1
190  3, 1, 0, 1
195  4, 1, 2, 1
200  1, 1, 2, 10, 100
```

```
210 2, 2, 3, 0, 0
220 3, 1, 4, 10, 10
230 4, 4, 3, 0, 0
240 5, 4, -2, 0, 0
```

For notes on the above example, see below.

Notes on the example data sheet:

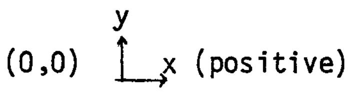
1. Line numbers must be in numerical order, with one blank space before the data.
2. Joints and members must be listed in numerical order.
3. The lower joint number must preceed the greater joint number.
4. 0 (zero) denotes the same area and inertia of the preceeding member, e.g., lines #210 and 230.
5. In member data, a minus sign before a joint number denotes a pin joint at that end of the member, e.g., line #240, member 5.
6. Chord members must be numbered from left to right, the first being #1, the second being #2, etc.
7. The line #120, any description up to 60 letters can be used.
8. The origin is at joint no. 1, see line #140.
9. The joint restraints, conforming to the sketch, are described in lines #180 and #190.
10. Panel lengths must be integer values, e.g., line #100.
11. Note that decimals are not used except to indicate a fraction.
12. Note that joint #4 is able to rotate and move horizontally without restraint, but, by coding, has been forced to have the same vertical deflection as joint #2. See line #195.

UNITS

Input:	Concentrated Pt. loads	kip
	Modulus of elasticity	kip/sq. in
	Member area	sq. in.
	Moment of inertia	in.^{4}
	Joint co-ordinates	ft.
	Spring constants	kips/ft. & kip-ft.
Output:	Axial, shear	kip
	Bending moment	kip-ft.
	Joint deflections	in.
	Member length	ft.

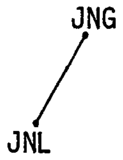
CONVENTIONS

JOINT CO-OR.



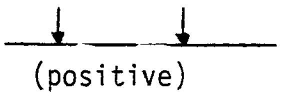
The origin, (0,0), may be located at any convenient position.

MEMBER IDENTIFICATION



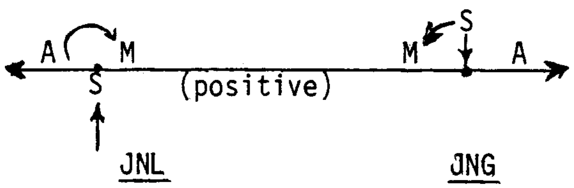
JNL - lower joint number, i.e., the joint with the algebraically lesser x-coordinate. For a vertical member, it is the joint with the lesser y-coordinate.

APPLIED LOADING



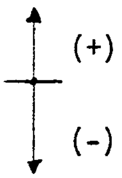
OUTPUT

Member stresses:



A - axial S - shear M - bending moment

Vertical Deflections:



Introduction to Example Problems

Four example problems — a simple beam, a two-span continuous beam, and two trusses — are described in the following pages. Through these problems, the coding and application of the program are demonstrated, as well as its scope and versatility. An interpretation of the printout is also given as well as a description of the format.

In all cases, the wheel loads and spacings will be listed in the printout. Likewise, the job title, as well the number of joints, members, and restrained joints will be listed. The user has the option to suppress the member and joint data from the printout.

A listing of the actual data file is given for each example problem. From these data files, the actual input, such as the area and moment of inertia of each member, can be verified.

Under the heading "MEMBER DATA", each member is listed by number, showing the lower and greater joint numbers (JNL and JNG); the member fixity at the lower and greater joint (KL and KG); and the area and moment of inertia. If KL or KG is equal to 1, then continuity occurs in the member; if KL or KG is equal to 0, then a pin connection is indicated.

Under the heading "JOINT DATA" each joint is listed by number, showing the horizontal and vertical co-ordinates for each joint.

Also, the structure code displacement numbers are shown for each joint, listing the horizontal, vertical, and rotation in order. Code "1". indicates no movement.

The band width and the number of unknowns are also listed, and, thus, the size of the array needed to store the band matrix can be determined.

As described earlier, the output is divided into two categories, that of the chord, and that of the web members (actually, all other remaining members).

A complete analysis is given for each member of the chord. The first heading, X, is the distance, measured from the left end of the panel member, at which the listed forces are calculated. It starts at zero (at the joint), and increases one foot at a time. The maximum positive bending moment to occur at that location (after all the wheels have passed on and off the structure) is shown in the second column. The associated shear and axial forces, i.e., those occurring simultaneously with the maximum positive bending moment, are listed in columns three and four. The associated axial force acts uniformly for the length of the member. Likewise, the maximum negative bending moment, and its associated shear and axial forces, are listed in the next three columns (5, 6 and 7). The absolute value for the shear force is listed in the next column, no. 8 (MAX. SHEAR). The value shown in the last column is the bending moment that occurs at that location when the axial force is a maximum.

The other structure members are listed in numerical order. For each member, the maximum tensile force and the absolute value of the associated bending moment occurring at either the lower or upper joint (the larger value being chosen) is given in the second and third columns. Likewise, the maximum compression and associated bending is given in the next two columns. The absolute value of the maximum shear is listed next. The member length is given in the final column.

Finally, the maximum deflection of the top chord, taken at the panel points, is listed.

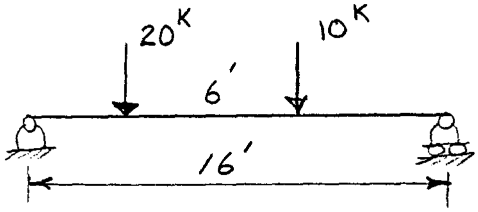
The results of program CRANE are verified by other programs in the first three examples.

Also, the relevance of the forces generated by the program CRANE with respect to design requirements is reviewed.

It cannot be overemphasized that the coding of a problem must reflect the realities of the actual design proposed: this is entirely in the hands of the designer. No attempt is made in the examples provided to justify the configuration, construction, or member selection. The function of this report is to illustrate the scope of the program, and to provide guidance in its usage.

Example #1 and #1A: Simple Beam

A simply supported beam is loaded as shown:



$A = 10 \text{ in.}^2$

$I = 1000 \text{ in.}^4$

From a design point of view, the most important information required is the maximum bending moment resulting from the movement of the loads across the beam: this value enables the designer to establish the cross-sectional properties to resist the stresses due to bending. Similarly, the maximum shear will allow the beam web to be designed. Having these two properties, a suitable beam can be safely designed. In the example given, these maximums are easily obtained by hand; however, in practice the number of wheels and span are generally much greater and the chore is disproportionately more difficult.

Having established the maximum bending moment and shear, it is advantageous to know the range of these forces, i.e., to have the envelope. In large girders (to support mill cranes) it is usually economical to change the cross-section at certain points to reflect the reduced stress levels. This is apparent in the graphs illustrating the envelopes for maximum bending and shear. Checking the bending values, it is possible to perhaps reduce the thickness of the beam flanges on the end sections. Regarding the shear, the center portion may have a reduced web thickness, or, using the graph, the intermediate stiffeners may be more widely spaced. Note that sign is not important for shear values.

A third benefit of the envelopes is that the designer can better locate any openings relative to the stress at a particular location. Accurate loads are available for the proper design of actual fabrication splices.

The printout of CRANE indicates that the maximum positive bending moment is 91.87 K-Ft., located 7 ft. from the left support, the simultaneous shear force at the same location is 13.12 Kips. Thus, it is possible to check combined bending and shear stresses as per the appropriate design codes.

The location and value of maximum positive bending are verified by hand:

$$X = \tfrac{1}{2} (\ell - P_2 a / P_1 + P_2) = \tfrac{1}{2} (16 - \frac{10\times6}{30}) = 7 \text{ Ft.}$$

$$M = (P_1 + P_2)X^2 / \ell \qquad = (10 + 20)\ 7^2 / 16 = 91.87 \text{ K-Ft.}$$

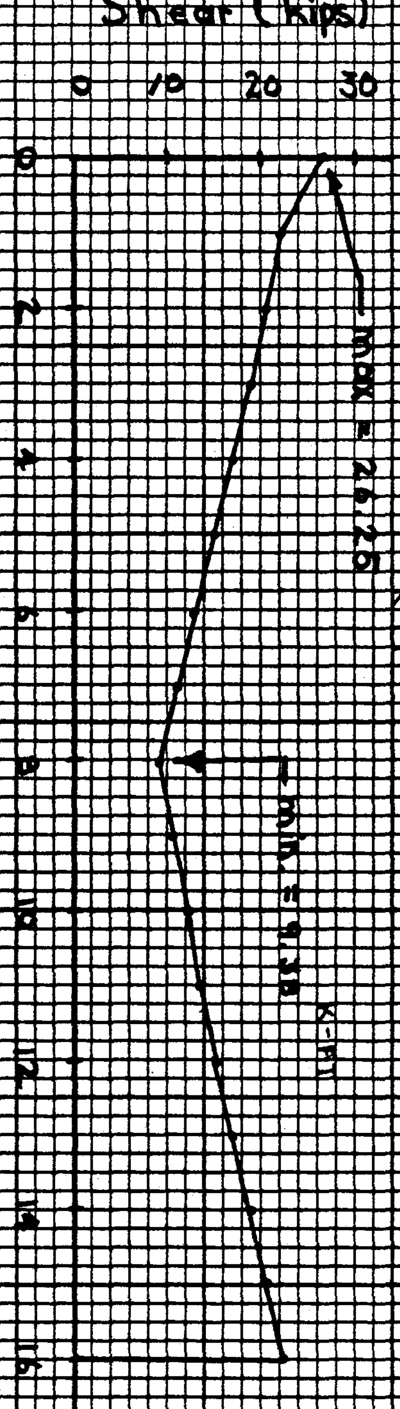
In many cases, the maximum deflection is a very strict parameter (span/1000 for crane girders), and these values are given for all joints on the chord. In example #1, the chord has been arbitrarily divided into 3 panels to demonstrate this facility in coding, as well as to provide a deflection printout. In example #1A, the same problem is done using a single member.

The deflection is a function of the moment of inertia, assumed 1000 in this case; if a different value were actually used, then the deflection would be a ratio of the inertias.

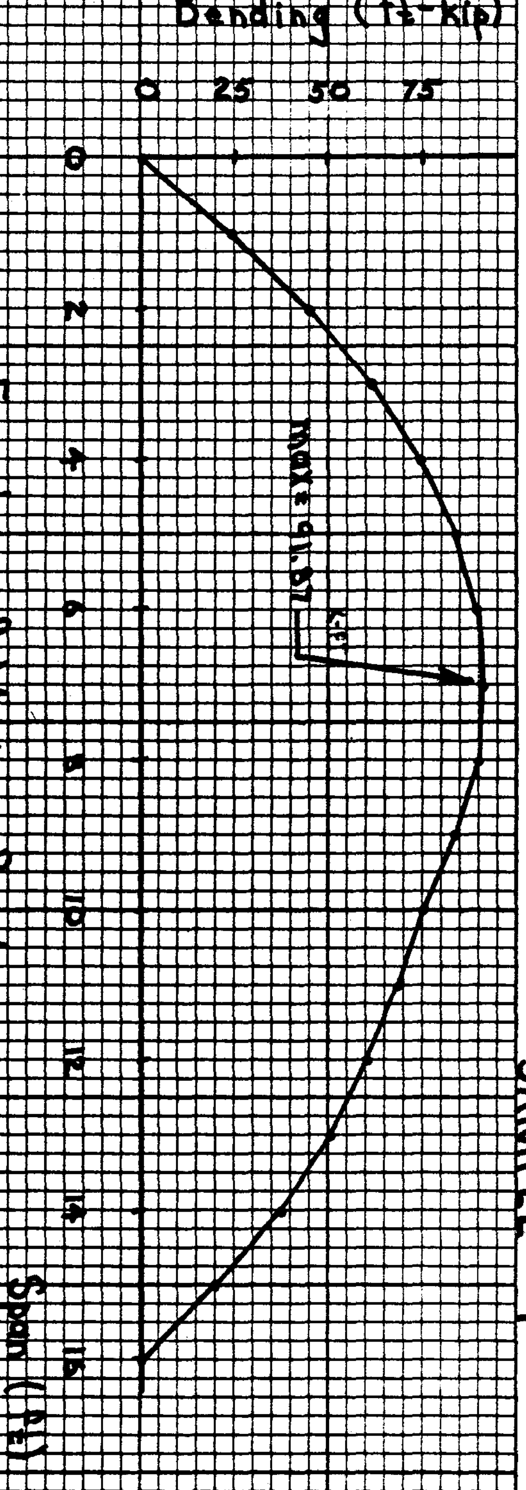
To further verify the output form CRANE, an unsophisticated program DEFN was written for simple beams. The results are shown here, confirming the results.

In example #1, the joint and member data is listed. Note that the KL and KG values are equal to 1, conforming to a continuous chord. In the joint data, the structure code numbers are listed. Note that at joint no. 1 the X and Y code is "1", indicating restraint conforming to the pin connection shown at the left support. Similarly, the roller connection at the right support is indicated by Y = 1 at joint no. 4.

The actual data files, FIRST and FIFTH, are also listed.



Envelope of Maximum Shear

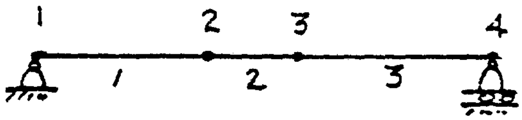


Envelope of Maximum Bending

SAMPLE #1

EXAMPLE #1

```
FILE NO. REQ'D. 3

DATA REQ@D:  NO. OF LOADS 2

DATA REQ'D:  WHEEL LOADS 10,20

DATA REQ'D:  LOAD SPACING 0,6

DATA PRINTOUT REQ'D.?   YES OR NO YES


SIMPLE BEAM  3 PANELS
```



```
JNTS.          MEM.         NO.RS.          MOD.E.
 4              3             2             29000.0



                 MEMBER DATA


MEMBER JNL JNG   KL   KG       AREA        INERTIA
 1       1   2    1    1      10.000      1000.000
 2       2   3    1    1      10.000      1000.000
 3       3   4    1    1      10.000      1000.000

                 JOINT DATA


JOINT   X-COORD.      Y-COORD.    X   Y   Z
  1          .00          .00     1   1   2
  2         7.00          .00     3   4   5
  3         9.00          .00     6   7   8
  4        16.00          .00     9   1  10

BAND WIDTH=  6          NO. OF UNKNOWNS=  10



WHEEL LOADS:  10.00  20.00
WHEEL POS'S:      0     -6



                                   **** TOP CHORD ANALYSIS ****



                                          MEM.#  1

                              MAX. AXIAL FORCE IN KIPS=     .00

 X      MAX.B.M.   ASS. AX.   ASS.SHR.   MAX.B.M.    ASS. AX.   ASS.SHR.      MAX.     ASS.SM.
        POSITIVE      FORCE      FORCE   NEGATIVE       FORCE      FORCE     SHEAR     MAX.AX.
 0          .00        .00      11.25      -.00         .00      15.00     26.25        .00
 1        24.37        .00      24.37       .00         .00        .00     24.37        .00
 2        45.00        .00      22.50       .00         .00        .00     22.50        .00
 3        61.87        .00      20.62       .00         .00        .00     20.62        .00
 4        75.00        .00      18.75       .00         .00        .00     18.75        .00
 5        84.37        .00      16.87       .00         .00
```

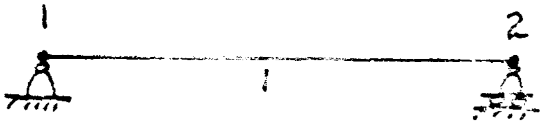
```
 7        91.87         .00       13.12        .00         .00         .00        13.12        .00

                                          MEM.#  2

                             MAX. AXIAL FORCE IN KIPS=     .00

 X       MAX.B.M.     ASS. AX.    ASS.SHR.    MAX.B.M.    ASS. AX.    ASS.SHR.       MAX.     ASS.BM.
         POSITIVE        FORCE       FORCE    NEGATIVE       FORCE       FORCE      SHEAR     MAX.AX.
 0        91.87         .00       -6.88        .00         .00         .00        11.25        .00
 1        89.99         .00       11.25        .00         .00         .00        11.25        .00
 2        84.37         .00        9.37        .00         .00         .00         9.37        .00

                                          MEM.#  3

                             MAX. AXIAL FORCE IN KIPS=     .00

 X       MAX.B.M.     ASS. AX.    ASS.SHR.    MAX.B.M.    ASS. AX.    ASS.SHR.       MAX.     ASS.BM.
         POSITIVE        FORCE       FORCE    NEGATIVE       FORCE       FORCE      SHEAR     MAX.AX.
 0        84.37         .00      -10.62        .00         .00         .00        10.62        .00
 1        75.00         .00      -12.50        .00         .00         .00        12.50        .00
 2        68.75         .00      -13.75        .00         .00         .00        13.75        .00
 3        60.00         .00      -15.00        .00         .00         .00        15.00        .00
 4        50.62         .00      -16.87        .00         .00         .00        16.87        .00
 5        37.50         .00      -18.75        .00         .00         .00        18.75        .00
 6        20.62         .00      -20.62        .00         .00         .00        20.62        .00
 7          .00         .00      -22.50       -.00         .00       -2.50        22.50        .00



                       **** MAX. VERTICAL DEFN'S. TOP CHORD ****

                                JNT. NO.     DEFLN'S.
                                    1          .0000
                                    2         -.1264
                                    3         -.1247
                                    4          .0000
 END OF PROGRAM
:
```

DATA SHEET, EXAMPLE # 1

```
 T THIRD,UNN
/L ALL
    1      3
    2      1,2,3,4
    3      SIMPLE BEAM  3 PANELS
    4      4,3,29000,1,0
    5      1,0,0
    6      2,7,0
    7      3,7,0
    8      4,16,0
    9      1,3,0,1
   10      4,1,0,1
   11      1,1,2,10,1000
   12      2,2,3,0,0
   13      3,3,4,0,0
/
```

EXAMPLE #1A

```
RUN CRANE

FILE NO. REQ'D. 2

DATA REQ0D:  NO. OF LOADS 2

DATA REQ'D:  WHEEL LOADS 10,20

DATA REQ'D:  LOAD SPACING 0,6

DATA PRINTOUT REQ'D.?   YES OR NO NO
```



```
SIMPLE BEAM



BAND WIDTH=  3          NO. OF UNKNOWNS=   4



WHEEL LOADS:  10.00  20.00
WHEEL POS'S:      0     -6



                                        **** TOP CHORD ANALYSIS ****



                                                   MEM.#  1

                                     MAX. AXIAL FORCE IN KIPS=     .00

X       MAX.B.M.     ASS. AX.     ASS.SHR.     MAX.B.M.     ASS. AX.     ASS.SHR.        MAX.      ASS.BM.
        POSITIVE        FORCE        FORCE     NEGATIVE        FORCE        FORCE        SHEAR      MAX.AX.
0            .00          .00          .00         -.00          .00        16.88        26.25          .00
1          24.38          .00        24.38          .00          .00          .00        24.38          .00
2          45.00          .00        22.50          .00          .00          .00        22.50          .00
3          61.87          .00        20.63          .00          .00          .00        20.63          .00
4          75.00          .00        18.75          .00          .00          .00        18.75          .00
5          84.37          .00        16.88          .00          .00          .00        16.88          .00
6          90.00          .00        15.00          .00          .00          .00        15.00          .00
7          91.88          .00        13.13          .00          .00          .00        13.13          .00
8          90.00          .00        11.25          .00          .00          .00        11.25          .00
9          84.38          .00       -10.62          .00          .00          .00        10.62          .00
10         75.00          .00       -12.50          .00          .00          .00        12.50          .00
11         68.75          .00       -13.75          .00          .00          .00        13.75          .00
12         60.00          .00       -15.00          .00          .00          .00        15.00          .00
13         50.63          .00       -16.88          .00          .00          .00        16.88          .00
14         37.50          .00       -18.75          .00          .00          .00        18.75          .00
15         20.63          .00       -20.63          .00          .00          .00        20.63          .00
16           .00          .00       -11.25          .00          .00          .00        22.50          .00



                              **** MAX. VERTICAL DEFN'S. TOP CHORD ****

                                         JNT. NO.     DEFLN'S.
                                             1          .0000
                                             2          .0000

 END OF PROGRAM
```

DATA, EXAMPLE #1A

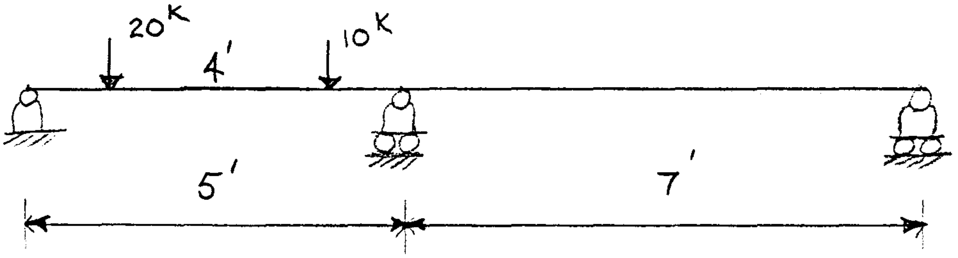
```
L ALL
   1      1
   2      1,2
   3      SIMPLE BEAM
   4      2,1,29000,2,0
   5      1,0,0
   6      2,16,0
   7      1,0,0,1
   8      2,1,0,1
   9      1,1,2,10,1000
/
```

VERIFICATION: EXAMPLE #1

```
DEFN        16:22EST     03/16/77

DATA REQ'D: NO. OF LDS.;SPAN;INERTIA;MOD.OF ELASTIC.?2,16,1000,29000

DATA REQ'D: LOADS?10,20

DATA REQ'D:  LOAD SPACING?0,6

       X          MAX.DEFL.        MAX.B.MOM.
       0           0.0000           0.0000
       1           0.0254          24.3750
       2           0.0499          45.0000
       3           0.0723          61.8750
       4           0.0918          75.0000
       5           0.1080          84.3750
       6           0.1198          90.0000
       7           0.1264          91.8750
       8           0.1279          90.0000
       9           0.1247          84.3750
      10           0.1170          75.0000
      11           0.1051          68.7500
      12           0.0894          60.0000
      13           0.0705          50.6250
      14           0.0487          37.5000
      15           0.0248          20.6250
      16           0.               0.


 MAX. REACTION=     26.25


 MAX. SHEAR=     26.25

 PROGRAM STOP AT 1010

 USED     6.68 UNITS
```

Example #2: Continuous Beam

A two-span continuous beam is loaded as shown:



The design requirements are essentially the same as for a simple beam except the added feature of an intermediate support creates the extra dimension of negative bending. The envelopes for both positive and negative bending are shown graphically, indicating the maximum values.

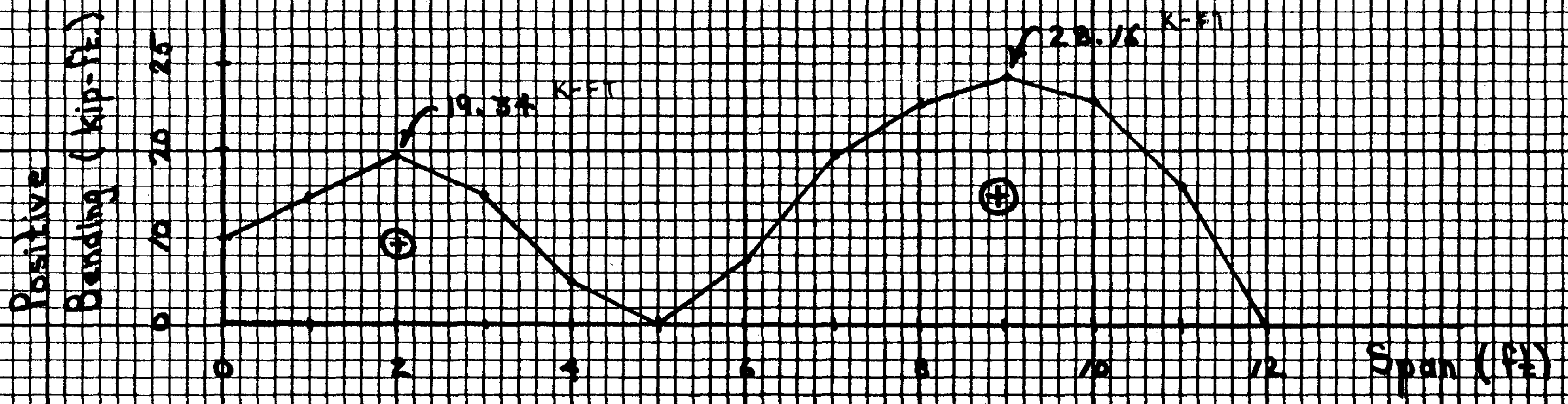
Because of the negative bending created over the center support, the compression flange is the bottom flange, and may have to be braced laterally.

Also, the range of stress reversal is established, and if fatigue is a design criteria, the data is available. Again, if fatigue is a concern, then the designer has a definition of the extent and magnitude of the tension zones, and can thus make a judgement regarding welded connections or fabrication imperfections located in these areas.

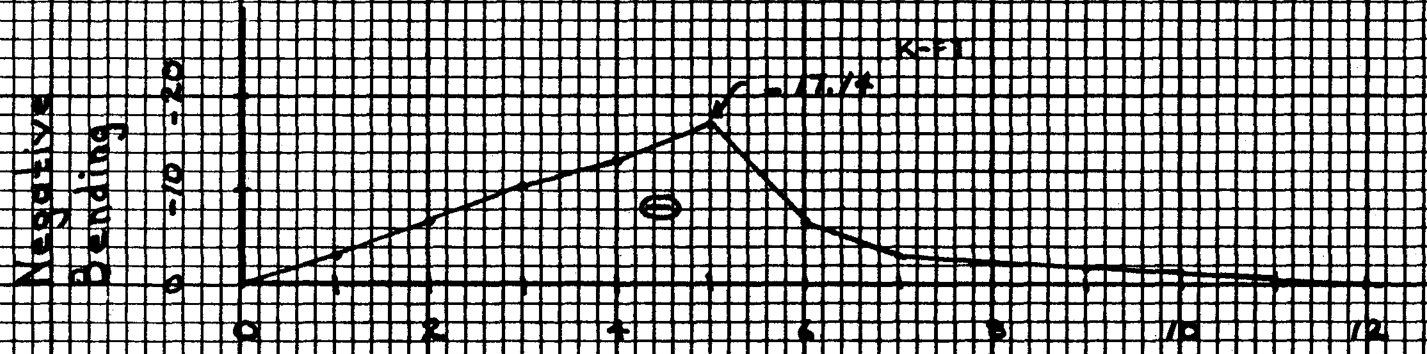
As in example #1, the numerical results of CRANE have been verified by a simple program CONT, based on the "three moment equation".

The coding diagram is shown on the printout, and the data file SECOND is listed. Again, the member and joint data are listed with the main printout. The structure code numbers reflect the joints which have been restrained in accordance with the diagram (1 indicates no movement allowed).

EXAMPLE # 2



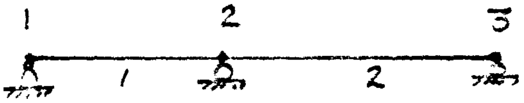
Envelope of Maximum Positive Bending



Envelope of Maximum Negative Bending

EXAMPLE #2

```
RUN CRANE

FILE NO. REQ'D. 1

DATA REQ'D:  NO. OF LOADS 2

DATA REQ'D:  WHEEL LOADS 10,20

DATA REQ'D:  LOAD SPACING 0,4

DATA PRINTOUT REQ'D.?   YES OR NO YES
```



```
CONT.BEAM


JNTS.          MEM.        NO.RS.          MOD.E.
 3              2            3             29000.0



                MEMBER DATA


MEMBER JNL JNG   KL   KG        AREA         INERTIA
 1      1   2    1    1        10.000       1000.000
 2      2   3    1    1        10.000       1000.000

                JOINT DATA


JOINT   X-COORD.     Y-COORD.    X   Y   Z
  1         .00          .00     1   1   2
  2        5.00          .00     3   1   4
  3       12.00          .00     5   1   6

BAND WIDTH=  4          NO. OF UNKNOWNS=   6



WHEEL LOADS:  10.00  20.00
WHEEL POS'S:      0     -4



                                  **** TOP CHORD ANALYSIS ****




                                          MEM.#  1

                              MAX. AXIAL FORCE IN KIPS=     .00

 X     MAX.B.M.   ASS. AX.   ASS.SHR.  MAX.B.M.   ASS. AX.   ASS.SHR.      MAX.    ASS.DX.
       POSITIVE     FORCE      FORCE   NEGATIVE     FORCE      FORCE      SHEAR    MAX.AX.
 0          .00       .00       5.30      -.00        .00       3.20      21.40       .00
 1        15.20       .00      15.20     -3.43        .00      -3.43      15.20      -.00
 2        19.34       .00     -10.33     -6.86        .00      -3.43      10.33      -.00
 3        14.91       .00     -15.03    -10.29        .00      -3.43      15.03      -.00
 4         5.60       .00      -9.60    -13.71        .00      -3.43      18.77      -.00
 5          .00       .00        .00    -17.14        .00      -3.43      21.43      -.00
```

```
                                        MEM.# 2

                                   MAX. AXIAL FORCE IN KIPS=      .00

X      MAX.B.M.     ASS. AX.     ASS.SHR.     MAX.B.M.     ASS. AX.     ASS.SHR.        MAX.      ASS.BM.
       POSITIVE        FORCE        FORCE     NEGATIVE        FORCE        FORCE       SHEAR      MAX.AX.
0           .00          .00          .00       -17.14          .00        18.16       25.31         -.00
1          7.45          .00        22.09        -6.16          .00         7.69       22.09         -.00
2         19.18          .00        18.16        -2.86          .00          .57       18.16          .00
3         25.31          .00        13.67        -2.29          .00          .57       13.67          .00
4         28.16          .00        10.61        -1.71          .00          .57       10.61          .00
5         25.51          .00       -12.76        -1.14          .00          .57       12.76          .00
6         16.33          .00       -16.33         -.57          .00          .57       16.33          .00
7           .00          .00       -11.84         -.00          .00          .57       20.00          .00



                           **** MAX. VERTICAL DEFN'S. TOP CHORD ****

                                    JNT. NO.     DEFLN'S.
                                        1           .0000
                                        2           .0000
                                        3           .0000
 END OF PROGRAM
:EDITOR

HP32201A.7.3  EDIT/3000  WED, DEC 20, 1978, 11:43 AM
(C) HEWLETT-PACKARD CO. 1978
/T FIRST,UNN
/L ALL
    1     2
    2     1,2,3
    3     CONT.BEAM
    4     3,2,29000,3,0
    5     1,0,0
    6     2,5,0
    7     3,12,0
    8     1,0,0,1
    9     2,1,0,1
   10     3,1,0,1
   11     1,1,2,10,1000
   12     2,2,3,0,0
/E

 END OF SUBSYSTEM
:
```

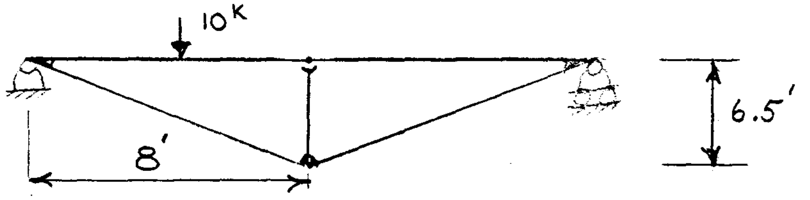
DATA

VERIFICATION, #2

```
CONT4      16:25EST    03/16/77

DATA REQ'D:  NO. OF LOADS; LEFT SPAN; RIGHT SPAN?2,5,7

DATA REQ'D:  MAGNITUDE OF LOADS?10,20

DATA REQ'D:  LOAD SPACING?0,4

     X       MAX.BM.P.     MAX.BM.N.
     1         15.200        -3.429
     2         19.343        -6.857
     3         14.914       -10.286
     4          5.600       -13.714
     5          0.          -17.143
     6          7.449        -6.163
     7         19.184        -2.857
     8         25.306        -2.286
     9         28.163        -1.714
    10         25.510        -1.143
    11         16.327        -0.571

MAX.L.R.=  21.40     MAX.C.R.=   26.73     MAX.R.R.=   20.00

PROGRAM STOP AT 1070

USED     6.61 UNITS
```

Example #3: King-Post Truss

The truss is loaded as shown.



The basic differences in this problem, compared to the first two examples, is that forces in the top chord are further complicated by the axial loads resulting from the truss action of the structure. Also, the analysis of the web members is included.

In this example, the data printout has been suppressed, by option. A listing of the actual data (generally kept in a designer's notes) can be found in data file THIRD. Note that all members are rigidly connected, except for the top of the vertical (mem. 5; line 240 of data file). This reflects actual fabrication practice.

The basic comments made in example #2 on the continuous beam re the negative bending are equally applicable here. However, the axial force must be accounted for.

The top chord must be designed as a beam-column. The three design combinations have been shown graphically, for one panel (structure is symmetrical):

1.0 Combination of maximum positive bending with the associated axial force.

2.0 Maximum negative bending combined with the associated axial force.

3.0 Maximum axial force combined with the associated bending.

The case which governs depends on the member sizes and bracing system which the designer employs.

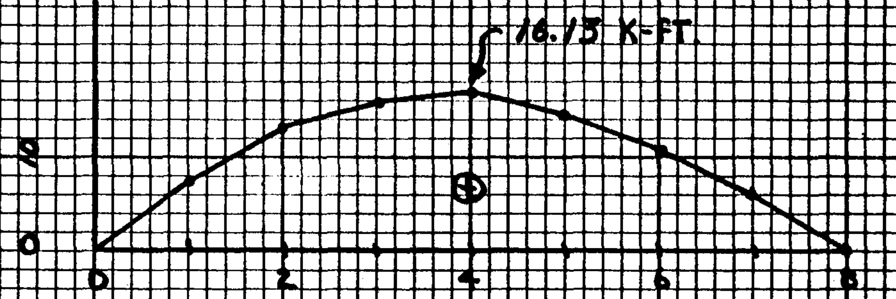
The chord members are also beam-columns in theory; however, the bending moments are so small that they can be neglected. Thus, the diagonals would be designed as tension members, and the center post as a compression member.

The option to suppress a data printout was used; however, data file THIRD has been listed.

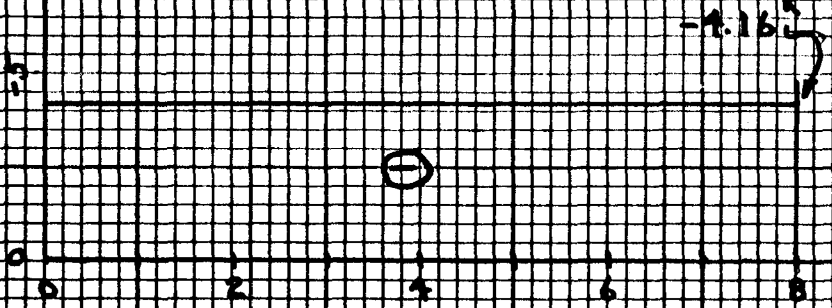
The results of CRANE were verified by a statical analysis . It is known that the axial forces, positive bending at the center support, and vertical deflection are all at a maximum when the single load is at mid-span.

EXAMPLE #3

①

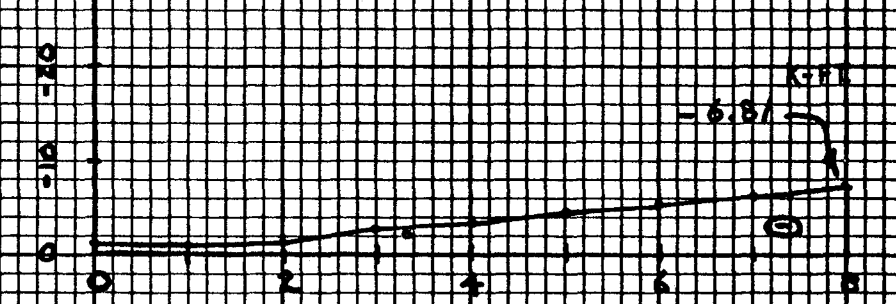


Envelope: Max. Pos. Bending

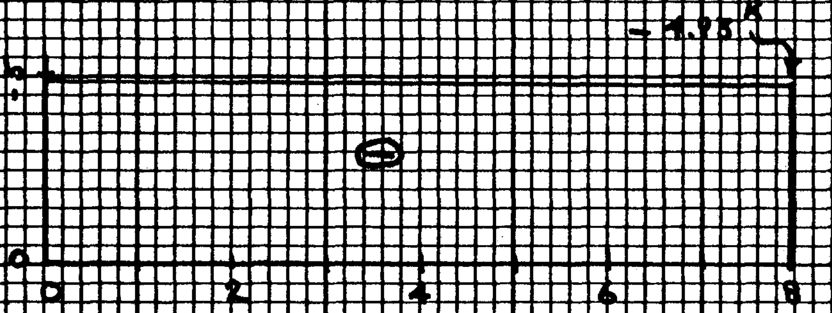


Associated Axial Force

②

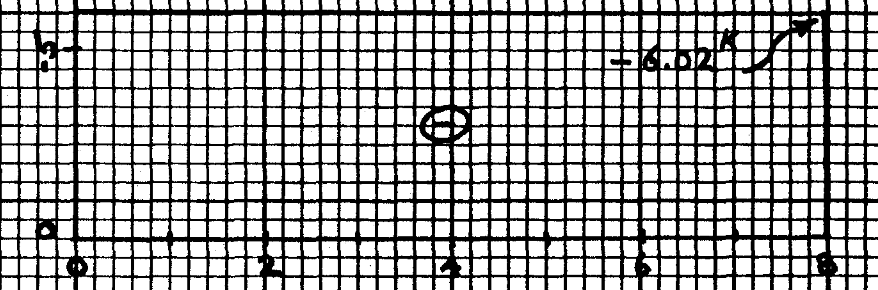


Envelope: Max. Neg. Bending

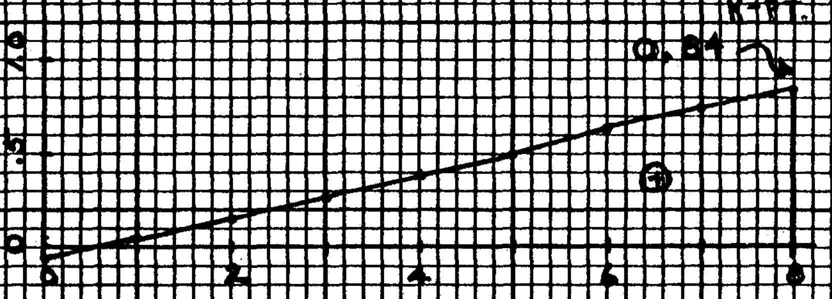


Associated Axial Force

③



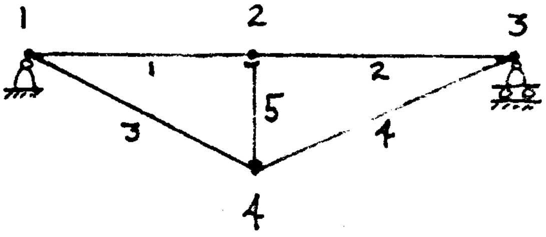
Maximum Axial Force



Associated Bending

EXAMPLE # 3

```
FILE NO. REQ'D. 4

DATA REQ@D:  NO. OF LOADS 1

DATA REQ'D:  WHEEL LOADS 10

DATA REQ'D:  LOAD SPACING 0

DATA PRINTOUT REQ'D.?   YES OR NO NO


SIMPLE KING-POST TRUSS
```



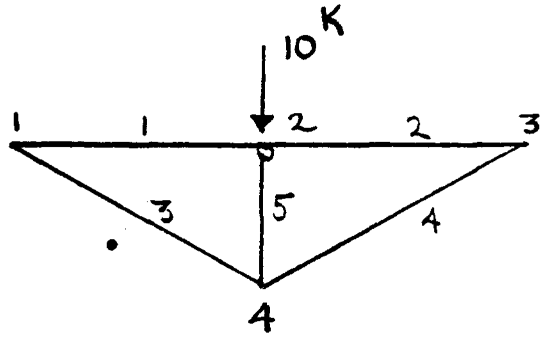
```
BAND WIDTH=  9          NO. OF UNKNOWNS=  10


WHEEL LOADS:  10.00
WHEEL POS'S:      0


                    **** TOP CHORD ANALYSIS ****


                              MEM.#  1

                    MAX. AXIAL FORCE IN KIPS=   -6.02

X     MAX.B.M.   ASS. AX.   ASS.SHR.   MAX.B.M.   ASS. AX.   ASS.SHR.      MAX.   ASS.BM.
      POSITIVE      FORCE      FORCE   NEGATIVE      FORCE      FORCE     SHEAR   MAX.AX.
0          .22      -4.89      -.88      -1.06      -3.25       5.66      8.56     -.05
1         7.94      -1.14      8.56       -.66      -4.12       -.87      8.56      .06
2        13.24      -2.23      7.10      -1.54      -4.89       -.88      7.10      .17
3        15.92      -3.25      5.66      -2.42      -4.89       -.88      5.66      .28
4        16.13      -4.16     -5.72      -3.29      -4.89       -.88      5.72      .39
5        14.19      -4.93     -7.00      -4.17      -4.89       -.88      7.00      .50
6        10.56      -5.52     -8.15      -5.05      -4.89       -.88      8.15      .62
7         5.86      -5.90     -9.12      -5.93      -4.89       -.88      9.12      .73
8          .84      -6.02       .11      -6.81      -4.89       -.88      9.12      .84

                              MEM.#  2

                    MAX. AXIAL FORCE IN KIPS=   -6.02

X     MAX.B.M.   ASS. AX.   ASS.SHR.   MAX.B.M.   ASS. AX.   ASS.SHR.      MAX.   ASS.BM.
      POSITIVE      FORCE      FORCE   NEGATIVE      FORCE      FORCE     SHEAR   MAX.AX.
0          .84      -6.02      -.11      -6.81      -4.89        .88      9.12      .84
1         5.86      -5.90      9.12      -5.93      -4.89        .88      9.12      .73
2        10.56      -5.52      8.15      -5.05      -4.89        .88      8.15      .62
3        14.19      -4.93      7.00      -4.17      -4.89        .88      7.00      .50
4        16.13      -4.16      5.72      -3.29      -4.89        .88      5.72      .39
5        15.92      -3.25     -5.66      -2.42      -4.89        .88      5.66      .28
6        13.24      -2.23     -7.10      -1.54      -4.89        .88      7.10      .17
7         7.94      -1.14     -8.56       -.66      -4.12        .87      8.56      .06
8          .22      -4.89       .88      -1.06      -3.25      -5.66     10.00     -.05
```

```
                         **** BTM.CHORD & WEB MEMBER ANALYSIS ****

  M     MAX.TEN.     ASS.B.M.     MAX.COM.     ASS.B.M.     MAX.SHR.       LENGTH
  3         7.76          .05          .00          .00          .14        10.31
  4         7.76          .05          .00          .00          .14        10.31
  5          .00          .00        -9.78          .00          .04         6.50


                         **** MAX. VERTICAL DEFN'S. TOP CHORD ****

                                   JNT. NO.     DEFLN'S.
                                       1          .0000
                                       2        -.0103
                                       3          .0000
 END OF PROGRAM
:
```

DATA, EXAMPLE # 3

```
? FIRTH,JNN
/L ALL
   1     2
   2     1,2,3
   3     SIMPLE KING-POST TRUSS
   4     4,5,29000,2,0
   5     1,0,0
   6     2,8,0
   7     3,16,0
   8     4,8,-6.5
   9     1,0,0,1
  10     3,1,0,1
  11     1,1,2,12,100
  12     2,2,3,0,0
  13     3,1,4,10,10
  14     4,4,3,0,0
  15     5,4,-2,0,0
/
```

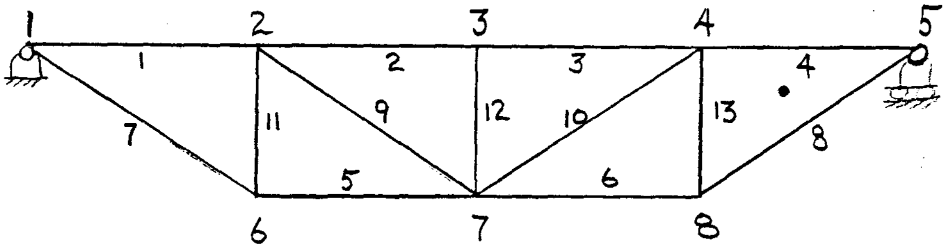
VERIFICATION, EXAMPLE #3



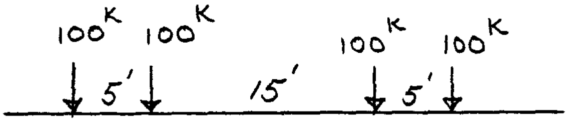
```
JACK1       16:20EST    03/17/77

FILE NO. REQ'D.?3

DATA PRINTOUT REQ'D? --- YES OR NO?NO


 SAMPLE TRUSS


JNTS.    MEM.    LD.CS.    E         NR    NS
  4       5       1      29000.0     2     0



BAND WIDTH=  9          NO. OF UNKNOWNS=  10



WEIGHT OF STRUCTURE(STEEL) IN TONS=    0.73




LOAD CASE  1 ****  10 KIP LOAD AT CENTER SPAN

 JOINT NO.   X-FORCE      Y-FORCE      MOMENT
     2          0.         -10.00        0.

 NO MEMBER LOADS


JOINT TRANS. REQ'D? -- YES OR NO?YES


JOINT   X-DEFLEC   Y-DEFLEC     ROTATION
 1         0.         0.        -0.00016
 2       -0.0020    -0.0103      0.00000
 3       -0.0040     0.          0.00016
 4       -0.0020    -0.0077      0.00000

MEMBER   AXIAL    SHEAR   B.M.LOWER  B.M.UPPER   LENGTH
 1       -6.02     0.11      -0.05       0.84      8.00
 2       -6.02    -0.11       0.84      -0.05      8.00
 3        7.76    -0.00       0.05       0.01     10.31
 4        7.76     0.00       0.01       0.05     10.31
 5       -9.78     0.00      -0.00       0.        6.50

PROGRAM STOP AT 4270

USED     3.41 UNITS
```

Example #4: Multi-panel Truss

The truss is loaded as shown:



Loading top chord:



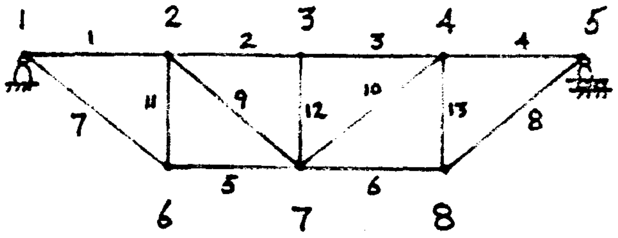
In this final example, no new aspects of the program are described. With the exception of stress reversal in the web members, no new interpretation of the printout is required. The essential purpose of this problem is to demonstrate the strength of the program as well providing additional coding guidelines. The loads and resulting member forces are however more indicative of actual design applications.

Of special importance is the stress reversal in members 9 and 10, the interior diagonals. These members, and their connections, must be designed for a maximum tensile force of 211.12 Kips as well as a maximum compressive force of 83.83 Kips.

The actual input is listed in data file THIRD. All members were assumed to be rigidly connected; the top chord had an area and moment of inertia of 50 and 3000 respectively, while all web and bottom chord members were given an area and moment of inertia of 25 and 100.

EXAMPLE #4

```
ERR 1
:RUN CRANE


FILE NO. REQ'D. 5

DATA REQ@D:  NO. OF LOADS 4

DATA REQ'D:  WHEEL LOADS 100,100,100,100

DATA REQ'D:  LOAD SPACING 0,5,15,5

DATA PRINTOUT REQ'D.?   YES OR NO YES


TEST RUN: TRUSS
```



```
JNTS.          MEM.          NO.RS.            MOD.E.
 8             13              2               29000.0



                 MEMBER DATA


MEMBER JNL JNG   KL   KG       AREA        INERTIA
  1      1   2    1    1      50.000       3000.000
  2      2   3    1    1      50.000       3000.000
  3      3   4    1    1      50.000       3000.000
  4      4   5    1    1      50.000       3000.000
  5      6   7    1    1      25.000        100.000
  6      7   8    1    1      25.000        100.000
  7      1   6    1    1      25.000        100.000
  8      8   5    1    1      25.000        100.000
  9      2   7    1    1      25.000        100.000
 10      7   4    1    1      25.000        100.000
 11      6   2    1    1      25.000        100.000
 12      7   3    1    1      25.000        100.000
 13      8   4    1    1      25.000        100.000

                 JOINT DATA


JOINT   X-COORD.     Y-COORD.     X   Y   Z
  1         .00          .00      1   1   2
  2       15.00          .00      3   4   5
  3       30.00          .00      6   7   8
  4       45.00          .00      9  10  11
  5       60.00          .00     12   1  13
  6       15.00       -10.00     14  15  16
  7       30.00       -10.00     17  18  19
  8       45.00       -10.00     20  21  22

BAND WIDTH= 17          NO. OF UNKNOWNS=  22



WHEEL LOADS: 100.00 100.00 100.00 100.00
WHEEL POS'S:      0     -5    -20    -25
```

```
                                             **** TOP CHORD ANALYSIS ****


                                                           MEM.#  1

                                             MAX. AXIAL FORCE IN KIPS= -328.77

  X      MAX.B.M.      ASS. AX.      ASS.SHR.      MAX.B.M.      ASS. AX.      ASS.SHR.          MAX.      ASS.BM.
         POSITIVE         FORCE         FORCE      NEGATIVE         FORCE         FORCE         SHEAR      MAX.AX.
  0          1.97       -283.96         -6.42        -14.49       -117.37        101.63        161.01        -4.69
  1        134.68        -65.49        145.70         -4.45       -283.96         -6.42        145.70        13.04
  2        248.28        -83.36        130.64        -10.87       -283.96         -6.42        130.64        30.77
  3        333.63       -100.59        115.92        -17.30       -283.96         -6.42        115.92        48.50
  4        392.03       -117.07        101.63        -23.72       -283.96         -6.42        101.63        66.22
  5        425.19       -132.64         87.88        -30.14       -283.96         -6.42         87.88        83.95
  6        435.21       -147.18         74.77        -36.56       -283.96         -6.42         74.77       101.68
  7        424.59       -160.55         62.40        -42.98       -283.96         -6.42         76.78       119.41
  8        413.21       -100.59        -84.08        -49.40       -283.96         -6.42         90.44       137.14
  9        400.18       -117.07        -98.37        -55.82       -283.96         -6.42        103.48       154.87
 10        364.60       -132.64       -112.12        -62.24       -283.96         -6.42        115.90       172.59
 11        309.07       -147.18       -125.23        -68.66       -283.96         -6.42        127.70       190.32
 12        236.58       -160.55       -137.60        -82.77       -242.56        -39.84        138.81       208.05
 13        150.52       -172.61       -149.14       -123.67       -246.75        -47.57        149.18       125.78
 14         93.10       -325.06        -93.44       -185.62       -271.36        -76.78        159.74        43.51
 15         47.74       -120.22          3.27       -268.84       -282.09        -90.44        159.74       -38.76

                                                           MEM.#  2

                                             MAX. AXIAL FORCE IN KIPS= -423.53

  X      MAX.B.M.      ASS. AX.      ASS.SHR.      MAX.B.M.      ASS. AX.      ASS.SHR.          MAX.      ASS.BM.
         POSITIVE         FORCE         FORCE      NEGATIVE         FORCE         FORCE         SHEAR      MAX.AX.
  0         45.61       -261.08        -10.90       -271.75       -317.03         73.22        153.86       -99.73
  1        105.93       -422.40        140.40       -202.03       -332.80         62.13        153.86        17.68
  2        184.95       -423.36        129.05       -146.13        -70.24         14.78        143.08       135.09
  3        252.50       -423.53        117.41       -131.35        -70.24         14.78        131.54       252.50
  4        306.72       -422.90        105.57       -116.58        -70.24         14.78        119.43       269.91
  5        346.16       -421.47         93.62       -101.80        -70.24         14.78        106.91       287.32
  6        369.81       -419.19         81.68        -87.03        -70.24         14.78         95.73       304.73
  7        377.37       -415.97         69.93        -72.25        -70.24         14.78         84.46       322.14
  8        369.21       -411.71         58.53        -57.47        -70.24         14.78         82.59       339.55
  9        354.60       -247.91        -80.57        -52.50       -261.08        -10.90         94.43       256.96
 10        334.09       -263.11        -93.09        -63.41       -261.08        -10.90        106.38       174.37
 11        295.45       -282.04       -104.27        -74.31       -261.08        -10.90        118.32        91.78
 12        243.81       -300.06       -115.54        -85.21       -261.08        -10.90        130.07         9.19
 13        180.08       -317.03       -126.78       -114.66       -420.68        -48.64        141.47       -73.40
 14        105.66       -332.80       -137.87       -168.83       -422.40        -59.60        152.34      -155.99
 15         45.99        -80.24         14.51       -238.58       -423.53        -82.59        152.34      -238.58

                                                           MEM.#  3

                                             MAX. AXIAL FORCE IN KIPS= -423.53

  X      MAX.B.M.      ASS. AX.      ASS.SHR.      MAX.B.M.      ASS. AX.      ASS.SHR.          MAX.      ASS.BM.
         POSITIVE         FORCE         FORCE      NEGATIVE         FORCE         FORCE         SHEAR      MAX.AX.
  0         45.99        -80.24        -14.51       -238.58       -423.53         82.59        152.34      -238.58
  1        105.66       -332.80        137.87       -168.83       -422.40         59.60        152.34      -155.99
  2        180.08       -317.03        126.78       -114.66       -420.68         48.64        141.47       -73.40
  3        243.81       -300.06        115.54        -85.21       -261.08         10.90        130.07         9.19
  4        295.45       -282.04        104.27        -74.31       -261.08         10.90        118.32        91.78
  5        334.09       -263.11         93.09        -63.41       -261.08         10.90        106.38       174.37
  6        354.60       -247.92         80.57        -52.50       -261.08         10.90         94.43       256.96
  7        369.21       -411.71        -58.53        -57.47        -70.24        -14.78         82.59       339.55
  8        377.37       -415.97        -69.93        -72.25        -70.24        -14.78         84.46       322.14
```

```
                                                      -87.02      -70.24      -14.78      95.73      304.73
  10       346.16      -421.47      -93.62      -101.80      -70.24      -14.78      106.91      287.32
  11       306.72      -422.90     -105.57      -116.58      -70.24      -14.78      119.43      269.91
  12       252.50      -423.53     -117.41      -131.35      -70.24      -14.78      131.54      252.50
  13       184.95      -423.36     -129.05      -146.13      -70.24      -14.78      143.08      135.09
  14       105.93      -422.40     -140.40      -202.03     -332.80      -62.13      153.86       17.68
  15        45.61      -261.08       10.90      -271.75     -317.03      -73.22      153.86      -99.73

                                          MEM.#  4

                              MAX. AXIAL FORCE IN KIPS= -329.77

   X      MAX.B.M.     ASS. AX.     ASS.SHR.     MAX.B.M.     ASS. AX.     ASS.SHR.       MAX.      ASS.BM.
          POSITIVE        FORCE        FORCE     NEGATIVE        FORCE        FORCE      SHEAR      MAX.AX.
   0         47.74      -120.22        -3.27      -260.04      -202.09        90.44     159.74       -38.76
   1         90.10      -325.06        93.44      -185.62      -271.36        76.78     159.74        43.51
   2        150.52      -172.61       149.14      -123.67      -246.75        47.57     149.18       125.78
   3        236.58      -160.55       137.60       -82.77      -242.56        39.84     138.81       208.05
   4        309.07      -147.18       125.23       -68.66      -283.96         6.42     127.70       190.32
   5        364.60      -132.64       112.12       -62.24      -283.96         6.42     115.90       172.60
   6        400.18      -117.07        98.37       -55.82      -283.96         6.42     103.48       154.87
   7        413.21      -100.59        84.08       -49.40      -283.96         6.42      90.44       137.14
   8        424.59      -160.55       -62.40       -42.98      -283.96         6.42      76.78       119.41
   9        435.21      -147.18       -74.77       -36.56      -283.96         6.42      74.77       101.68
  10        425.19      -132.64       -87.88       -30.14      -283.96         6.42      87.88        83.95
  11        392.03      -117.07      -101.63       -23.72      -283.96         6.42     101.63        66.23
  12        333.63      -100.59      -115.92       -17.29      -283.96         6.42     115.92        48.50
  13        248.28       -83.36      -130.64       -10.87      -283.96         6.42     130.64        30.77
  14        134.68       -65.49      -145.70        -4.45      -283.96         6.42     145.70        13.04
  15          1.97      -283.96         6.42       -14.49      -117.07      -101.63     161.01        -4.69


                        **** BTM.CHORD & WEB MEMBER ANALYSIS ****

   M      MAX.TEN.      ASS.B.M.      MAX.COM.      ASS.B.M.      MAX.SHR.       LENGTH
   5        329.27          5.06           .00           .00           .67        15.00
   6        329.27          5.06           .00           .00           .67        15.00
   7        394.99          4.69           .00           .00          1.12        18.03
   8        394.99          4.69           .00           .00          1.12        18.03
   9        211.12          2.63        -83.83          3.29           .70        18.03
  10        211.12          2.63        -83.83          3.29           .70        18.03
  11           .00           .00       -218.52          2.78          2.60        10.00
  12         17.87          1.38       -161.12          6.24          2.03        10.00
  13           .00           .00       -218.52          2.78          2.60        10.00


                        **** MAX. VERTICAL DEFN'S. TOP CHORD ****

                                  JNT. NO.      DEFLN'S.
                                     1            .0000
                                     2           -.4978
                                     3           -.6635
                                     4           -.4978
                                     5            .0000

END OF PROGRAM
:
```

DATA, EXAMPLE #4

```
FIFTH,UNN
ALL
 1      4
 2      1,2,3,4,5
 3      TEST RUN, TRIES
 4      8,13,29000,2,0
 5      1,0,0
 6      2,15,0
 7      3,30,0
 8      4,45,0
 9      5,60,0
10      6,15,-10
11      7,10,-10
12      8,45,-10
13      1,8,0,1
14      5,1,0,1
15      1,1,2,50,3000
16      2,2,3,0,0
17      3,3,4,0,0
18      4,4,5,0,0
19      5,6,7,25,100
20      6,7,8,0,0
21      7,1,6,0,0
22      8,8,5,0,0
23      9,2,7,0,0
24      10,7,4,0,0
25      11,6,2,0,0
26      12,7,8,0,0
27      13,8,4,0,0
```

Conclusions

In practice, the program CRANE has been an unqualified success. Experienced designers have concluded that it provides the required structural forces in an accurate, quick, and facile manner. The program has been documented within Stelco, and is in use by the various engineering offices in the company.

In general terms, it enables a better design in less time. The Engineer is better able to devote more of his time to developing concepts, rather than on repetitive calculations. Several practical structural solutions can be studied, regardless of the geometry or degree of indeterminance of the structure.

In practice, many of the situations that were briefly discussed in the Introduction have been handled successfully with the aid of this program. For example, in the design of a new steelmaking facility, the wheel loadings and spacing of 4 cranes were considerably revised at a very late date. The deadline for placing an order for the steel plate for fabricating the girders was due. With varying spans and load combinations, 16 separate analyses would have been required. The results were, via CRANE, in the hands of the consultant in 3 hours. The plate order was placed.

In one of the mills at Hilton Works, Stelco, a newer, heavier crane was installed. The program quickly confirmed that the existing girder could be made into a king-post truss.

The alternate solution of adding a center column, making the simple girder into a continuous beam, was also quickly analysed.

At a construction site recently, a bracket was indiscriminately welded to a crane girder. A review of the original analysis by CRANE revealed that the stress in that particular area was below the critical value for fatique strength. The bracket was allowed to remain, as the process of removal might have done more harm than leaving it.

A rewarding side effect of the program has become apparent. It is an excellent teacher. Because of its relatively simple format and its availability, engineers and technologists are able to experiment. In effect, mathematical models are built and modified. Areas and moments of inertia can be revised, members can be deleted or added, and the results can be instantly evaluated.

It is hoped to combine CRANE with an optimization program to design an optimum runway girder.

APPENDIX

Program CRANE

DEC. 20/78

```
. ALL
$CONTROL   INIT,LOCATION,FILE=1-6,NOSOURCE,NOWARN,SEGMENT=ONE
      CHARACTER*5 INFILE(5)
      CHARACTER*21 FILE
      DIMENSION Z(1400),D1(25),D2(25),D3(25)
      DIMENSION BM(40),UM(40),VY(40),VYO(40)
      DIMENSIONND(25,3),NPM(40,6),JN(25),X(25),Y(25)
      DIMENSIONA(40),SM(40,36),KL(40),B(40),XM(40),YM(40),KG(40)
      DIMENSIONMN(40),JNL(40),JNG(40),NA(3),D(6),DM(40)
      DIMENSION FF(75)
      CHARACTER*3 NNN(20)
      DIMENSION XP(10,15),P(10,15),WL(15),LP(10),SHEAR(40),
     $AXIAL(40),BML(40),BMG(40),BP(10,25),S(10,25),
     $SMAX(10,25),BMMAX(10),BMNMAX(10),SSMAX(40),AMAX(10),
     $KSP(10),AAF(10,25),ASF(10,25),AAFN(10,25),ASFN(10,25)
      DIMENSION AAFE(10),ASFE(10),AAFEN(10),ASFEN(10)
      DIMENSION ABMM(10),AXP(40),AXN(40),ABMT(40),ABMC(40)
      DIMENSION ABM(10,25),D2M(11),SUBSHR(10),JNTC(11)
      REAL MAXPBM(10,25),MAXNBM(10,25)
      INTEGER RL(10),DB(15)
      CHARACTER*2 MAN,KAT
      DATA ND/75*1/,KL/40*1/,KG/40*1/
      DATA INFILE/"FIRST","SECND","THIRD","FORTH","FIFTH"/
      DATA FILE/"FILE FTN01=     ,OLD"/
      FILE[21]=%15C
      WRITE(6,*)"FILE NO. REQ'D."
      READ(5,*)IDF
      FILE[12:5]=INFILE(IDF)
      CALL COMMAND(FILE,I,J)
      IF(I.NE.0)DISPLAY "MPE ERR NO.",I,"ON FILE ",IDF
      WRITE(6,*)"DATA REQ@D:  NO. OF LOADS"
      READ(5,*)NWL
      WRITE(6,*)"DATA REQ'D:  WHEEL LOADS"
      READ(5,*)(WL(I),I=1,NWL)
      WRITE(6,*)"DATA REQ'D:  LOAD SPACING"
      READ(5,*)(DB(J),J=1,NWL)
      READ(1,*)NP
      DO 371 I=1,NWL
      DBR=DBR+DB(I)
  371 DB(I)=DBR
      DO 123 I=1,NWL
  123 DB(I)=-DB(I)
      NJTC=NP+1
      READ(1,*)(JNTC(N),N=1,NJTC)
      WRITE(6,*)"DATA PRINTOUT REQ'D.?   YES OR NO"
      READ(5,*)MAN
      READ(1,8866)NNN
 8866 FORMAT(20A3)
      WRITE(6, 8867)NNN
 8867 FORMAT(1H0,20A3,///)
      READ(1,*)NJ,NM,E,NR,NSP
      IF(MAN.EQ."NO") GOTO 950
      WRITE(6,*)"JNTS.         MEM.        NO.RS.          MOD.E."
      WRITE(6, 999)NJ,NM,NR,E
  999 FORMAT(1X,I2,11X,I3,12X,I1,13X,F7.1 ,///)
  950 DO90M=1,NJ
      READ(1,*)JN(M),X(M),Y(M)
      IF(JN(M)-M)8086,90,8086
   90 CONTINUE
      DO 214 I=1,NP
      LX1=JNTC(I)
      IX=I+1
      LX2=JNTC(IX)
```

```
      LP(I)=X(LX2)-X(LX1)
      LTC=LTC+LP(I)
214   RL(I)=LTC
      IF(NR.EQ.0) GO TO 963
      DO 962 I=1,NR
      READ(1,*)JNR,NR1,NR2,NR3
      ND(JNR,1)=NR1
      ND(JNR,2)=NR2
      ND(JNR,3)=NR3
962   CONTINUE
963   CONTINUE
      NU=2
      DO5I=1,NJ
      DO6J=1,3
      IF(ND(I,J))11,7,8
7     ND(I,J)=1
      GOTO11
8     IF(ND(I,J)-1)11,9,10
9     ND(I,J)=NU
      NU=NU+1
      GOTO11
10    N=ND(I,J)
      ND(I,J)=ND(N,J)
11    CONTINUE
6     CONTINUE
5     CONTINUE
      NU=NU-1
      IF(MAN.EQ."NO") GO TO 8418
      WRITE(6, 1200)
1200 FORMAT(17X,"MEMBER DATA",//)
      WRITE(6,*)"MEMBER JNL JNG   KL   KG       AREA        INERTIA"
8418 CONTINUE
      DO310I=1,NM
      READ(1,*)MN(I),JNL(I),JNG(I),A(I),B(I)
      IF(JNL(I).GT.0) GOTO 9301
      KL(I)=0
      JNL(I)=JNL(I)*(-1)
9301 IF(JNG(I).GT.0) GOTO 9302
      KG(I)=0
      JNG(I)=JNG(I)*(-1)
9302 KXX=I-1
      IF(A(I))8426,8425,8426
8425 A(I)=A(KXX)
      B(I)=B(KXX)
8426 ZL=JNL(I)
      ZG=JNG(I)
      IF(X(ZL)-X(ZG))9615,9617,9618
9618 JNL(I)=ZG
      JNG(I)=ZL
      WRITE(6,*)" MEM. DATA CHANGED"
      GOTO 9615
9617 IF(Y(ZL).GT.Y(ZG)) GOTO 9618
9615 IF(MN(I)-I)9614,9611,9614
9611 IF(MAN.EQ."NO") GOTO 310
      WRITE(6, 15)MN(I),JNL(I),JNG(I),KL(I),KG(I),A(I),B(I)
15    FORMAT (I6,I7,I4,2I5,3X,F10.3,3X,F11.3)
310   CONTINUE
      DO 500 I=1,NM
      JL=JNL(I)
      JG=JNG(I)
      NPM(I,1)=ND(JL,1)
      NPM(I,2)=ND(JL,2)
      NPM(I,3)=ND(JL,3)
      NPM(I,4)=ND(JG,1)
      NPM(I,5)=ND(JG,2)
```

```
 500  CONTINUE
      IF(MAN.EQ."NO") GOTO 22
C   BUILDING STRUCTURE STIFFNESS MATRIX
      WRITE(6, 23)
 23   FORMAT(1H0,16X,"JOINT DATA",//)
      WRITE(6,*)"JOINT   X-COORD.     Y-COORD.    X   Y   Z"
      DO71I=1,NJ
 71   WRITE(6, 3500)I,X(I),Y(I),ND(I,1),ND(I,2),ND(I,3)
 3500 FORMAT(2X,I2,4X,F8.2,5X,F8.2,4X,I2,2X,I2,2X,I2)
 22   NB=0
      DO 200 I=1,NM
      MAX=0
      MIN=3000
      DO 201 J=1,6
      IF(NPM(I,J).EQ.1) GOTO 201
      IF(NPM(I,J)-MAX) 203,203,204
 204  MAX=NPM(I,J)
 203  IF(NPM(I,J)-MIN)205,201,201
 205  MIN=NPM(I,J)
 201  CONTINUE
      NB1=MAX-MIN
      IF(NB1.GT.NB) NB=NB1
 200  CONTINUE
      NB=NB+1
      NV=NB*NU
      WRITE(6, 1305)NB,NU
      IF(NV.GT.1400) GOTO 444
 1305 FORMAT(1H0,"BAND WIDTH=",I3,10X,"NO. OF UNKNOWNS=",I4,//)
      WRITE(6, 1442)(WL(I),I=1,NWL)
      WRITE(6, 1447)(DB(K),K=1,NWL)
 1442 FORMAT(1H0,"WHEEL LOADS:",15F7.2)
 1447 FORMAT(1H ,"WHEEL POS'S:",15I7,///)
      DO 112 I=1,NM
      JG=JNG(I)
      JL=JNL(I)
      XM(I)=X(JG)-X(JL)
      YM(I)=Y(JG)-Y(JL)
      DM(I)=(XM(I)*XM(I)+YM(I)*YM(I))**.5
      C7=A(I)*E/DM(I)**3
      DO113J=1,36
 113  SM(I,J)=0.0
      SM(I,1)=XM(I)*XM(I)*C7
      SM(I,2)=XM(I)*YM(I)*C7
      SM(I,4)=-SM(I,1)
      SM(I,5)=-SM(I,2)
      SM(I,8)=YM(I)*YM(I)*C7
      SM(I,10)=-XM(I)*YM(I)*C7
      SM(I,11)=-SM(I,8)
      SM(I,22)=SM(I,1)
      SM(I,23)=SM(I,2)
      SM(I,29)=SM(I,8)
      IF(KL(I)+KG(I)-1)115,116,117
 116  C7=3.*E*B(I)/DM(I)**5/144.
      GOTO119
 117  C7=12.*E*B(I)/DM(I)**5/144.
 119  SM(I,1)=SM(I,1)+YM(I)*YM(I)*C7
      SM(I,2)=SM(I,2)-XM(I)*YM(I)*C7
      SM(I,8)=SM(I,8)+XM(I)*XM(I)*C7
      SM(I,4)=SM(I,4)-YM(I)*YM(I)*C7
      SM(I,5)=SM(I,5)+XM(I)*YM(I)*C7
      SM(I,10)=SM(I,10)+XM(I)*YM(I)*C7
      SM(I,11)=SM(I,11)-XM(I)*XM(I)*C7
      SM(I,22)=SM(I,22)+YM(I)*YM(I)*C7
      SM(I,23)=SM(I,23)-XM(I)*YM(I)*C7
      SM(I,29)=SM(I,29)+XM(I)*XM(I)*C7
      IF(KL(I)-KG(I))120,121,122
```

```
120 C7=3.*E*B(I)/DM(I)**5/144.
    SM(I,6)=SM(I,6)-YM(I)*DM(I)*DM(I)*C7
    SM(I,12)=SM(I,12)+~~XM(I)*DM(I)*DM(I)*C7~~
    SM(I,24)=SM(I,24)+YM(I)*DM(I)*DM(I)*C7
    SM(I,30)=SM(I,30)-XM(I)*DM(I)*DM(I)*C7
    SM(I,36)=SM(I,36)+DM(I)**4*C7
    GOTO115
121 C7=12.*E*B(I)/DM(I)**5/144.
    SM(I,3)=SM(I,3)-YM(I)*DM(I)*DM(I)*(C7/2.)
    SM(I,9)=SM(I,9)+DM(I)*DM(I)*(C7/2.)*XM(I)
    SM(I,15)=SM(I,15)+DM(I)**4*C7/3.
    SM(I,16)=SM(I,16)+YM(I)*DM(I)*DM(I)*(C7/2.)
    SM(I,17)=SM(I,17)-DM(I)*DM(I)*(C7/2.)*XM(I)
    SM(I,18)=SM(I,18)+DM(I)**4*C7/6.
    SM(I,6)=SM(I,6)-YM(I)*DM(I)*DM(I)*(C7/2.)
    SM(I,12)=SM(I,12)+DM(I)*DM(I)*(C7/2.)*XM(I)
    SM(I,24)=SM(I,24)+YM(I)*DM(I)*DM(I)*(C7/2.)
    SM(I,30)=SM(I,30)-DM(I)*DM(I)*(C7/2.)*XM(I)
    SM(I,36)=SM(I,36)+DM(I)**4*C7/3.
    GOTO115
122 C7=3.*E*B(I)/DM(I)**5/144.0
    SM(I,3)=SM(I,3)-YM(I)*DM(I)*DM(I)*C7
    SM(I,9)=SM(I,9)+XM(I)*DM(I)*DM(I)*C7
    SM(I,15)=SM(I,15)+DM(I)**4*C7
    SM(I,16)=SM(I,16)+YM(I)*DM(I)*DM(I)*C7
    SM(I,17)=SM(I,17)-XM(I)*DM(I)*DM(I)*C7
115 CONTINUE
    SM(I,7)=SM(I,2)
    SM(I,13)=SM(I,3)
    SM(I,14)=SM(I,9)
    SM(I,19)=SM(I,4)
    SM(I,20)=SM(I,10)
    SM(I,21)=SM(I,16)
    SM(I,25)=SM(I,5)
    SM(I,26)=SM(I,11)
    SM(I,27)=SM(I,17)
    SM(I,28)=SM(I,23)
    SM(I,31)=SM(I,6)
    SM(I,32)=SM(I,12)
    SM(I,33)=SM(I,18)
    SM(I,34)=SM(I,24)
    SM(I,35)=SM(I,30)
112 CONTINUE
    DO 521 I=1,NM
    DO 522 JJ=1,6
    IF(NPM(I,JJ).EQ.1)GOTO 522
    DO 523 II=JJ,6
    IF(NPM(I,II).EQ.1)GOTO 523
    IF(NPM(I,JJ)-NPM(I,II))524,526,526
526 KKS=(NPM(I,II)-1)*(NB-1)+NPM(I,JJ)
    KS=(JJ-1)*6+II
    Z(KKS)=Z(KKS)+SM(I,KS)
    GOTO 523
524 KKS=(NPM(I,JJ)-1)*(NB-1)+NPM(I,II)
    KS=(JJ-1)*6+II
    Z(1)=1.
    Z(KKS)=Z(KKS)+SM(I,KS)
523 CONTINUE
522 CONTINUE
521 CONTINUE
    IF(NSP.EQ.0)GOTO 2271
    WRITE(6, 2390)
    WRITE(6, 2274)
    DO 42 K=1,NSP
```

```
           WRITE(6, 2278)JS,NTYP,SK
      2390 FORMAT(1H0,6X,"SPRING DATA")
      2274 FORMAT(1H0,"JOINT  TYPE  K-CONSTANT")
~~      2278 FORMAT(1X,I3,I6,F10.4)~~
           KK=(ND(JS,NTYP)-1)*NB+1
           Z(KK)=Z(KK)+SK
      42   CONTINUE
      2271 LTCC=LTC-DB(NWL)
           DO 140 LL=1,LTCC
           DO 700 K=1,NP
           BM(K)=0.
           UM(K)=0.
           VY(K)=0.
           VYG(K)=0.
      700  CONTINUE
           DO141I=1,NU
      141  FF(I)=0.0
           DO 2672 M=1,NP
      2672 KSP(M)=0
           DO 19 N=1,NWL
           DB(N)=DB(N)+1
           IF(DB(N).GT.LTC) WL(N)=0.0
      19   CONTINUE
           DO 2840 K=1,NWL
           IF(WL(K).EQ.0)GOTO 2840
           IF(DB(K).LT.0) GOTO 2840
           DO 12 J=1,NP
           IF(DB(K).LE.RL(J)) GOTO 27
      12   CONTINUE
      27   I=J
           IF(DB(K).EQ.0) GOTO 2774
           KSP(I)=KSP(I)+1
           KZ=KSP(I)
           XP(I,KZ)=DB(K)-(RL(I)-LP(I))
           P(I,KZ)=WL(K)
           BB=-(P(I,KZ)*XP(I,KZ)*(DM(I)-XP(I,KZ))**2)/DM(I)**2
           UU=(P(I,KZ)*(XP(I,KZ)**2)*(DM(I)-XP(I,KZ)))/DM(I)**2
           VV=-(P(I,KZ)*(DM(I)-XP(I,KZ))**2*(2.*XP(I,KZ)+DM(I)))/DM(I)*
          $**3
           VVG=-(P(I,KZ)*(XP(I,KZ))**2*(3.*DM(I)-2.*XP(I,KZ)))/DM(I)**3
      2774 CONTINUE
           JL=JNL(I)
           JG=JNG(I)
           N2=ND(JL,2)
           IF(DB(K).EQ.0) GOTO 2825
           N3=ND(JL,3)
           N5=ND(JG,2)
           N6=ND(JG,3)
           FF(N2)=FF(N2)+VV
           FF(N3)=FF(N3)+BB
           FF(N5)=FF(N5)+VVG
           FF(N6)=FF(N6)+UU
           BM(I)=BM(I)+BB
           UM(I)=UM(I)+UU
           VY(I)=VY(I)+VV
           VYG(I)=VYG(I)+VVG
      2825 IF(DB(K).EQ.0)  FF(N2)=FF(N2)-WL(K)
      2840 CONTINUE
           DET=1.E-7
           CALL BAND(Z,FF,NU,NB,LL,DET)
           IF(DET)46,46,48
      46   WRITE(6,*)"STRUCTURE IS UNSTABLE"
           GOTO444
      48   CONTINUE
           DO611J=1,NJ
```

```
      K2=ND(J,2)
      K3=ND(J,3)
      IF(K1-1)361,361,362
362   D1(J)=FF(K1)*12.
      GOTO 363
361   D1(J)=0.
363   IF(K2-1)368,368,369
369   D2(J)=FF(K2)*12.
      GOTO 379
368   D2(J)=0.
379   IF(K3-1)386,386,387
387   D3(J)=FF(K3)
      GOTO 941
386   D3(J)=0.
941   DO 3260 M=1,NJTC
      KQ=JNTC(M)
      IF(J.EQ.KQ) GOTO 686
3260  CONTINUE
      GOTO 9053
686   IF(D2(J).LT.D2M(M)) D2M(M)=D2(J)
9053  CONTINUE
      D1(J)=D1(J)/12.
      D2(J)=D2(J)/12.
611   CONTINUE
      DO61I=1,NM
      N1=JNL(I)
      N2=JNG(I)
      D(1)=D1(N1)
      D(2)=D2(N1)
      D(3)=D3(N1)
      D(4)=D1(N2)
      D(5)=D2(N2)
      D(6)=D3(N2)
      F1=0.
      F2=0.0
      F3=0.0
      F6=0.0
      DO65K=1,6
65    F1=F1+D(K)*SM(I,K)
      DO66K=7,12
66    F2=F2+D(K-6)*SM(I,K)
      DO67K=13,18
67    F3=F3+D(K-12)*SM(I,K)
      DO68K=31,36
68    F6=F6+D(K-30)*SM(I,K)
      AXIAL(I)=-(F1*(XM(I))+F2*(YM(I)))/DM(I)
      SHEAR(I)=(-F1*(YM(I))+F2*(XM(I)))/DM(I)-VY(I)
      BML(I)=-F3+BM(I)
      BMG(I)=F6-UM(I)
      IF(I.GT.NP) GOTO 589
      T=JNL(I)
      TT=JNG(I)
      SUBSHR(I)=SHEAR(I)
      LEX=LP(I)
      DDE=RL(I)-LP(I)
      DO 3564 M=1,NWL
      IF(DB(M).EQ.DDE.AND.ND(T,2).EQ.1) SUBSHR(I)=SUBSHR(I)+WL(M)
3564  CONTINUE
      DO 60 L=1,LEX
      REL=L
      S(I,L)=SHEAR(I)
      BP(I,L)=BML(I)+SHEAR(I)*REL
      NUT=KSP(I)
      IF(NUT.LE.0)GOTO 60
      KICK=0
```

```
      DO 3669 K=1,NQ
      IF(L.EQ.LP(I).AND.XP(I,K).EQ.L)GOTO 3710
      IF(XP(I,K).LT.L) S(I,L)=S(I,L)-P(I,K)
      GOTO 3669
 3710 IF(ND(TT,2).EQ.1) S(I,L)~~=S(I,L)-P(I,K)~~
 3669 CONTINUE
      IF(XP(I,K).LT.L) BP(I,L)=BP(I,L) +P(I,K)*(XP(I,K)-REL)
      IF(L.EQ.LP(I).AND.XP(I,K).EQ.L) GO TO 880
      IF(XP(I,K).NE.L) GO TO 880
      SL=P(I,K)*(LP(I)-XP(I,K))/LP(I)
      SR=SL-P(I,K)
      KICK=1
 880  CONTINUE
      IF(KICK.NE.1) GO TO 7909
      S1=S(I,L)-SL+SR
      IF(ABS(S1).GT.ABS(S(I,L))) S(I,L)=S1
 7909 CONTINUE
 60   CONTINUE
      NEX=LP(I)
      DO 50 L=1,NEX
      BMP=BP(I,L)
      IF(BMP.GE.MAXPBM(I,L)) GOTO 3780
      GOTO 3782
 3780 MAXPBM(I,L)=BMP
      AAF(I,L)=AXIAL(I)
      ASF(I,L)=S(I,L)
 3782 CONTINUE
      IF(BMP.LT.MAXNBM(I,L)) GOTO 3792
      GOTO 3794
 3792 CONTINUE
      AAFN(I,L)=AXIAL(I)
      ASFN(I,L)=S(I,L)
      MAXNBM(I,L)=BMP
 3794 CONTINUE
      SHR=ABS(S(I,L))
      IF(SHR.GT.SMAX(I,L)) SMAX(I,L)=SHR
 50   CONTINUE
      BMP=BML(I)
      IF(BMP.GT.BMMAX(I)) GOTO 3840
      GOTO 3842
 3840 BMMAX(I)=BMP
      AAFE(I)=AXIAL(I)
      ASFE(I)=SUBSHR(I)
 3842 CONTINUE
      IF(BMP.LT.BMNMAX(I)) GOTO 3852
      GOTO 3854
 3852 BMNMAX(I)=BMP
      AAFEN(I)=AXIAL(I)
      ASFEN(I)=SUBSHR(I)
 3854 CONTINUE
      AX=ABS(AXIAL(I))
      ZY=ABS(AMAX(I))
      IF(AX.GE.ZY) AMAX(I)=AXIAL(I)
      IF(AMAX(I).EQ.AXIAL(I)) GOTO 3894
      GOTO 3893
 3894 DO 3892 L=1,NEX
      ABM(I,L)=BP(I,L)
 3892 CONTINUE
 3893 CONTINUE
      SHR=ABS(SUBSHR(I))
      IF(SHR.GT.SSMAX(I)) SSMAX(I)=SHR
      IF(AMAX(I).EQ.AXIAL(I)) ABMM(I)=BML(I)
      GOTO 61
 589  CONTINUE
      BMP=ABS(BML(I))
```

```
      BMQ=ABS(BMG(I))
      IF(BMG.GT.BMP)BMP=BMQ
      IF(AXIAL(I).GE.AXP(I)) GOTO 3960
      GOTO 3970
 3960 AXP(I)=AXIAL(I)
      ~~ABMT(I)=BMP~~
 3970 IF(AXIAL(I).LT.AXN(I)) GOTO 3973
      GOTO 3974
 3973 AXN(I)=AXIAL(I)
      ABMC(I)=BMP
 3974 CONTINUE
      SHR=ABS(SHEAR(I))
      IF(SHR.GT.SSMAX(I)) SSMAX(I)=SHR
 61   CONTINUE
 140  CONTINUE
      WRITE(6, 4362)
 4362 FORMAT(1H0," ")
      WRITE(6, 81)
 81   FORMAT(1H0,35X,"**** TOP CHORD ANALYSIS ****",///)
      DO 592 I=1,NM
 99   FORMAT(1H0,45X,"MEM.#",I3)
      IF(I.GT.NP)GOTO 560
      WRITE(6, 99)I
      WRITE(6, 4162)AMAX(I)
 4162 FORMAT(1H0,32X,"MAX. AXIAL FORCE IN KIPS=",F8.2)
      WRITE(6, 82)
 82   FORMAT(1H0,1X,"X",5X,"MAX.B.M.",4X,"ASS. AX.",4X,"ASS.SHR.",
     $ 4X,"MAX.B.M.",4X,"ASS. AX.",4X,"ASS.SHR.",8X,"MAX.",5X,
     $"ASS.BM.")
      WRITE(6, 84)
 84   FORMAT(1H ,7X,"POSITIVE",7X,"FORCE",7X,"FORCE",4X,"NEGATIVE",
     $ 7X,"FORCE",7X,"FORCE",7X,"SHEAR",5X,"MAX.AX.")
      WRITE(6, 85)NL,BMMAX(I),AAFE(I),ASFE(I),BMNMAX(I),AAFEN(I),ASFE
     $N(I),
     $ SSMAX(I),ABMM(I)
 85   FORMAT(1H ,I2,1X,8F12.2)
      MEX=LP(I)
      DO 550 L=1,MEX
      WRITE(6, 86)L,MAXPBM(I,L),AAF(I,L),ASF(I,L),MAXNBM(I,L),AAFN(I,
     $L),
     $ ASFN(I,L),SMAX(I,L),ABM(I,L)
 86   FORMAT(1H ,I2,1X,8F12.2)
 550  CONTINUE
      GOTO 592
 560  CONTINUE
      JM=NP+1
      IF(I.GT.JM)GOTO 4262
      WRITE(6, 4635)
 4635 FORMAT(1H0," ")
      WRITE(6, 87)
 87   FORMAT(1H0,25X,"**** BTM.CHORD & WEB MEMBER ANALYSIS ****")
      WRITE(6, 88)
 88   FORMAT(1H0,2X,"M",5X,"MAX.TEN.",5X,"ASS.B.M.",5X,"MAX.COM.",
     $ 5X,"ASS.B.M.",5X,"MAX.SHR.",7X,"LENGTH")
 4262 CONTINUE
      WRITE(6, 89)I,AXP(I),ABMT(I),AXN(I),ABMC(I),SSMAX(I),DM(I)
 89   FORMAT(1H ,I3,6F13.2)
 592  CONTINUE
 4720 FORMAT(1H0," ")
      WRITE(6, 4720)
      WRITE(6, 4721)
 4721 FORMAT(1H0,25X,"**** MAX. VERTICAL DEFN'S. TOP CHORD ****")
      WRITE(6, 4723)
 4723 FORMAT(1H0,35X,"JNT. NO.",5X,"DEFLN'S.")
      DO 4725 K=1,NJTC
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      WRITE(6, 4726)JA(C(K)),D2M(K)
 4726 FORMAT(1H ,38X,I2,0X,F8.4)
 4725 CONTINUE
      GOTO 444
 9614 WRITE(6,*)"ERROR IN MEMBER DATA"
      GOTO 444
~~ 9896 WRITE(6,*)" ERROR IN JOINT DATA"~~
C  777  FORMAT(V)
  444 STOP
      END
$CONTROL INIT,LOCATION,NOSOURCE,NOWARN,SEGMENT=TWO
      SUBROUTINE BAND(A,B,N,M,LT,DET)
      DIMENSION A(1400),B(75)
      MM=M-1
      NM=N*M
      NM1=NM-MM
      IF (LT.NE.1) GO TO 55
      MP=M+1
      KK=2
      FAC=DET
      A(1)=1./SQRT(A(1))
      BIGL=A(1)
      SML=A(1)
      A(2)=A(2)*A(1)
      A(MP)=1./SQRT(A(MP)-A(2)*A(2))
      IF(A(MP).GT.BIGL)BIGL=A(MP)
      IF(A(MP).LT.SML)SML=A(MP)
      MP=MP+M
      DO 62 J=MP,NM1,M
      JP=J-MM
      MZC=0
      IF(KK.GE.M) GO TO 1
      KK=KK+1
      II=1
      JC=1
      GO TO 2
 1    KK=KK+M
      II=KK-MM
      JC=KK-MM
 2    DO 65 I=KK,JP,MM
      IF(A(I).EQ.0.)GO TO 64
      GO TO 66
 64   JC=JC+M
 65   MZC=MZC+1
      ASUM1=0.
      GO TO 61
 66   MMZC=MM*MZC
      II=II+MZC
      KM=KK+MMZC
      A(KM)=A(KM)*A(JC)
      IF(KM.GE.JP)GO TO 6
      KJ=KM+MM
      DO 5 I=KJ,JP,MM
      ASUM2=0.
      IM=I-MM
      II=II+1
      KI=II+MMZC
      DO 7 K=KM,IM,MM
      ASUM2=ASUM2+A(KI)*A(K)
 7    KI=KI+MM
 5    A(I)=(A(I)-ASUM2)*A(KI)
 6    CONTINUE
      ASUM1=0.
      DO 4 K=KM,JP,MM
 4    ASUM1=ASUM1+A(K)*A(K)
```

```
      IF(S.LT.0.)DET=S
      IF(S.EQ.0.)DET=0.
      IF(S.GT.0.)GO TO 63
      RETURN
 63   A(J)=1./SQRT(S)
      IF(A(J).GT.BIGL)BIGL=A(J)
      ~~IF(A(J).LT.SML)SML=A(J)~~
 62   CONTINUE
      IF(SML.LE.FAC*BIGL)GO TO 54
      GO TO 53
 54   DET=0.
      RETURN
 53   DET=SML/BIGL
 55   B(1)=B(1)*A(1)
      KK=1
      K1=1
      J=1
      DO 8 L=2,N
      BSUM1=0.
      LM=L-1
      J=J+M
      IF(KK.GE.M)GO TO 12
      KK=KK+1
      GO TO 13
 12   KK=KK+M
      K1=K1+1
 13   JK=KK
      DO 9 K=K1,LM
      BSUM1=BSUM1+A(JK)*B(K)
      JK=JK+MM
 9    CONTINUE
 8    B(L)=B(L)*A(J)-BSUM1*A(J)
      B(N)=B(N)*A(NM1)
      NMM=NM1
      NN=N-1
      ND=N
      DO 10 L=1,NN
      BSUM2=0.
      NL=N-L
      NL1=N-L+1
      NMM=NMM-M
      NJ1=NMM
      IF(L.GE.M)ND=ND-1
      DO 11 K=NL1,ND
      NJ1=NJ1+1
      BSUM2=BSUM2+A(NJ1)*B(K)
 11   CONTINUE
 10   B(NL)=(B(NL)-BSUM2)*A(NMM)
      RETURN
      END
```