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FINITE ELEMENT ANALYSIS OF A RAILWAY TRACK SUPPORT SYSTEM

BALLAST AND FOUNDATION MATERIALS RESEARCH PROGRAM

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JULY 1976

USERS MANUAL

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16. Abstract

A computer program for the finite element analysis of conventional railway track support systems has been developed. This report details a User's Manual and a Program Listing of the computer program.

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PREFACE

This report has been generated as part of a sub-contract between the Association of American Railroads Research and Test Department, and the University of Illinois.

This sub-contract is part of a larger contract which is a cooperative effort between the Federal Railroad Administration and the Association of American Railroads on improved track structures. The entire program is in response to recognition of the desire for a more durable track structure. To this end, the program is a multi-task effort involving 1) the development of empirical and analytical tools for the description of the track structure so that the economic trade-offs among track construction parameters such as tie size, rail size, ballast depth and cross section, type, subgrade type, stiffness, may be determined. 2) methodologies to upgrade the existing track structures to withstand new demands in loading, 3) development of performance specifications for track components, and 4) investigating the effects of various levels of maintenance.

This particular report describes a computer program for the finite element analysis of conventional railway track support systems.

A special note of thanks is given to Mr. William S. Autrey, Chief Engineer of Santa Fe, Mr. R. M. Brown, Chief Engineer of Union Pacific, Mr. F. L. Peckover, Engineer of Geotechnical Services, Canadian National Railway, Mr. C. E. Webb, Asst. Vice President, Southern Railway System, as they have served in the capacity of members of the Technical Review Committe for this Ballast and Foundation Materials Program, and Dr. R. M. McCafferty as the contracting Officer's Technical Representative of the FRA on the entire research program.

G. C. Martin
Director-Dynamics Research
Principal Investigator
Track Structures Research Program
Association of American Railroads

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PART 1

USER'S MANUAL

1.1 Introduction:

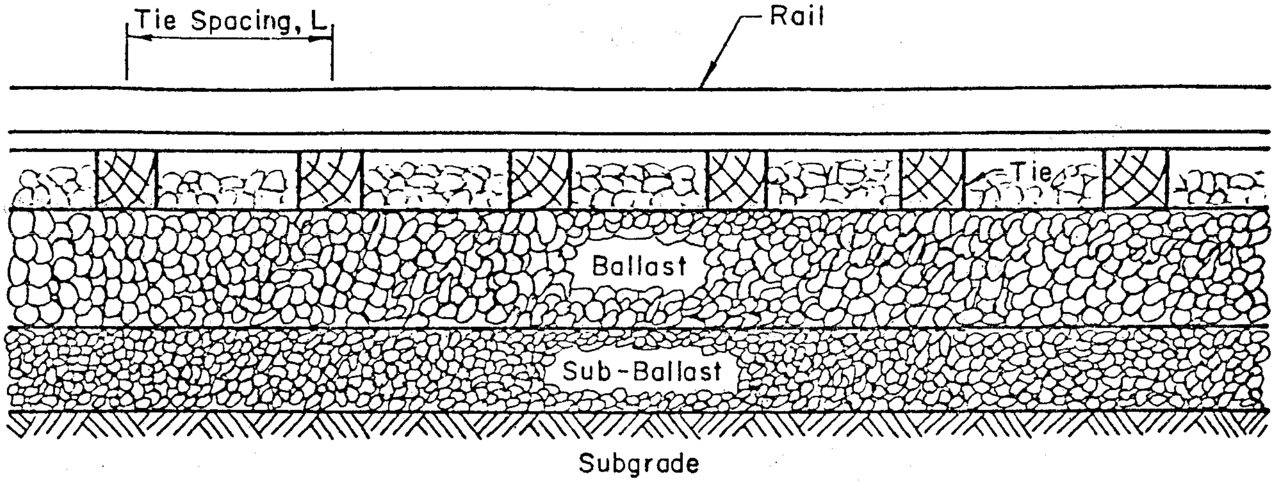
The finite element program was developed to evaluate the structural response of conventional railway track system, shown in Figure 1. The theoretical development of the finite element model is described in detail in Reference 1. A brief discussion of the modelling is given below.

The analysis is broken down into 2 stages. In the first stage, a longitudinal analysis is performed. Rail-tie representation is of the beam-spring type shown in Figure 2, which shows a typical finite element mesh used for longitudinal analysis. Wheel loads are input as point loads acting on the rail.

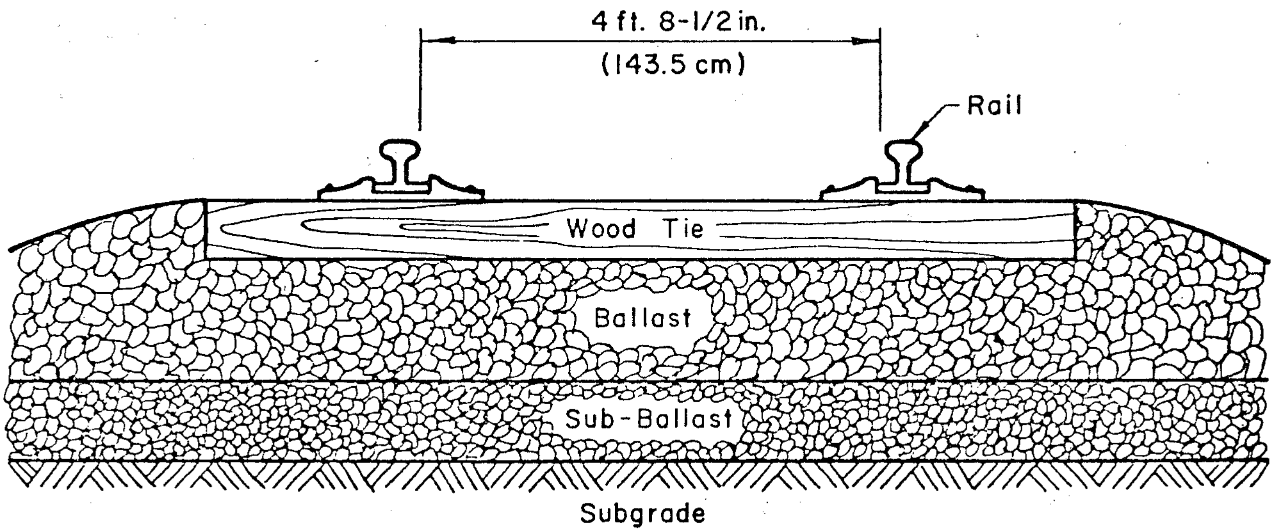
In the second stage, a transverse analysis is performed. The analysis considers a tie resting on the ballast. An option is included to consider the tie either as a two dimensional body or as a beam. A typical finite element mesh used for transverse analysis is shown in Figure 3. The maximum reaction or the maximum deflection at a tie obtained from the longitudinal analysis is used as input. Constant strain triangular elements can also be used to incorporate sloping ballast shoulder.

1.2 Modelling:

In each stage, a plane-strain type analysis is performed. The section to be analyzed is divided into a set of rectangular elements connected at their nodal points. Each node has two degrees of freedom: that for the beam-spring element are rotation and vertical displacement and that for the planar elements of ballast/subgrade system are horizontal and vertical displacements. The tie compression modulus for the longitudinal analysis is



(a) Longitudinal Section



(b) Transverse Section

Figure 1. A Typical Longitudinal and a Typical Transverse Section of a Conventional Railway Track Support System.

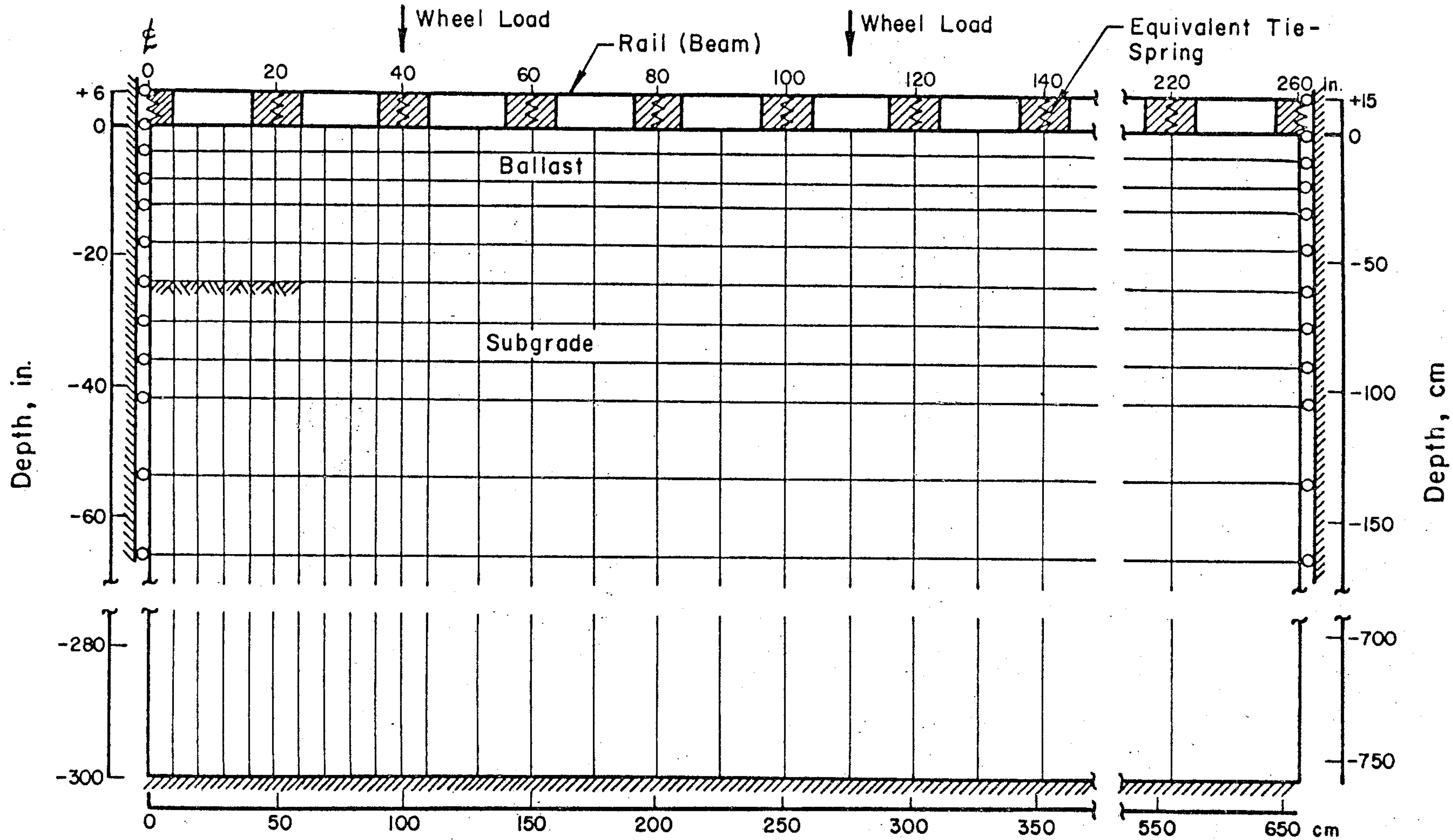
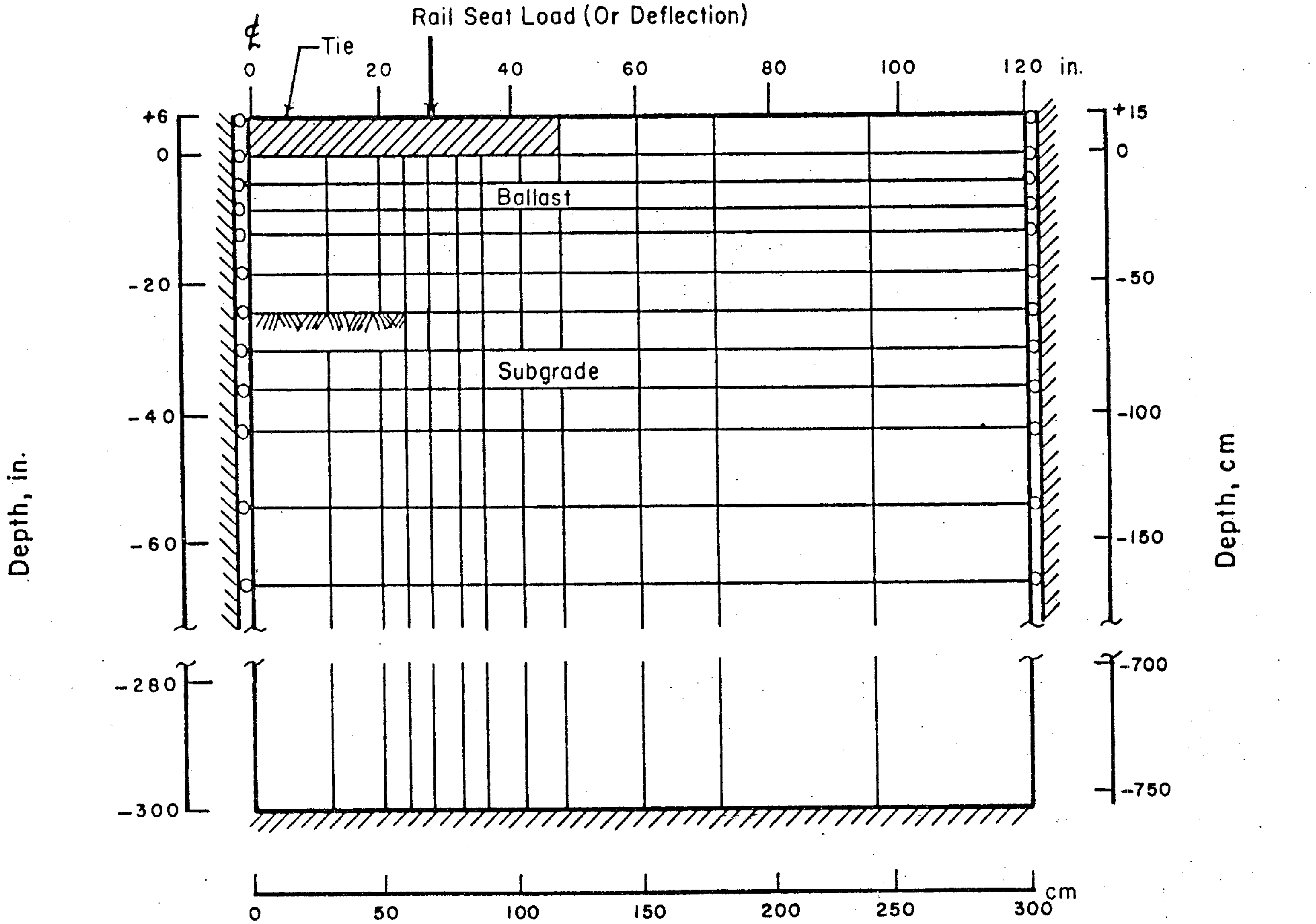


Figure 2. A Typical Finite Element Mesh Used for Longitudinal Analysis.



Note: Triangular elements can be used to incorporate sloping ballast shoulder.

Figure 3. A Typical Finite Element Mesh Used for Transverse Analysis.

converted into an equivalent spring constant. Presently, standard meshes are used, that for the longitudinal analysis being dependent on tie spacing and tie width. Typical element and nodal point numbering is shown in Figure 4.

A pseudo-plane strain state is considered for the ballast and the subgrade. The plane strain state generally distributes the load in two directions only and thus severely restricts the diminishing of the stress with depth as would be expected under the actual track system. In a pseudo-plane strain analysis, the finite element thickness is allowed to increase with depth to simulate 3 dimensional stress distribution with depth. The pseudo-plane strain state is shown in Figure 5.

1.3 <u>Material Characterization</u>

Granular and fine-grained materials exhibit, under repeated loading, strength characteristics that depend on the state of stress existing in the material. This response, termed the resilient response can be evaluated in the laboratory as follows:

a. Ballast Material (Ref. 2), Figure 6

$$E_R = K_1 (\theta)^{K_2}$$

where:

$$E_R = \text{resilient modulus} = \frac{\text{repeated deviator stress}}{\text{elastic or recoverable strain}}$$

$$\theta = \text{sum of the principal stresses} = \sigma_1 + \sigma_2 + \sigma_3$$

$$= \sigma_1 + 2\sigma_3 \text{ in a triaxial test}$$

K_1, K_2 = constants determined from laboratory tests

b. Fine-Grained Soils (Ref. 3)

Generally the resilient modulus of fine-grained soils decreases with an increase in deviator stress ($\sigma_d = \sigma_1 - \sigma_3$). At higher values of

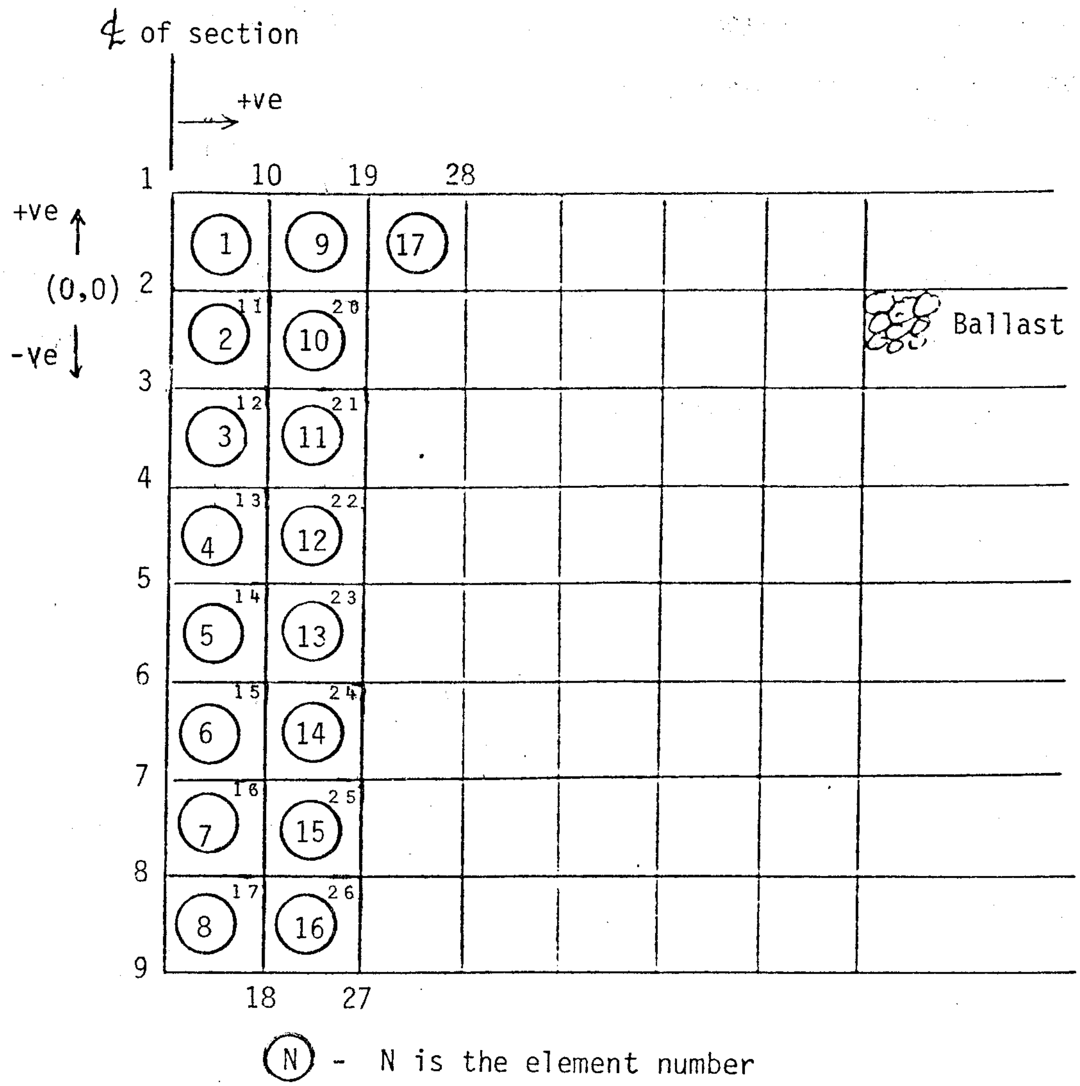
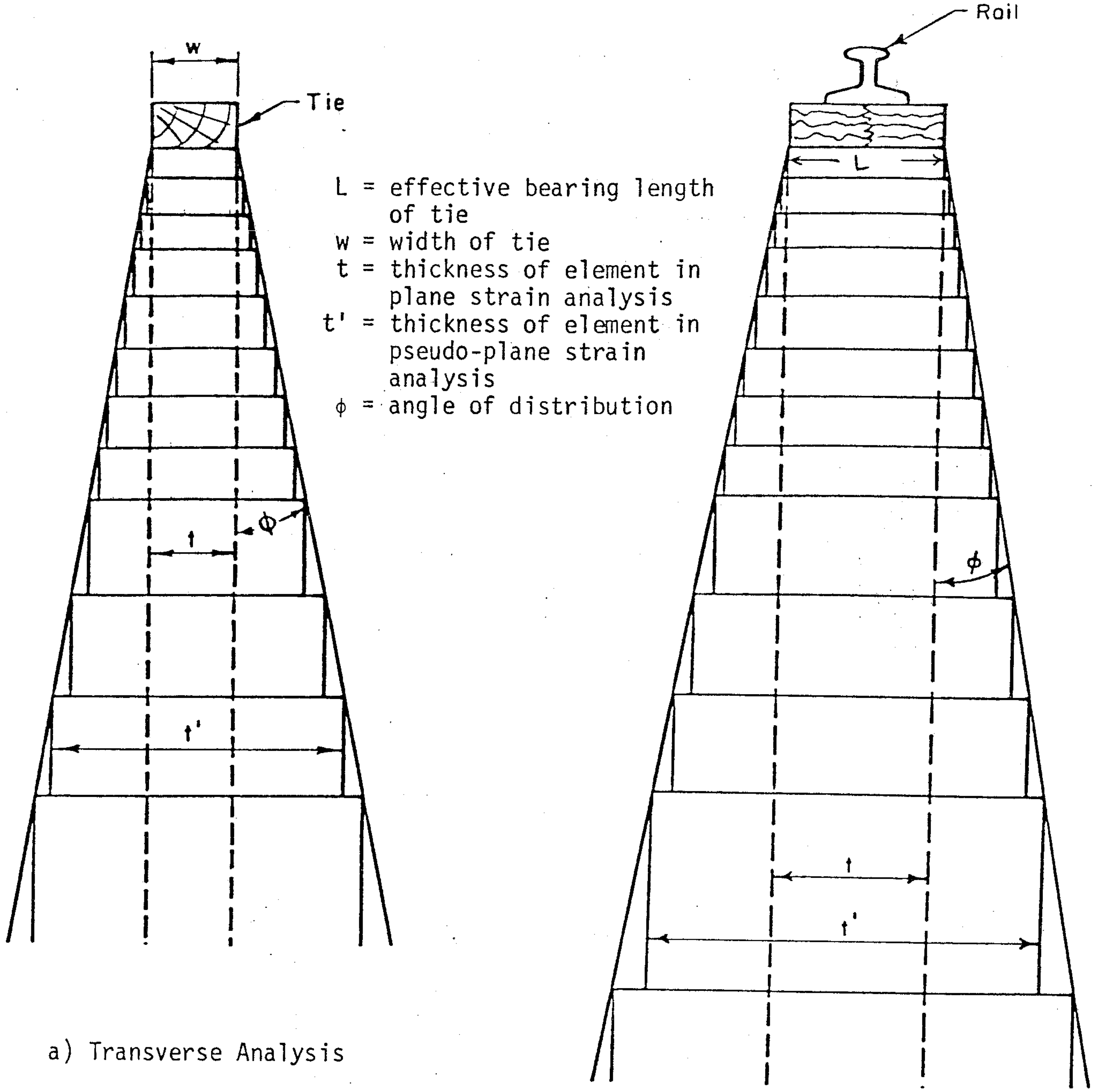


Figure 4. Typical Scheme for nodal and element numbering.

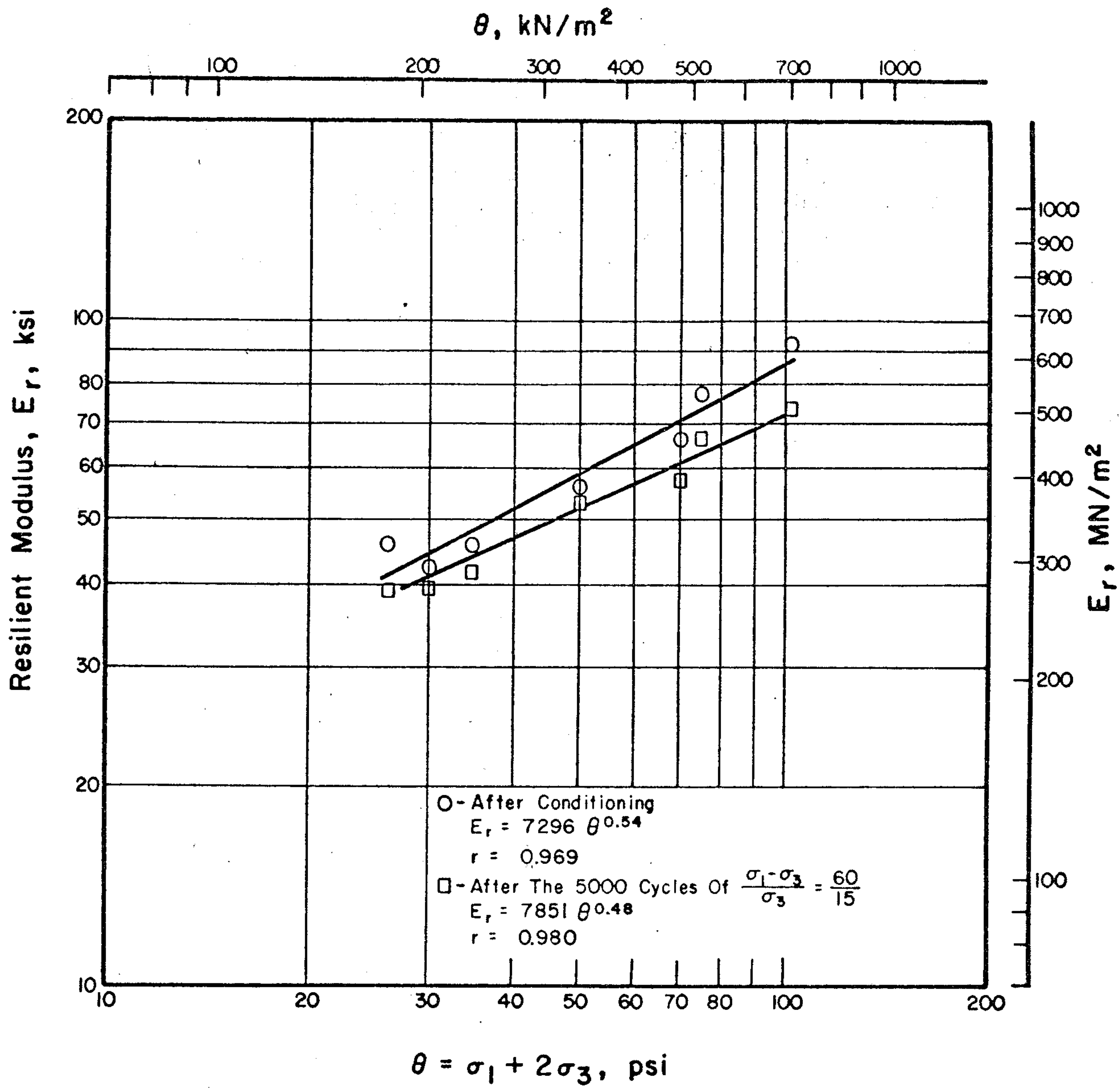


L = effective bearing length of tie
w = width of tie
t = thickness of element in plane strain analysis
t' = thickness of element in pseudo-plane strain analysis
φ = angle of distribution

a) Transverse Analysis

b) Longitudinal Analysis

Figure 5. Pseudo-Plane Strain Approximation.



(No. 5 Gradation Limestone, High Density)

Figure 6. Typical Resilient Data for Ballast Material

deviatoric stress, the resilient modulus is almost constant. A typical resilient response curve for fine-grained soils is shown in Figure 7.

c. Sandy Subgrades

The response for sandy subgrades is usually similar to that for granular materials and can be evaluated in the laboratory as follows:

$$E_R = K_1 \ (\theta)^{K_2}$$

The above type of material characterization is incorporated into the finite element program. Three types of non-linear analysis techniques can be used to incorporate stress-dependent material characterization. These techniques are:

1. Additive Incremental Loading. The load is divided into equal increments and at each step an increment of load is added to the previous step load. For example, in the first step only one increment of load is used and in the second step, two increments of load are used. Initial moduli values are assumed for the stress-dependent materials and are used to solve the problem with the first load increment. After the total load is applied, a single iterative analysis is carried out (with total load applied) so that the moduli values used in the final load increment are more compatible with the state of stress existing at the end of the final load increment.

2. Iterative Loading. The full load is applied for each iteration. Moduli values are assumed for the first iteration and the moduli values used for subsequent iterations are derived from the stress results of the preceding analysis.

3. Equal Incremental Loading. The load is divided into equal increments. Moduli values are assumed for analysis using the first load increment. Subsequently, the analysis is conducted using the same incremental

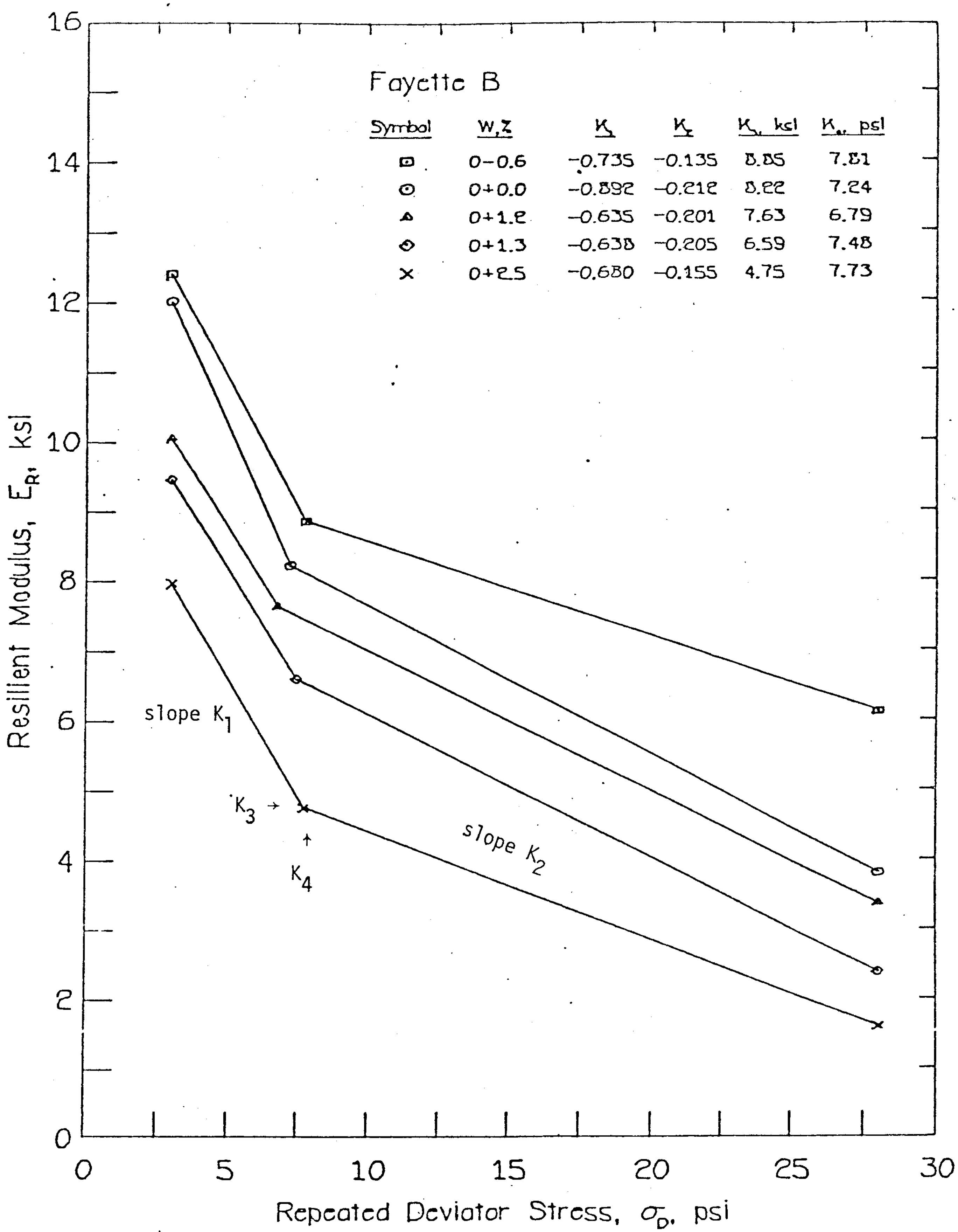


Figure 7. Typical Resilient Response Data for a Fine-Grained Soil (From Ref. 3).

load until the full load is applied. The deformations at the end of any increment are given by cumulatively adding the deformations of all the preceding load increments. The strains and stresses are then evaluated from the cumulative deformations.

Presently, only the load induced stresses are considered in the analysis and in calculating the bulk stress, θ, for the granular materials, and the deviator stress, σ_d, for the subgrade soils.

1.4 Failure Criteria

Failure criteria is incorporated in terms of:

1. minimum value of the minor principal stress, σ_3, for the granular materials, (tensile stress taken as negative),
2. maximum principal stress ratio, $|\sigma_1/\sigma_3|$, for the granular materials, and,
3. maximum shear stress $(\sigma_1 - \sigma_3)/2$ for the subgrade soils. This is a special case of Mohr - Coloumb failure condition for zero angle of internal friction.

1.5 Boundary Conditions Used in the Longitudinal Analysis

In the present version of the longitudinal model, symmetrical loading is considered and only half of the system is analyzed. Loads are input as point loads acting on the rail at given distances from the center line of the section.

Due to loading symmetry, the nodes along the vertical boundary representing the centerline of the section to be analyzed are restrained from horizontal movement. Also, since horizontal deformation dissipates rapidly with distance from the loaded zone, a horizontal restraint on the other vertical boundary has been placed at a distance of 260 in. (6.6 m) from the center of the loaded area. The nodes along the bottom boundary, at a depth of about 300 in. (7.6 m), are restrained, both from horizontal as well as vertical movement to simulate a rigid boundary. The above grid boundaries were chosen after several trial runs with different grid dimensions. The vertical external boundary and the bottom boundary will have some influence on the magnitude of the computed deflections but the influence would be small.

1.6 Boundary Conditions Used in the Transverse Analysis

Due to loading symmetry in the transverse direction, only half the transverse section is considered in the modeling and analysis. Loads are input as point loads and deflections are input as nodal deflections.

Again, due to loading symmetry, the nodes along the vertical boundary representing the centerline of the system are restrained from horizontal movement and as explained previously the other vertical boundary at a distance of 120 in. (3.1 m) is also restrained from horizontal movement. The nodes along the bottom boundary at a depth of about 300 in. (7.6 m) are restrained both from horizontal as well as vertical movement to simulate a rigid boundary.

1.7 General Logic of the Modelling

Relationships are established between generalized displacements (usually denoted as $\{u\}$) and generalized forces (usually denoted as $\{p\}$) applied at the nodes using the principle of virtual work or some other variational principle. This element force-displacement relationship is expressed in the form of element stiffness matrix (usually denoted as $[k]$ which incorporates the material and geometrical properties of the element, viz.

$$[k] \{u\} = \{p\}$$

The overall structural stiffness matrix, $[K]$ is then formulated by superimposing the effects of the individual element stiffness using the topological or the element connectivity properties of the structure. The overall stiffness matrix is used to solve the set of simultaneous equations of the form:

$$[K]\{U\} = \{P\}$$

where

$\{P\}$ = applied nodal forces for the whole system

$\{U\}$ = resulting nodal displacements for the whole system

The generalized stresses and strains are then calculated.

1.8 Additional Program Guidelines

1) The Poisson's ratio for granular materials ranges from 0.30 to 0.40 and that for fine-grained soils ranges from 0.35 to 0.45.

2) The assumed initial moduli values can be evaluated as follows.

   a) For the incremental loading techniques, the initial moduli values can be obtained as follows:

   $$\text{Initially assumed moduli} = \frac{\text{Expected final moduli}}{\text{Number of steps}}$$

   b) For the iterative loading technique, the initially assumed moduli value should equal the expected final moduli.

3) Presently it is suggested that the effective tie bearing length under each rail be equal to 18 in. (45.7 cm) and that the angle of distribution for pseudo-plane strain consideration, ϕ, be equal to 10 degrees.

4) Low moduli values should be used when elements fail, i.e., satisfy failure criteria. Suggested failure moduli are 4000 psi (27579 kN/m^2) for ballast and 100 psi (689 kN/m^2) for subgrade.

5) Use of constant modulus value is suggested for stabilized layers. This can be incorporated as follows:

$$E_R = KONE\ (\theta)^{KTWO}$$

where KONE = constant modulus value to be used

KTWO = 0.0

6) The subgrade can be separated into an upper layer and a lower layer. The upper layer of the subgrade should not exceed 30 in. (76.2 cm). Different material characterization can then be used for the two subgrade layers.

1.9 General Flow Chart

1. Data input
2. Generate vertical and horizontal boundaries
3. Generate nodal point data and element connectivity data
4. Assign input data to individual element
5. For each incremental load step
   a. Formulate the overall stiffness matrix
   b. Solve for displacements
   c. Calculate generalized stresses and strains
   d. Calculate the element moduli corresponding to the existing state of stress
6. For final iterative step, do steps (5a) to (5c)
7. Stop

1.10 Sloping Ballast Shoulder

When a sloping ballast shoulder is to be incorporated into the transverse analysis, the following steps need to be carried out. The transverse section grid nodes and elements should be numbered and the sloping shoulder should be drawn diagonally through the respective elements as shown in Figure 8(a). The elements containing the diagonal shoulder line should then be converted to constant strain triangular elements (see input data card types 8 and 17) and the rectangular elements above the sloping shoulder line would need to have their moduli value reduced to zero, i.e., constant moduli of zero (see input data card types 8 and 17), as shown in Figure 8(b). Also a node point belonging to the elements above the sloping shoulder line would need to be fixed in the vertical direction (see input data card types 14 and 18).

1.11 Data Requirements

a. Rail

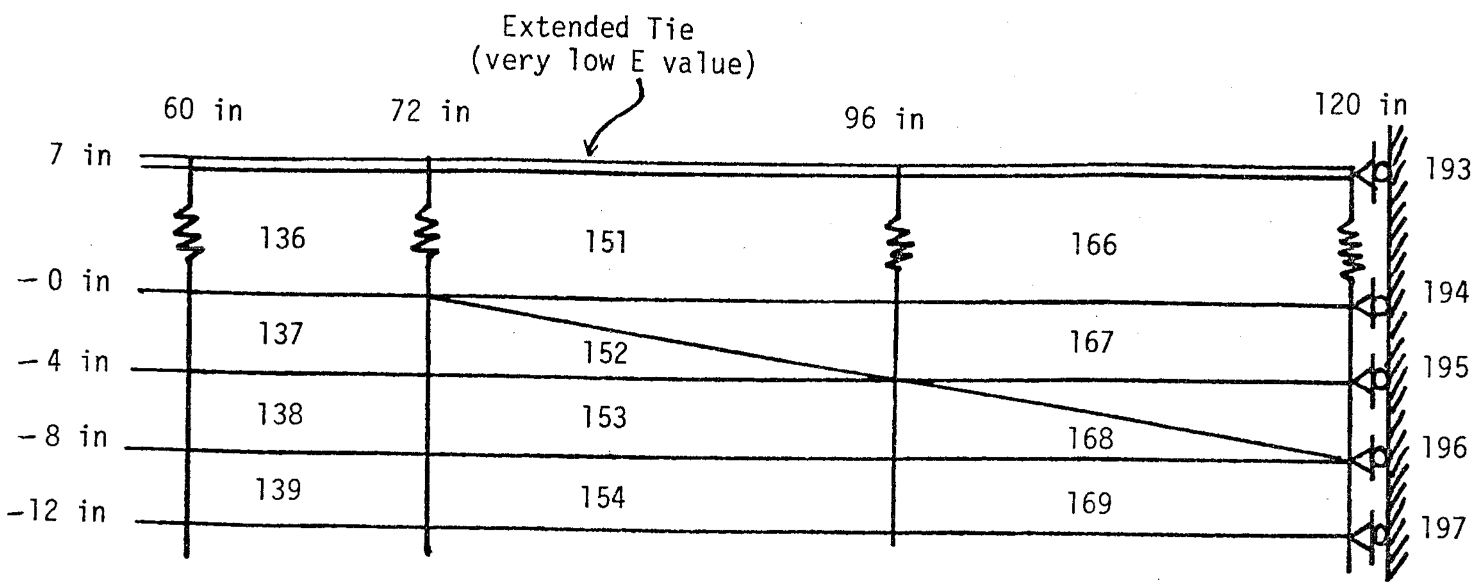
1. Rail section moment of inertia (in^4)
2. Modulus of elasticity (psi)

b. Ties

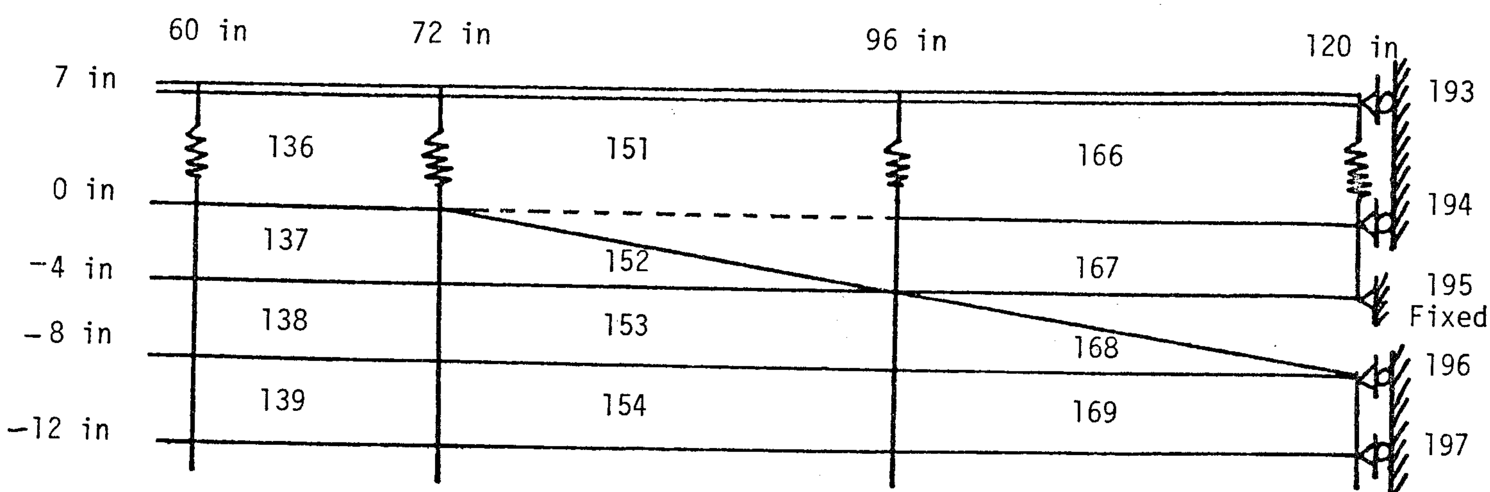
1. Width, thickness and length (in)
2. Tie section moment of inertia (for transverse analysis - optional) (in^4)
3. Effective tie bearing length under each rail (in)
4. Modulus of elasticity (psi)
5. Poisson's ratio (for Transverse analysi)
6. Tie spacing (in)

c. Ballast or Subballast

1. Depth of ballast or subballast (in)
2. Initial modulus to be used (psi)
3. Resilient response model (psi)
4. Poisson's ratio
5. Failure criteria (psi)



(a) Transverse Section of CRTSS (Tie as beam).



Elements 152 and 168 changed to CST (triangular) elements
Element 167 changed to Type 10 element with zero modulus
Node 195 is fixed both horizontally and vertically

(b) Transverse section of CRTSS (Tie as beam) with sloping ballast shoulder.

Figure 8. Incorporation of Sloping Ballast Shoulder.

d. <u>Subgrade</u>

1. Total depth of section (including ballast/subballast) to be analyzed (in)
2. Depth of upper subgrade layer (if to be considered as a different material) (in)
3. For each subgrade layer
   a. Initial modulus to be used (psi)
   b. Resilient response curve data (psi)
   c. Poisson's ratio
   d. Failure criteria (psi)

e. <u>Loading</u>

1. Magnitude of point load (lb) or point deflection (in) and its distance from the centerline of the section to be analyzed. (Note: Since symmetrical loading is considered, only loading on one side of the centerline should be input).

1.12 Output:

The output given by the computer program is:

1. Rail moment and tie moment (at appropriate node points) (lbf in)
2. Rail deflection and tie deflection (at appropriate node points) (in)
3. Tie reaction (lb)
4. Stress patterns in the ballast, the subballast, and the subgrade (at centroid of appropriate elements)

   σ_{xx}(SIGXX) - horizontal stress (psi)

   σ_{yy}(SIGYY) - vertical stress (psi)

   τ_{xy}(TAUXY) - shear stress (psi)

   σ_1 (SIG1) - major principal stress (psi)

   σ_3 (SIG3) - minor principal stress (psi)

5. Deflection and strain patterns in the ballast, the subballast, and the subgrade (deflection at appropriate node points, strains at centroid of appropriate elements)

   ε_x(EXXX) - horizontal strain

   ε_y(EXYY) - vertical strain

   γ_{xy}(EXXY) - shear strain

1.13 Material Type

The material types used in the computer program are designated as follows:

	Material Type
Ballast	1
Subballast	2
Lower (or the only) subgrade layer	3
Rail	4
Tie (as two-dimensional body)	5
Upper (if any) subgrade layer	6
Tie (as beam, for the length of tie)	7
Tie (as beam, beyond the length of tie)	8
Constant strain triangular element for sloping ballast shoulder	9
Constant modulus material for rectangular elements only	10

1.14 Present Usage

At present it is recommended that the "iterative loading" scheme be used for the "stress-dependent" analysis with failure criteria checked for at the end of the specified number of iterations (see data card Type 12). The final iteration is then carried out with the failure state incorporated into the analysis. Three iterations are sufficient to provide converging results.

INPUT DATA STATEMENTS

The program can accept only fixed form type of format which is detailed below.

Data Card Type 1

NPROB	
I5	

1 5

NPROB = Number of separate problems to be solved.

The following input is repeated for NPROB times.

Data Card Type 2

Title (1)	Title (2)	Title (3)		Title (20)
A4	A4	A4		A4

1 4 5 8 9 12 76 80

Title (1) to Title (20) = Title of individual problem

Data Card Type 3

ANAL	ABCD	
F 10.2	F 10.2	

1 10 20

ANAL = Type of analysis

= 1.0 for transverse analysis - tie as planar element
= 2.0 for longitudinal analysis
= 3.0 for transverse analysis - tie as beam element

ABCD = Type of non-linear (stress dependent) scheme to be used (See Sec 1.3)

= 0.0 for additive incremental loading
= 1.0 for full-load iterative loading
= 2.0 for equal-step incremental loading

Data Card Type 4

RLTIE	WTIE	TTHICK	BDEPTH	SBDEPT	TSPACE	BTHICK	PHI
F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2
1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80

RLTIE = Length of tie, in

WTIE = Width ot tie, in.

TTHICK = Thickness of tie, in.

BDEPTH = Ballast depth, in.

SBDEPT = Subballast depth, in.

TSPACE = Tie spacing, in.

BTHICK = Effect bearing length of tie under each rail, for longitudinal analysis in.

PHI = Angle of distribution used for pseudo plane strain analysis (Presently 10.0 degrees is suggested)

Data Card Type 5

DEPTH	UPPER	LCOL
F 10.2	F 10.2	I5
1 10	11 20	21 25

DEPTH = Total depth of section to be analyzed, in.

UPPER = Depth of upper (separate) layer of subgrade, in.

LCOL = Number of vertical boundaries to be used

= 0 for default condition, that is, when standard mesh is used.

Then for LCOL = 0

Number of vertical boundaries used = 13 for transverse analysis

= 27 for longitudinal analysis

Data Card Type 6

ETS (4)	DATA11	ETS(5)	PSRS(5)	DATA22	TIEKK
F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2
1 10	11 20	21 30	31 40	41 50	51 60

ETS(4) = Modulus of elasticity of rail steel, psi

DATA(11) = Moment of inertia of rail section, for longitudinal analysis, in^4

ETS(5) = Modulus of elasticity of tie, psi

PSRS(5) = Poisson's ratio for tie

DATA(22) = Moment of inertia of tie section for transverse analysis considering tie as a beam, in^4

TIEKK = Spring constant used in transverse analysis considering tie as a beam, psi

Data Card Type 7

BONE1	BTWO1	ETS(1)	PSRS(1)	BONE2	BTWO2	ETS(2)	PSRS(2)
F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2
1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80

BONE1 and BTWO1 are the constants of the resilient response model obtained from the laboratory testing of ballast, viz.

$$E_R = \text{BONE1} \; (\theta)^{\text{BTWO1}} \text{ for Ballast (units-psi)}$$

ETS(1) = Initially assumed modulus for ballast, psi

PSRS(1) = Poisson's ratio for ballast

BONE2 and BTWO2 are the constants of the resilient response model obtained from the laboratory testing of subballast, viz.

$$E_R = \text{BONE2} \; (\theta)^{\text{BTWO2}} \text{ for subballast (units-psi)}$$

ETS(2) = Initially assumed modulus for subballast, psi

PSRS(2) = Poisson's ratio for subballast

Data Card Type 8

NPOINT	JPOINT	NCST	NSUBL	NSUBU
I5	I5	I5	I5	I5
1 5	6 10	15	20	25

NPOINT = Numbers of points for the lower (or the only) subgrade layer resilient modulus curve data points = between 2 and 8 = 3 if NSUBL is 1.

JPOINT = Number of points for the upper (if any) subgrade layer resilient modulus curve data points = between 2 and 8, or 0 = 3 if NSUBU is 1.

NCST = Total number of elements to have either element type changed or to have constant modulus value. (See Sec 1.10) i.e., to Type (N) = 9.0 for CST element for sloping shoulder or Type (N) = 10.0 for constant modulus value element.

NSUBL = 0 if E_R vs σ_D relationship is used for the lower (or the only) subgrade.

= 1 if $E_R = K(\theta)^n$ relationship is used for the lower (or the only) subgrade (e.g. for sandy subgrades)

NSUBU = 0 if E_R vs σ_D relationship is used for the upper (if any) subgrade

= 1 if $E_R = K(\theta)^n$ relationship is used for the upper (if any) subgrade (e.g. for sandy subgrades)

Data Card Type 9

Lower (or the only) subgrade layer resilient modulus curve data points (NPOINT data cards)

RMOD(I)	DEV(I)	No. of data cards = NPOINT
F 10.2	F 10.2	

1 10 11 20

RMOD(I) = Resilient modulus value for the Ith data points, psi

UDEV(I) = Deviatoric Stress $(\sigma_1-\sigma_3)$ value for the Ith data point, psi (I goes from 1 to NPOINT)

If NSUBL = 1, the following resilient modulus relationship is used (e.g. for sandy subgrades):

$$E_R = BONE(\theta)^{BTWO} \quad \text{(units-psi)}$$

Then,

RMOD(1) = BONE = Constant obtained from laboratory testing

DEV(1) = BTWO = Constant obtained from laboratory testing

RMOD(2) = Marker for failure criteria usage

= 0.0 if failure criteria is to be used (normal case)

= 1.0 if failure criteria is to be used in the final step (cycle) only

= 2.0 if failure criteria is not to be used

RMOD(3) = AMXSR

= Maximum allowable stress ratio, σ_1/σ_3 for the sandy subgrade, psi

DEV(3) = SIGMN

= Minimum allowable principal stress, σ_3 for the sandy subgrade, psi

Data Card Type 10

(If JPOINT not equal to zero) Upper (if any) subgrade layer resilient modulus curve data points (JPOINT data cards).

UMOD(I)	UDEV(I)	
F 10.2	F 10.2	No. of data cards = JPOINT
1 10	11 20	

UMOD(I) = Resilient modulus value for the Ith data point, psi

UDEV(I) = Deviatoric stress (σ_1/σ_3) value for the Ith data point, psi (I goes from 1 to JPOINT)

If NSUBU = 1, the following resilient modulus relationship is used (e.g. for sandy subgrades):

$$E_R = BONE(\theta)^{BTWO} \text{ (units-psi)}$$

Then,

UMOD(1) = BONE = Constant obtained from laboratory testing

UDEV(1) = BTWO = Constant obtained from laboratory testing.

UMOD(2) = Marker for failure criteria usage

= 0.0 if failure criteria is to be used (normal case)

= 1.0 if failure criteria is to be used in the final step (cycle) only

= 2.0 if failure criteria is not to be used

UMOD(3) = AMXSR

= Maximum allowable stress ratio, σ_1/σ_3 for the sandy subgrade, psi

UDEV(3) = SIGMN

= Minimum allowable principal stress, σ_3 for the sandy subgrade, psi

Data Card Type 11

ETS (3)	PSRS (3)	ETS (6)	PSRS (6)
F 10.2	F 10.2	F 10.2	F 10.2
1 10	11 20	21 30	31 40

ETS (3) = Initially assumed modulus for the lower (or the only) subgrade layer, psi

PSRS (3) = Poisson's ratio for the lower (or the only) subgrade layer

ETS (6) = Initially assumed modulus for the upper (if any) subgrade layer, psi

PSRS (6) = Poisson's ratio for the upper (if any) subgrade layer

Data Card Type 12

AMXSR1	SIGMN1	EFAIL1	AMXSR2	SIGMN2	EFAIL2	BFLAG	CFLAG
F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2	F 10.2
1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80

AMXSR1 = Maximum allowable stress ratio, σ_1/σ_3, for ballast

SIGMN1 = Minimum allowable minimum principal stress, σ_3, for ballast, psi

EFAIL1 = Failure modulus for ballast, psi

AMXSR2 = Maximum allowable stress ratio, σ_1/σ_3, for subballast

SIGMN2 = Minimum allowable minimum principal stress, σ_3, for subballast, psi

EFAIL2 = Failure modulus for subballast, psi

BFLAG = Marker for failure criteria usage of ballast
= 0.0 if failure criteria is to be used
= 1.0 if failure criteria is to be used in final step

= 2.0 if failure criteria is not to be used

CFLAG = Marker for failure criteria usage of subballast
= 0.0 if failure criteria is to be used
= 0.1 if failure criteria is to be used in the final step
= 2.0 if failure criteria is not to be used

Data Card Type 13

TAUSUB	EFAIL3	UTAUSB	EFAIL6	
F 10.2	F 10.2	F 10.2	F 10.2	
1 10	11 20	21 30	31 40	

TAUSUB = Maximum allowable shear stress for the lower (or the only) subgrade layer, psi

EFAIL3 = Failure modulus for the lower (or the only) subgrade layer, psi

UTAUSB = Maximum allowable shear stress for the upper (if any) subgrade layer, psi

EFAIL6 = Failure modulus for the upper (if any) subgrade layer, psi

NOTE: the subgrade is assumed to be fine-grained soil and the minimum allowable shear stress would be given by half the unconfined compressive strength.

Data Card Type 14

NDSPEC	NFSPEC	NSTEPS	NFIX
I5	I5	I5	I5
1 — 5	6 — 10	11 — 15	16 — 20

NDSPEC = Number of specified displacements in vertical direction only

NFSPEC = Number of specified loads in vertical direction only

NSTEPS = Number of incremental load steps

NFIX = Number of fixed degrees of freedom (displacements). This is used to fix nodes a specified amount in a given direction. Used primarily when using CST elements (See Sec. 1.10)

Data Card Type 15 (if NFSPEC not equal to zero)

RLOAD(I)	DIST(I)	No. of data cards = NFSPEC
F 10.2	F 10.2	
1 — 10	11 — 20	

RDISP(I) = Magnitude of Ith point load (vertical), pounds

DIST(I) = Distance from center line of the Ith point load, in.

Data Card Type 16 (if NDSPEC not equal to zero)

RDISP(I)	DIST1(I)	No. of data cards = NDSPEC
F 10.2	F 10.2	
1 — 10	11 — 20	

RDISP(I) = Magnitude of Ith point displacement (vertical), in

DISTI(I) = Distance from center line of the Ith point displacement, in

Data Card Type 17 (if NCST not equal to zero)

NECST	TYPE (NECST)	ETMM	No. of data cards = NCST
I5	F 10.2	F 10.2	
1 5	6 15	16 25	

NECST = Element number for the element to be modified (Type modification or constant modulus modification)

TYPE(NECST)= New type number of element (See Sec. 1.10)

= 9.0 for constant strain triangular element for ballast shoulder slope

= 10.0 if constant modulus is to be assigned to that element. (Element is then "linear")

ETMM = Constant modulus value to be used in the analysis for TYPE (N) = 10.0 only.

Data Card Type 18 (if NFIX not equal to zero)

The set of NFIX cards are repeated (NSTEPS + 1) times

M	N	TD(N, M)	No. of data cards = NFIX Repeated (NSTEPS + 1) times
I5	I5	F 10.2	
1 5	6 10	11 20	

M = Node number whose displacement is to be fixed

N = Direction of displacement to be fixed

= 1 if horizontal displacement is to be fixed

= 2 if vertical displacement is to be fixed

TD(N, M) = Amount of displacement (normally equals 0.0)

If TD(N, M) is not equal to zero, then if ABDC = 0.0 (for additive incremental loading)

$$TD(N, M) = TD(N, M) \quad X \quad \frac{N}{NSTEPS}$$

where $TD(N, M)_N$ is the amount of displacement to be used in the N^{th} set of data cards and TD(N, M) is the total amount of displacement. If ABCD = 2.0 (for equal-step incremental loading)

$$TD(N, M) = TD(N, M)_T \Big/ NSTEPS$$

where TD(N, M) is the amount of displacement to be used in all the NSTEPS set of data cards and $TD(N, M)_T$ is the total amount of displacement.

REFERENCES

1. Robnett, Q. L., et al., "Development of a Structural Model and Materials Evaluation Procedures," Ballast and Foundation Materials Research Program, Department of Civil Engineering, University of Illinois at Urbana-Champaign, November, 1975, to be published by the U. S. Department of Transportation.

2. Unpublished Laboratory Data, Ballast and Foundation Materials Research Program, Department of Civil Engineering, University of Illinois at Urbana-Champaign, 1975.

3. Thompson, M. R., and Q. L. Robnett, "Resilient Properties of Subgrade Soils, Final Report, Project IHR-603, Transportation Research Laboratory, Department of Civil Engineering, Engineering Experiment Station, University of Illinois, Urbana, October, 1975.

PART 2

TYPICAL EXAMPLES

Example 1:

Given:

A conventional railway track support system is comprised of the following.

Rail - 136 lb/yd (68 kg/m) rail

Moment of Inertia: $I = 94.90\ in^4$ ($3954\ cm^4$)

Modulus of Elasticity: $E = 30{,}000$ ksi ($207{,}000\ MN/m^2$)

Ties - Timber ties

Width = 8 in. (20.3 cm)

Thickness = 7 in. (17.8 cm)

Length = 8 ft (2.44 m)

Tie Spacing = 20 in. (50.8 cm)

Compressive Modulus = 1,250 ksi ($8618\ MN/m^2$)

Effective bearing length under each rail = 18 in. (45.7 cm)

Ballast - Crushed stone ballast, AREA #4 Gradation

Resilient Response Modulus: $E_R = 5082\ (\theta)^{0.58}$

Initial modulus used = 30,000 psi ($207{,}000\ kN/m^2$)

Poisson's ratio: $\mu = 0.35$

Ballast Depth = 12 in. (30.5 cm)

Subballast - none

Subgrade (Embankment Material) - Depth = 275 in. (6.99 m)

$\mu = 0.47$

Resilient Response Curve Data: (Average Subgrade)

σ_D, psi (kN/m^2)	E_R, psi (kN/m^2)
0.1 (0.7)	14820.0 (102180.0)
6.2 (42.8)	8000.0 (55160.0)
36.2 (249.6)	2900.0 (19990.0)

Initial modulus used = 5,000 psi (34,500 kN/m^2)

The following failure criteria is given:

1) Maximum stress ratio, σ_1/σ_3, for ballast = 10

2) Minimum compressive stress, σ_3, for ballast = 0 psi (0 kN/m^2)

3) Maximum shear stress, $(\sigma_1-\sigma_3)/2$, of subgrade = 25 psi (172 kN/m^2)

(The failure criterion that tie springs cannot take tensile loads is incorporated in the computer program).

The loading to be used in the analysis consists of two trucks of two adjacent freight cars, each car having a gross weight of 240,000 lb (108800 kg), thus giving approximate wheel load of 30,000 lb (13600 kg). The truck spacing equals 150 in. (3.81 m) and the axle spacing equals 70 in. (1.78 m).

A longitudinal analysis is to be performed, using the angle of distribution for pseudo-plane strain analysis of 10^o and the effective bearing length of tie of 18 in. (45.7 cm).

Example 2:

Given:

For the track support system given in Example 1 perform a transverse analysis at a "critical" tie. The maximum tie deflection (at the surface of the ballast) of 0.1025 in. (2.6 mm) obtained from the longitudinal analysis is to be used as input. Consider tie as a beam resting at the surface of the ballast.

Additional data required for the transverse analysis follows.

Tie

E = Compressive modulus = 1,250 ksi (8618 MN/m^2)

I = 229.0 in^4

TIEKK = Spring constant used in the transverse analysis considering tie as a beam = 999999 lbf/in./in.

Rail-tie intersections are 60 in. (1.52 m) apart.

(Note: Standard gage is 56 1/2 in. (1.44 m))

Computer Inputs for Examples 1 and 2:

(see following pages).

Job: Example 1 - Longitudinal Analysis

Date:

1	11	21	31	41	51	61	71
NPROB 1							
TITLE EXAMPLE 1 - LONGITUDINAL ANALYSIS							
ANAL 2.0	ABCD 0.0						
RLTIE 96.0	WTIE 8.0	TTHICK 7.0	BDEPTH 12.0	SBDEPT 0.0	TSPACE 20.0	BTHICK 18.0	PHI 10.0
DEPTH 275.0	UPPER 0.0	LCOL 0					
ETS(4) 30000000.	DATA11 94.9	ETS(5) 1250000.	PSRS(5) /	DATA22 /	TIEKK /		
BONE1 5082.0	BTWO1 0.58	ETS(1) 30000.0	PSRS(1) 0.35	BONE 2 /	BTWO2 /	ETS(2) /	PSRS(2) /
NPOINT 3 · JPOINT /	NCST / · NSUBL /	NSUBU /					
RMOD(I) 14820.0	DEV(I) 0.1						
8000.0	6.2						
2900.0	36.2						
UMOD(I) /	DEV(I) /	}	IF (JPOINT > 0)				
/	/						
/	/						
ETS(3) 5000.	PSRS(3) 0.47	ETS(6) /	PSRS(6) /				
AMXSR1 10.0	SIGMN1 0.0	EFAIL1 4000.0	AMXSR2 /	SIGMN2 /	EFAIL2 /	BFLAG /	CFLAG /
TAUSUB 25.0	EFAIL3 100.0	UTAUSB /	EFAIL6 /				
NDSPEC 0 · NFSPEC 2	NSTEPS 3 · NFIX 0						
RLOAD(I) 30000.0	DIST(I) 40.0						
3000.0	110.0						
RDISP(I) /	DIST1(I) /						
/	/						
NECST / · TYPE(NECST) /	ETMM /		} IF (NCST > 0)				
/ · /	/						
M / · N /	TD(N,M) /	} IF(NFIX > 0) REPEAT NSTEPS TIMES					
/ · /	/						

/ means not required

Job: Example 2 - Transverse Analysis

Date:

1	11	21	31	41	51	61	71–80
NPROB 1							
TITLE EXAMPLE 2-TRANSVERSE ANALYSIS							
ANAL 3.0	ABCD 0.0						
RLTIE 96.0	WTIE 8.0	TTHICK 7.0	BDEPTH 12.0	SBDEPT 0.0	TSPACE 20.0	BTHICK 18.0	PHI 10.0
DEPTH 275.0	UPPER 0.0	LCOL 0					
ETS(4) 30000000.	DATA11 94.9	ETS(5) 1250000.0	PSRS(5) –	DATA22 229.0	TIEKK 999999.0		
BONE1 5082.0	BTWO1 0.58	ETS(1) 30000.0	PSRS(1) 0.35	BONE 2 –	BTWO2 –	ETS(2) –	PSRS(2) –
NPOINT 3 / JPOINT –	NCST – / NSUBL –	NSUBU –					
RMOD(I) 14820.0	DEV(I) 0.1						
8000.0	6.2						
2900.0	362						
UMOD(I) –	UDEV(I) –	} IF (JPOINT >0)					
–	–						
–	–						
ETS(3) 5000.0	PSRS(3) 0.47	ETS(6) –	PSRS(6) –				
AMXSR1 10.0	SIGMN1 0.0	EFAIL1 4000.0	AMXSR2 –	SIGMN2 –	EFAIL2 –	BFLAG –	CFLAG –
TAUSUB 25.0	EFAIL3 100.0	UTAUSB –	EFAIL6 –				
NDSPEC 1 / NFSPEC 0	NSTEPS 3 / NFIX 0						
RLOAD(I) –	DIST(I) –						
–	–						
RDISP(I) 0.1025	DIST1(I) 30.0						
–	–						
NECST – / TYPE(NECST) –	ETMM –		} IF (NCST >0)				
– / –	–						
M – / N –	TD(N,M) –	} IF(NFIX >0) REPEAT NSTEPS TIMES					
– / –	–						

Typical Computer Output:

The following pages give the output for Example 1. The output for Example 2 would be similar in form.

```
*****************************************************************************************************************
STRUCTURAL ANALYSIS PROGRAM FOR CONVENTIONAL RAILWAY TRACK SYSTEM - ILLI-TRACK - VERSION 2
DEVELOPED BY THE TRANSPORTATION GROUP, CIVIL ENGINEERING DEPARTMENT,
UNIVERSITY OF ILLINOIS, URBANA,
*****************************************************************************************************************

NUMBER OF PROBLEMS IN THIS RUN=  1

****STANDARD TRACK, LONG ANALYSIS                                                              *****

TYPE OF ANALYSIS=    2.00

GEOMETRICAL DATA
----------------

TIE LENGTH=  96.00     TIE WIDTH=    8.00     TIE THICKNESS=   7.00     TIE SPACING=  20.00
BALLAST DEPTH GIVEN=  12.00
SUBBALLAST DEPTH GIVEN=    0.0

*** ANGLE OF SPREAD ,PHI IS 10.00
*** EFFECTIVE LENGTH OF TIE UNDER EACH RAIL IS        18.00
***TOTAL DEPTH OF SECTION REQUIRED IS    275.00
*** DEPTH OF UPPER LAYER OF SUBGRADE IS       0.0

VERTICAL GRID LINES

          R( 1)=     0.0
          R( 2)=     4.00
          R( 3)=     8.00
          R( 4)=    12.00
          R( 5)=    16.00
          R( 6)=    20.00
          R( 7)=    24.00
          R( 8)=    28.00
          R( 9)=    32.00
          R(10)=    36.00
          R(11)=    40.00
          R(12)=    44.00
          R(13)=    52.00
          R(14)=    60.00
          R(15)=    70.00
          R(16)=    80.00
          R(17)=    90.00
          R(18)=   100.00
          R(19)=   110.00
          R(20)=   120.00
          R(21)=   130.00
          R(22)=   140.00
          R(23)=   160.00
          R(24)=   180.00
          R(25)=   200.00
          R(26)=   220.00
          R(27)=   260.00
```

HORIZONTAL GRID LINES

```
Z( 1)=     7.00
Z( 2)=     0.0
Z( 3)=    -4.00
Z( 4)=    -8.00
Z( 5)=   -12.00
Z( 6)=   -18.00
Z( 7)=   -24.00
Z( 8)=   -36.00
Z( 9)=   -48.00
Z(10)=   -72.00
Z(11)=   -96.00
Z(12)=  -120.00
Z(13)=  -170.00
Z(14)=  -220.00
Z(15)=  -270.00
Z(16)=  -370.00
```

```
NO. OF HORIZONTAL BOUNDARY LINES=   16
NO. OF VERTICAL BOUNDARY LINES=   27
NO. OF ELEMENTS USED=  390
NO. OF NODE POINTS USED=  432
```

MATERIAL DATA

```
RAIL
  RAIL MODULUS OF ELASTICITY=   30000000.00
  RAIL SECTION MOMENT OF INERTIA=      94.90
TIES
  TIE COMPRESSIVE MODULUS=    1250000.00
  TIE SECTION MOMENT OF INERTIA=     229.00
  TIE POISSONS RATIO=        0.20
  SPRING CONSTANT USED FOR TRANSVERSE ANALYSIS=     999999.00
BALLAST
  BALLAST RESILIENT RESPONSE MODEL -     5082.00(THETA)**0.58
  BALLAST INITIAL MODULUS=  30000.00
  BALLAST POISSONS RATIO=       0.35
SUBBALLAST
  SUBBALLAST RESILIENT RESPONSE MODEL -    50000.00(THETA)**0.0
  SUBBALLAST INITIAL MODULUS=  50000.00
  SUBBALLAST POISSONS RATIO=        0.25
SUBGRADE
   3 POINTS FOR THE SUBGRADE RESILIENT RESPONSE CURVE
             RMOD            DEV
           14220.00          0.10
            6000.00          6.20
            2900.00         36.20
  SUBGRADE INITIAL MODULUS=   5000.00
  SUBGRADE POISSONS RATIO=       0.47
```

FAILURE CRITERIA

```
BALLAST
  MAXIMUM ALLOWABLE PRINCIPAL STRESS RATIO=      10.00
  MINIMUM ALLOWABLE MINIMUM PRINCIPAL STRESS=       0.0
  FAILURE MODULUS=    4000.00
SUBBALLAST
  MAXIMUM ALLOWABLE PRINCIPAL STRESS RATIO= 999999.00
  MINIMUM ALLOWABLE MINIMUM PRINCIPAL STRESS=     -20.00
  FAILURE MODULUS=    4000.00
```

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SUBGRADE
MAXIMUM ALLOWABLE SHEAR STRESS= 25.00
FAILURE MODULUS= 100.00

ELEMENT CONNECTIVITY

ELEM NO.	NODE PTS ANTI-CLOCK				INITIAL MOD.	P. RATIO	ELEM TYPE
1	1	2	18	17	0.300E 08	0.0	4.00
2	2	3	19	18	0.300E 05	0.35	1.00
3	3	4	20	19	0.300E 05	0.35	1.00
4	4	5	21	20	0.300E 05	0.35	1.00
5	5	6	22	21	0.500E 04	0.47	3.00
6	6	7	23	22	0.500E 04	0.47	3.00
7	7	8	24	23	0.500E 04	0.47	3.00
8	8	9	25	24	0.500E 04	0.47	3.00
9	9	10	26	25	0.500E 04	0.47	3.00
10	10	11	27	26	0.500E 04	0.47	3.00
11	11	12	28	27	0.500E 04	0.47	3.00
12	12	13	29	28	0.500E 04	0.47	3.00
13	13	14	30	29	0.500E 04	0.47	3.00
14	14	15	31	30	0.500E 04	0.47	3.00
15	15	16	32	31	0.500E 04	0.47	3.00
16	17	18	34	33	0.300E 08	0.0	4.00
17	18	19	35	34	0.300E 05	0.35	1.00
18	19	20	36	35	0.300E 05	0.35	1.00
19	20	21	37	36	0.300E 05	0.35	1.00
20	21	22	38	37	0.500E 04	0.47	3.00
21	22	23	39	38	0.500E 04	0.47	3.00
22	23	24	40	39	0.500E 04	0.47	3.00
23	24	25	41	40	0.500E 04	0.47	3.00
24	25	26	42	41	0.500E 04	0.47	3.00
25	26	27	43	42	0.500E 04	0.47	3.00
26	27	28	44	43	0.500E 04	0.47	3.00
27	28	29	45	44	0.500E 04	0.47	3.00
28	29	30	46	45	0.500E 04	0.47	3.00
29	30	31	47	46	0.500E 04	0.47	3.00
30	31	32	48	47	0.500E 04	0.47	3.00
31	33	34	50	49	0.300E 08	0.0	4.00
32	34	35	51	50	0.300E 05	0.35	1.00
33	35	36	52	51	0.300E 05	0.35	1.00
34	36	37	53	52	0.300E 05	0.35	1.00
35	37	38	54	53	0.500E 04	0.47	3.00
36	38	39	55	54	0.500E 04	0.47	3.00
37	39	40	56	55	0.500E 04	0.47	3.00
38	40	41	57	56	0.500E 04	0.47	3.00
39	41	42	58	57	0.500E 04	0.47	3.00
40	42	43	59	58	0.500E 04	0.47	3.00
41	43	44	60	59	0.500E 04	0.47	3.00
42	44	45	61	60	0.500E 04	0.47	3.00
43	45	46	62	61	0.500E 04	0.47	3.00
44	46	47	63	62	0.500E 04	0.47	3.00
45	47	48	64	63	0.500E 04	0.47	3.00
46	49	50	66	65	0.300E 08	0.0	4.00
47	50	51	67	66	0.300E 05	0.35	1.00
48	51	52	68	67	0.300E 05	0.35	1.00
49	52	53	69	68	0.300E 05	0.35	1.00
50	53	54	70	69	0.500E 04	0.47	3.00
51	54	55	71	70	0.500E 04	0.47	3.00
52	55	56	72	71	0.500E 04	0.47	3.00
53	56	57	73	72	0.500E 04	0.47	3.00
54	57	58	74	73	0.500E 04	0.47	3.00
55	58	59	75	74	0.500E 04	0.47	3.00
56	59	60	76	75	0.500E 04	0.47	3.00
57	60	61	77	76	0.500E 04	0.47	3.00

330	351	352	368	367	0.500E	04	0.47	3.00
331	353	354	370	369	0.300E	08	0.0	4.00
332	354	355	371	370	0.300E	05	0.35	1.00
333	355	356	372	371	0.300E	05	0.35	1.00
334	356	357	373	372	0.300E	05	0.35	1.00
335	357	358	374	373	0.500E	04	0.47	3.00
336	358	359	375	374	0.500E	04	0.47	3.00
337	359	360	376	375	0.500E	04	0.47	3.00
338	360	361	377	376	0.500E	04	0.47	3.00
339	361	362	378	377	0.500E	04	0.47	3.00
340	362	363	379	378	0.500E	04	0.47	3.00
341	363	364	380	379	0.500E	04	0.47	3.00
342	364	365	381	380	0.500E	04	0.47	3.00
343	365	366	382	381	0.500E	04	0.47	3.00
344	366	367	383	382	0.500E	04	0.47	3.00
345	367	368	384	383	0.500E	04	0.47	3.00
346	369	370	386	385	0.300E	08	0.0	4.00
347	370	371	387	386	0.300E	05	0.35	1.00
348	371	372	388	387	0.300E	05	0.35	1.00
349	372	373	389	388	0.300E	05	0.35	1.00
350	373	374	390	389	0.500E	04	0.47	3.00
351	374	375	391	390	0.500E	04	0.47	3.00
352	375	376	392	391	0.500E	04	0.47	3.00
353	376	377	393	392	0.500E	04	0.47	3.00
354	377	378	394	393	0.500E	04	0.47	3.00
355	378	379	395	394	0.500E	04	0.47	3.00
356	379	380	396	395	0.500E	04	0.47	3.00
357	380	381	397	396	0.500E	04	0.47	3.00
358	381	382	398	397	0.500E	04	0.47	3.00
359	382	383	399	398	0.500E	04	0.47	3.00
360	383	384	400	399	0.500E	04	0.47	3.00
361	385	386	402	401	0.300E	08	0.0	4.00
362	386	387	403	402	0.300E	05	0.35	1.00
363	387	388	404	403	0.300E	05	0.35	1.00
364	388	389	405	404	0.300E	05	0.35	1.00
365	389	390	406	405	0.500E	04	0.47	3.00
366	390	391	407	406	0.500E	04	0.47	3.00
367	391	392	408	407	0.500E	04	0.47	3.00
368	392	393	409	408	0.500E	04	0.47	3.00
369	393	394	410	409	0.500E	04	0.47	3.00
370	394	395	411	410	0.500E	04	0.47	3.00
371	395	396	412	411	0.500E	04	0.47	3.00
372	396	397	413	412	0.500E	04	0.47	3.00
373	397	398	414	413	0.500E	04	0.47	3.00
374	398	399	415	414	0.500E	04	0.47	3.00
375	399	400	416	415	0.500E	04	0.47	3.00
376	401	402	418	417	0.300E	08	0.0	4.00
377	402	403	419	418	0.300E	05	0.35	1.00
378	403	404	420	419	0.300E	05	0.35	1.00
379	404	405	421	420	0.300E	05	0.35	1.00
380	405	406	422	421	0.500E	04	0.47	3.00
381	406	407	423	422	0.500E	04	0.47	3.00
382	407	408	424	423	0.500E	04	0.47	3.00
383	408	409	425	424	0.500E	04	0.47	3.00
384	409	410	426	425	0.500E	04	0.47	3.00
385	410	411	427	426	0.500E	04	0.47	3.00
386	411	412	428	427	0.500E	04	0.47	3.00
387	412	413	429	428	0.500E	04	0.47	3.00
388	413	414	430	429	0.500E	04	0.47	3.00
389	414	415	431	430	0.500E	04	0.47	3.00
390	415	416	432	431	0.500E	04	0.47	3.00

NODE NO. COORDINATES(HORI-VERT)

1	0.0	7.00000	2	0.0	0.0	3	0.0	-4.00000	4	0.0	-8.00000
5	0.0	-12.00000	6	0.0	-18.00000	7	0.0	-24.00000	8	0.0	-36.00000

281	100.00000	-48.00000	282	100.00000	-72.00000	283	100.00000	-96.00000	284	100.00000	-120.00000
285	100.00000	-170.00000	286	100.00000	-220.00000	287	100.00000	-270.00000	288	100.00000	-370.00000
289	110.00000	7.00000	290	110.00000	0.0	291	110.00000	-4.00000	292	110.00000	-8.00000
293	110.00000	-12.00000	294	110.00000	-18.00000	295	110.00000	-24.00000	296	110.00000	-36.00000
297	110.00000	-48.00000	298	110.00000	-72.00000	299	110.00000	-96.00000	300	110.00000	-120.00000
301	110.00000	-170.00000	302	110.00000	-220.00000	303	110.00000	-270.00000	304	110.00000	-370.00000
305	120.00000	7.00000	306	120.00000	0.0	307	120.00000	-4.00000	308	120.00000	-8.00000
309	120.00000	-12.00000	310	120.00000	-18.00000	311	120.00000	-24.00000	312	120.00000	-36.00000
313	120.00000	-48.00000	314	120.00000	-72.00000	315	120.00000	-96.00000	316	120.00000	-120.00000
317	120.00000	-170.00000	318	120.00000	-220.00000	319	120.00000	-270.00000	320	120.00000	-370.00000
321	130.00000	7.00000	322	130.00000	0.0	323	130.00000	-4.00000	324	130.00000	-8.00000
325	130.00000	-12.00000	326	130.00000	-18.00000	327	130.00000	-24.00000	328	130.00000	-36.00000
329	130.00000	-48.00000	330	130.00000	-72.00000	331	130.00000	-96.00000	332	130.00000	-120.00000
333	130.00000	-170.00000	334	130.00000	-220.00000	335	130.00000	-270.00000	336	130.00000	-370.00000
337	140.00000	7.00000	338	140.00000	0.0	339	140.00000	-4.00000	340	140.00000	-8.00000
341	140.00000	-12.00000	342	140.00000	-18.00000	343	140.00000	-24.00000	344	140.00000	-36.00000
345	140.00000	-48.00000	346	140.00000	-72.00000	347	140.00000	-96.00000	348	140.00000	-120.00000
349	140.00000	-170.00000	350	140.00000	-220.00000	351	140.00000	-270.00000	352	140.00000	-370.00000
353	160.00000	7.00000	354	160.00000	0.0	355	160.00000	-4.00000	356	160.00000	-8.00000
357	160.00000	-12.00000	358	160.00000	-18.00000	359	160.00000	-24.00000	360	160.00000	-36.00000
361	160.00000	-48.00000	362	160.00000	-72.00000	363	160.00000	-96.00000	364	160.00000	-120.00000
365	160.00000	-170.00000	366	160.00000	-220.00000	367	160.00000	-270.00000	368	160.00000	-370.00000
369	180.00000	7.00000	370	180.00000	0.0	371	180.00000	-4.00000	372	180.00000	-8.00000
373	180.00000	-12.00000	374	180.00000	-18.00000	375	180.00000	-24.00000	376	180.00000	-36.00000
377	180.00000	-48.00000	378	180.00000	-72.00000	379	180.00000	-96.00000	380	160.00000	-120.00000
381	180.00000	-170.00000	382	180.00000	-220.00000	383	180.00000	-270.00000	384	180.00000	-370.00000
385	200.00000	7.00000	386	200.00000	0.0	387	200.00000	-4.00000	388	200.00000	-8.00000
389	200.00000	-12.00000	390	200.00000	-18.00000	391	200.00000	-24.00000	392	200.00000	-36.00000
393	200.00000	-48.00000	394	200.00000	-72.00000	395	200.00000	-96.00000	396	200.00000	-120.00000
397	200.00000	-170.00000	398	200.00000	-220.00000	399	200.00000	-270.00000	400	200.00000	-370.00000
401	220.00000	7.00000	402	220.00000	0.0	403	220.00000	-4.00000	404	220.00000	-8.00000
405	220.00000	-12.00000	406	220.00000	-18.00000	407	220.00000	-24.00000	408	220.00000	-36.00000
409	220.00000	-48.00000	410	220.00000	-72.00000	411	220.00000	-96.00000	412	220.00000	-120.00000
413	220.00000	-170.00000	414	220.00000	-220.00000	415	220.00000	-270.00000	416	220.00000	-370.00000
417	260.00000	7.00000	418	260.00000	0.0	419	260.00000	-4.00000	420	260.00000	-8.00000
421	260.00000	-12.00000	422	260.00000	-18.00000	423	260.00000	-24.00000	424	260.00000	-36.00000
425	260.00000	-48.00000	426	260.00000	-72.00000	427	260.00000	-96.00000	428	260.00000	-120.00000
429	260.00000	-170.00000	430	260.00000	-220.00000	431	260.00000	-270.00000	432	260.00000	-370.00000

BOUNDARY CONDITIONS

DISPLACEMENTS SPEC	FORCES SPEC	NO. STEPS SPEC		
0	2	3	0	0

FORCES SPECIFIED ARE
30000.00 POUNDS AT 40.00 INCHES FROM CENTER LINE
30000.00 POUNDS AT 110.00 INCHES FROM CENTER LINE

****
** STEP NO. 1 OF A TOTAL OF 3 STEPS **
****

SPECIFIED DISPLACEMENTS

NO.PT	DIR	DIS	NO.PT	DIR	DIS
1	1	0.0	431	1	0.0
2	1	0.0	430	1	0.0
3	1	0.0	429	1	0.0
4	1	0.0	428	1	0.0
5	1	0.0	427	1	0.0
6	1	0.0	426	1	0.0
7	1	0.0	425	1	0.0

8	1	0.0	424	1	0.0
9	1	0.0	423	1	0.0
10	1	0.0	422	1	0.0
11	1	0.0	421	1	0.0
12	1	0.0	420	1	0.0
13	1	0.0	419	1	0.0
14	1	0.0	418	1	0.0
15	1	0.0	417	1	0.0
16	1	0.0	16	2	0.0
32	1	0.0	32	2	0.0
48	1	0.0	48	2	0.0
64	1	0.0	64	2	0.0
80	1	0.0	80	2	0.0
96	1	0.0	96	2	0.0
112	1	0.0	112	2	0.0
128	1	0.0	128	2	0.0
144	1	0.0	144	2	0.0
160	1	0.0	160	2	0.0
176	1	0.0	176	2	0.0
192	1	0.0	192	2	0.0
208	1	0.0	208	2	0.0
224	1	0.0	224	2	0.0
240	1	0.0	240	2	0.0
256	1	0.0	256	2	0.0
272	1	0.0	272	2	0.0
288	1	0.0	288	2	0.0
304	1	0.0	304	2	0.0
320	1	0.0	320	2	0.0
336	1	0.0	336	2	0.0
352	1	0.0	352	2	0.0
368	1	0.0	368	2	0.0
384	1	0.0	384	2	0.0
400	1	0.0	400	2	0.0
416	1	0.0	416	2	0.0
432	1	0.0	432	2	0.0

SPECIFIED FORCES

ND PT	DIR	FORCE
161	2	0.1000000E 05
289	2	0.1000000E 05

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AT NODE   1 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.61326E-04, TIE REACTION IS    262.82
AT NODE  17 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.73355E-04, TIE REACTION IS    628.75
AT NODE  33 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.16304E-02, TIE REACTION IS      0.0
AT NODE  49 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.16602E-02, TIE REACTION IS      0.0
AT NODE  65 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.78302E-04, TIE REACTION IS    671.16
AT NODE  81 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.70244E-04, TIE REACTION IS    602.09
AT NODE  97 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.91575E-04, TIE REACTION IS    784.93
AT NODE 113 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.21396E-02, TIE REACTION IS      0.0
AT NODE 129 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.22344E-02, TIE REACTION IS      0.0
AT NODE 145 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.10784E-03, TIE REACTION IS    924.37
AT NODE 161 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.97491E-04, TIE REACTION IS    835.64
AT NODE 177 TIE SPRING RATE IS     8571428., TIE SETTLEMENT IS  0.14807E-03, TIE REACTION IS   1269.16
AT NODE 193 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.40123E-02, TIE REACTION IS      0.0
AT NODE 209 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.86237E-04, TIE REACTION IS   2217.51
AT NODE 225 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.50252E-02, TIE REACTION IS      0.0
AT NODE 241 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.95405E-04, TIE REACTION IS   2453.26
AT NODE 257 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.53247E-02, TIE REACTION IS      0.0
AT NODE 273 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.10814E-03, TIE REACTION IS   2780.68
AT NODE 289 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.59756E-02, TIE REACTION IS      0.0
AT NODE 305 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.96124E-04, TIE REACTION IS   2471.75
AT NODE 321 TIE SPRING RATE IS           0., TIE SETTLEMENT IS  0.38184E-02, TIE REACTION IS      0.0
AT NODE 337 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.62909E-04, TIE REACTION IS   1617.66
AT NODE 353 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.30692E-04, TIE REACTION IS    789.22
AT NODE 369 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.11019E-04, TIE REACTION IS    283.36
AT NODE 385 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS  0.28200E-05, TIE REACTION IS     72.52
AT NODE 401 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS -0.52340E-05, TIE REACTION IS   -134.59
AT NODE 417 TIE SPRING RATE IS    25714272., TIE SETTLEMENT IS -0.11720E-04, TIE REACTION IS   -301.36
TOTAL TIE REACTION=     18228.91
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**  STEP NO.  2  OF A TOTAL OF    3  STEPS  **
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SPECIFIED DISPLACEMENTS

ND PT	DIR	DIS	ND PT	DIR	DIS
1	1	0.0	431	1	0.0
2	1	0.0	430	1	0.0
3	1	0.0	429	1	0.0
4	1	0.0	428	1	0.0
5	1	0.0	427	1	0.0
6	1	0.0	426	1	0.0
7	1	0.0	425	1	0.0
8	1	0.0	424	1	0.0
9	1	0.0	423	1	0.0
10	1	0.0	422	1	0.0
11	1	0.0	421	1	0.0
12	1	0.0	420	1	0.0
13	1	0.0	419	1	0.0
14	1	0.0	418	1	0.0
15	1	0.0	417	1	0.0
16	1	0.0	16	2	0.0
32	1	0.0	32	2	0.0
48	1	0.0	48	2	0.0
64	1	0.0	64	2	0.0
80	1	0.0	80	2	0.0
96	1	0.0	96	2	0.0
112	1	0.0	112	2	0.0
128	1	0.0	128	2	0.0
144	1	0.0	144	2	0.0
160	1	0.0	160	2	0.0
176	1	0.0	176	2	0.0
192	1	0.0	192	2	0.0
208	1	0.0	208	2	0.0
224	1	0.0	224	2	0.0
240	1	0.0	240	2	0.0
256	1	0.0	256	2	0.0
272	1	0.0	272	2	0.0
288	1	0.0	288	2	0.0
304	1	0.0	304	2	0.0
320	1	0.0	320	2	0.0
336	1	0.0	336	2	0.0
352	1	0.0	352	2	0.0
368	1	0.0	368	2	0.0
384	1	0.0	384	2	0.0
400	1	0.0	400	2	0.0
416	1	0.0	416	2	0.0
432	1	0.0	432	2	0.0

SPECIFIED FORCES

ND PT	DIR	FORCE
161	2	0.20000000E 05
289	2	0.20000000E 05

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AT NODE   1 TIE SPRING RATE IS   8571428., TIE SETTLEMENT IS  0.19978E-03, TIE REACTION IS    856.22
AT NODE  17 TIE SPRING RATE IS   8571428., TIE SETTLEMENT IS  0.14511E-03, TIE REACTION IS   1243.84
AT NODE  33 TIE SPRING RATE IS        0., TIE SETTLEMENT IS  0.95538E-02, TIE REACTION IS      0.0
AT NODE  49 TIE SPRING RATE IS        0., TIE SETTLEMENT IS  0.99615E-02, TIE REACTION IS      0.0
AT NODE  65 TIE SPRING RATE IS   8571428., TIE SETTLEMENT IS  0.11160E-03, TIE REACTION IS    956.56
AT NODE  81 TIE SPRING RATE IS   8571428., TIE SETTLEMENT IS  0.22110E-03, TIE REACTION IS   1895.17
AT NODE  97 TIE SPRING RATE IS   8571428., TIE SETTLEMENT IS  0.23922E-03, TIE REACTION IS   2050.45
AT NODE 113 TIE SPRING RATE IS        0., TIE SETTLEMENT IS  0.14623E-01, TIE REACTION IS      0.0
AT NODE 129 TIE SPRING RATE IS        0., TIE SETTLEMENT IS  0.14976E-01, TIE REACTION IS      0.0
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AT NODE 145 TIE SPRING RATE IS      8571428.,  TIE SETTLEMENT IS   0.16372E-03,  TIE REACTION IS   1403.34
AT NODE 161 TIE SPRING RATE IS      8571428.,  TIE SETTLEMENT IS   0.31949E-03,  TIE REACTION IS   2738.50
AT NODE 177 TIE SPRING RATE IS      8571428.,  TIE SETTLEMENT IS   0.31114E-03,  TIE REACTION IS   2666.91
AT NODE 193 TIE SPRING RATE IS            0.,  TIE SETTLEMENT IS   0.31347E-01,  TIE REACTION IS      0.0
AT NODE 209 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.14096E-03,  TIE REACTION IS   3624.81
AT NODE 225 TIE SPRING RATE IS            0.,  TIE SETTLEMENT IS   0.42990E-01,  TIE REACTION IS      0.0
AT NODE 241 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.16162E-03,  TIE REACTION IS   4155.98
AT NODE 257 TIE SPRING RATE IS            0.,  TIE SETTLEMENT IS   0.37878E-01,  TIE REACTION IS      0.0
AT NODE 273 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.23115E-03,  TIE REACTION IS   5943.96
AT NODE 289 TIE SPRING RATE IS            0.,  TIE SETTLEMENT IS   0.21108E-01,  TIE REACTION IS      0.0
AT NODE 305 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.22822E-03,  TIE REACTION IS   5868.48
AT NODE 321 TIE SPRING RATE IS            0.,  TIE SETTLEMENT IS   0.16402E-01,  TIE REACTION IS      0.0
AT NODE 337 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.14335E-03,  TIE REACTION IS   3686.22
AT NODE 353 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS   0.67913E-04,  TIE REACTION IS   1746.34
AT NODE 369 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS  -0.67726E-05,  TIE REACTION IS   -174.15
AT NODE 385 TIE SPRING RATE IS     25714272.,  TIE SETTLEMENT IS  -0.27709E-04,  TIE REACTION IS   -712.51
AT NODE 401 TIE SPRING RATE IS            2.,  TIE SETTLEMENT IS  -0.86856E-02,  TIE REACTION IS     -0.02
AT NODE 417 TIE SPRING RATE IS            2.,  TIE SETTLEMENT IS  -0.11797E-01,  TIE REACTION IS     -0.02
TOTAL TIE REACTION=   37950.06
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**  STEP NO.   3  OF A TOTAL OF   3  STEPS     **
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SPECIFIED DISPLACEMENTS

ND PT	DIR	DIS	ND PT	DIR	DIS
1	1	0.0	431	1	0.0
2	1	0.0	430	1	0.0
3	1	0.0	429	1	0.0
4	1	0.0	428	1	0.0
5	1	0.0	427	1	0.0
6	1	0.0	426	1	0.0
7	1	0.0	425	1	0.0
8	1	0.0	424	1	0.0
9	1	0.0	423	1	0.0
10	1	0.0	422	1	0.0
11	1	0.0	421	1	0.0
12	1	0.0	420	1	0.0
13	1	0.0	419	1	0.0
14	1	0.0	418	1	0.0
15	1	0.0	417	1	0.0
16	1	0.0	16	2	0.0
32	1	0.0	32	2	0.0
48	1	0.0	48	2	0.0
64	1	0.0	64	2	0.0
80	1	0.0	80	2	0.0
96	1	0.0	96	2	0.0
112	1	0.0	112	2	0.0
128	1	0.0	128	2	0.0
144	1	0.0	144	2	0.0
160	1	0.0	160	2	0.0
176	1	0.0	176	2	0.0
192	1	0.0	192	2	0.0
208	1	0.0	208	2	0.0
224	1	0.0	224	2	0.0
240	1	0.0	240	2	0.0
256	1	0.0	256	2	0.0
272	1	0.0	272	2	0.0
288	1	0.0	288	2	0.0
304	1	0.0	304	2	0.0
320	1	0.0	320	2	0.0
336	1	0.0	336	2	0.0
352	1	0.0	352	2	0.0

368	1	0.0	368	2	0.0
384	1	0.0	384	2	0.0
400	1	0.0	400	2	0.0
416	1	0.0	416	2	0.0
432	1	0.0	432	2	0.0

SPECIFIED FORCES

NC PT	DIR	FORCE
161	2	0.3000000E 05
289	2	0.3000000E 05

	DISPLACEMENT MATRIX HORIZONTAL	VERTICAL	FORCE MATRIX HORIZONTAL	VERTICAL

AT NODE 1 TIE SPRING RATE IS 8571428., TIE SETTLEMENT IS 0.22518E-03, TIE REACTION IS 965.07

1	0.0	0.50394E-01	0.0	0.0
2	0.0	0.50169E-01	0.0	0.0
3	0.0	0.48567E-01	0.0	0.0
4	0.0	0.46523E-01	0.0	0.0
5	0.0	0.44852E-01	0.0	0.0
6	0.0	0.43548E-01	0.0	0.0
7	0.0	0.42615E-01	0.0	0.0
8	0.0	0.40552E-01	0.0	0.0
9	0.0	0.38095E-01	0.0	0.0
10	0.0	0.32557E-01	0.0	0.0
11	0.0	0.27192E-01	0.0	0.0
12	0.0	0.22268E-01	0.0	0.0
13	0.0	0.13806E-01	0.0	0.0
14	0.0	0.79645E-02	0.0	0.0
15	0.0	0.41267E-02	0.0	0.0
16	0.0	0.0	0.0	0.0

AT NODE 17 TIE SPRING RATE IS 8571428., TIE SETTLEMENT IS 0.21202E-03, TIE REACTION IS 1817.36

17	0.16944E-03	0.50735E-01	0.0	0.0
18	-0.66307E-03	0.50523E-01	0.0	0.0
19	-0.94758E-03	0.47900E-01	0.0	0.0
20	-0.64709E-03	0.46048E-01	0.0	0.0
21	-0.16930E-03	0.44632E-01	0.0	0.0
22	0.51530E-04	0.43611E-01	0.0	0.0
23	0.74851E-05	0.42725E-01	0.0	0.0
24	-0.17506E-03	0.40613E-01	0.0	0.0
25	-0.36452E-03	0.38125E-01	0.0	0.0
26	-0.48859E-03	0.32557E-01	0.0	0.0
27	-0.52446E-03	0.27183E-01	0.0	0.0
28	-0.50714E-03	0.22259E-01	0.0	0.0
29	-0.36607E-03	0.13798E-01	0.0	0.0
30	-0.23806E-03	0.79598E-02	0.0	0.0
31	-0.12646E-03	0.41245E-02	0.0	0.0
32	0.0	0.0	0.0	0.0

AT NODE 33 TIE SPRING RATE IS 0., TIE SETTLEMENT IS 0.55815E-02, TIE REACTION IS 0.0

33	0.32791E-03	0.51735E-01	0.0	0.0
34	-0.10016E-02	0.46153E-01	0.0	0.0
35	-0.15292E-02	0.45901E-01	0.0	0.0
36	-0.77780E-03	0.45295E-01	0.0	0.0
37	0.19591E-04	0.44532E-01	0.0	0.0
38	0.15810E-03	0.43939E-01	0.0	0.0
39	-0.16799E-04	0.43055E-01	0.0	0.0
40	-0.37473E-03	0.40789E-01	0.0	0.0
41	-0.74001E-03	0.38204E-01	0.0	0.0
42	-0.98133E-03	0.32560E-01	0.0	0.0
43	-0.10503E-02	0.27162E-01	0.0	0.0
44	-0.10143E-02	0.22230E-01	0.0	0.0
45	-0.73173E-03	0.13775E-01	0.0	0.0
46	-0.47569E-03	0.79456E-02	0.0	0.0
47	-0.25264E-03	0.41180E-02	0.0	0.0
48	0.0	0.0	0.0	0.0

AT NODE 49 TIE SPRING RATE IS 0., TIE SETTLEMENT IS 0.63410E-02, TIE REACTION IS 0.0

369	-0.12923E-02	-0.31434E-01	0.0	0.0
370	-0.85464E-02	-0.17902E-01	0.0	0.0
371	-0.10778E-01	-0.18167E-01	0.0	0.0
372	-0.13475E-01	-0.17869E-01	0.0	0.0
373	-0.15728E-01	-0.17318E-01	0.0	0.0
374	-0.17790E-01	-0.15919E-01	0.0	0.0
375	-0.19045E-01	-0.14499E-01	0.0	0.0
376	-0.19883E-01	-0.11827E-01	0.0	0.0
377	-0.19558E-01	-0.95309E-02	0.0	0.0
378	-0.17069E-01	-0.60275E-02	0.0	0.0
379	-0.14023E-01	-0.35533E-02	0.0	0.0
380	-0.11141E-01	-0.18798E-02	0.0	0.0
381	-0.72516E-02	0.12141E-03	0.0	0.0
382	-0.43811E-02	0.10126E-02	0.0	0.0
383	-0.22146E-02	0.11286E-02	0.0	0.0
384	0.0	0.0	0.0	0.0

AT NODE 385 TIE SPRING RATE IS 2., TIE SETTLEMENT IS -0.29218E-01, TIE REACTION IS -0.06

385	-0.96917E-03	-0.54049E-01	0.0	0.0
386	-0.83148E-02	-0.24831E-01	0.0	0.0
387	-0.92217E-02	-0.24561E-01	0.0	0.0
388	-0.10121E-01	-0.24257E-01	0.0	0.0
389	-0.11137E-01	-0.23843E-01	0.0	0.0
390	-0.12471E-01	-0.22634E-01	0.0	0.0
391	-0.13504E-01	-0.21267E-01	0.0	0.0
392	-0.14531E-01	-0.18472E-01	0.0	0.0
393	-0.14760E-01	-0.15811E-01	0.0	0.0
394	-0.13223E-01	-0.11259E-01	0.0	0.0
395	-0.11065E-01	-0.77225E-02	0.0	0.0
396	-0.89169E-02	-0.51148E-02	0.0	0.0
397	-0.58324E-02	-0.16555E-02	0.0	0.0
398	-0.35338E-02	0.13861E-03	0.0	0.0
399	-0.17872E-02	0.75930E-03	0.0	0.0
400	0.0	0.0	0.0	0.0

AT NODE 401 TIE SPRING RATE IS 2., TIE SETTLEMENT IS -0.42449E-01, TIE REACTION IS -0.08

401	-0.64612E-03	-0.70202E-01	0.0	0.0
402	-0.60314E-02	-0.27752E-01	0.0	0.0
403	-0.64284E-02	-0.27438E-01	0.0	0.0
404	-0.68837E-02	-0.27083E-01	0.0	0.0
405	-0.73296E-02	-0.26697E-01	0.0	0.0
406	-0.79719E-02	-0.25663E-01	0.0	0.0
407	-0.85962E-02	-0.24524E-01	0.0	0.0
408	-0.94231E-02	-0.22061E-01	0.0	0.0
409	-0.97535E-02	-0.19496E-01	0.0	0.0
410	-0.89075E-02	-0.14686E-01	0.0	0.0
411	-0.75540E-02	-0.10644E-01	0.0	0.0
412	-0.61647E-02	-0.74565E-02	0.0	0.0
413	-0.40533E-02	-0.29789E-02	0.0	0.0
414	-0.24655E-02	-0.52337E-03	0.0	0.0
415	-0.12518E-02	0.48267E-03	0.0	0.0
416	0.0	0.0	0.0	0.0

AT NODE 417 TIE SPRING RATE IS 2., TIE SETTLEMENT IS -0.53301E-01, TIE REACTION IS -0.11

417	0.0	-0.83124E-01	0.0	0.0
418	0.0	-0.29823E-01	0.0	0.0
419	0.0	-0.29477E-01	0.0	0.0
420	0.0	-0.29117E-01	0.0	0.0
421	0.0	-0.28734E-01	0.0	0.0
422	0.0	-0.27724E-01	0.0	0.0
423	0.0	-0.26640E-01	0.0	0.0
424	0.0	-0.24281E-01	0.0	0.0
425	0.0	-0.21760E-01	0.0	0.0
426	0.0	-0.16871E-01	0.0	0.0
427	0.0	-0.12612E-01	0.0	0.0
428	0.0	-0.91367E-02	0.0	0.0
429	0.0	-0.40373E-02	0.0	0.0
430	0.0	-0.11142E-02	0.0	0.0
431	0.0	0.19715E-03	0.0	0.0
432	0.0	0.0	0.0	0.0

TOTAL TIE REACTION= 57465.59

ELEM STRAIN STRESS

ELEM	EXXX	EXYY	EXXY	SIGXX	SIGYY	TAUXY	SIG1	SIG3	MODULUS	STRS RATIO	
1	DISTANCE=	0.0	CURVATURE=	-0.43053E-04	MOMENT=	-0.12257E 06					
1	DISTANCE=	4.00	CURVATURE=	-0.41667E-04	MOMENT=	-0.11863E 06					
2	-0.2013E-03	0.5280E-03	-0.3610E-05	0.6043E 01	0.3056E 02	-0.6068E-01	0.3056E 02	0.6043E 01	45383.3	5.1	1.
3	-0.1993E-03	0.4871E-03	-0.1804E-03	0.3611E 01	0.2179E 02	-0.2388E 01	0.2210E 02	0.3303E 01	35755.1	6.7	1.
4	-0.1020E-03	0.3859E-03	-0.1465E-03	0.5208E 01	0.1630E 02	-0.1666E 01	0.1655E 02	0.4964E 01	30693.6	3.3	1.
5	-0.1472E-04	0.1937E-03	-0.3793E-04	0.1166E 02	0.1342E 02	-0.1594E 00	0.1343E 02	0.1165E 02	12356.3	1.2	3.
6	0.7377E-05	0.1516E-03	0.2527E-04	0.1137E 02	0.1268E 02	0.1147E 00	0.1269E 02	0.1136E 02	13344.2	1.1	3.
7	-0.2095E-04	0.1739E-03	0.2903E-04	0.1065E 02	0.1241E 02	0.1313E 00	0.1242E 02	0.1064E 02	13292.9	1.2	3.
8	-0.6745E-04	0.2059E-03	0.1899E-04	0.9885E 01	0.1127E 02	0.8293E-01	0.1128E 02	0.8882E 01	12840.6	1.3	3.
9	-0.1066E-03	0.2314E-03	0.6072E-05	0.7400E 01	0.1027E 02	0.2580E-01	0.1027E 02	0.7400E 01	12490.0	1.4	3.
10	-0.1266E-03	0.2237E-03	-0.1155E-06	0.5389E 01	0.8369E 01	-0.4911E-03	0.8369E 01	0.5389E 01	12503.0	1.6	3.
11	-0.1289E-03	0.2052E-03	-0.2518E-05	0.4043E 01	0.6927E 01	-0.1086E-01	0.6927E 01	0.4043E 01	12687.3	1.7	3.
12	-0.1092E-03	0.1692E-03	-0.3593E-05	0.3215E 01	0.5691E 01	-0.1598E-01	0.5692E 01	0.3215E 01	13075.4	1.8	3.
13	-0.7552E-04	0.1168E-03	-0.2850E-05	0.2297E 01	0.4079E 01	-0.1320E-01	0.4079E 01	0.2297E 01	13623.8	1.8	3.
14	-0.4557E-04	0.7673E-04	-0.1980E-05	0.1902E 01	0.3073E 01	-0.9480E-02	0.3073E 01	0.1902E 01	14079.8	1.6	3.
15	-0.1581E-04	0.4126E-04	-0.9050E-06	0.1813E 01	0.2377E 01	-0.4470E-02	0.2377E 01	0.1813E 01	14522.0	1.3	3.
16	DISTANCE=	4.00	CURVATURE=	-0.41731E-04	MOMENT=	-0.11881E 06					
16	DISTANCE=	8.00	CURVATURE=	-0.37506E-04	MOMENT=	-0.10678E 06					
17	-0.1150E-03	0.3504E-03	-0.6945E-03	0.2201E 01	0.8341E 01	-0.4494E 01	0.1071E 02	-0.1719E 00	17472.9	-62.3	1.
18	-0.8904E-04	0.3073E-03	-0.4755E-03	0.3500E 01	0.1188E 02	-0.5025E 01	0.1423E 02	0.1147E 01	28533.0	12.4	1.
19	0.7273E-05	0.2723E-03	-0.2661E-03	0.7108E 01	0.1276E 02	-0.2836E 01	0.1394E 02	0.5930E 01	28777.3	2.3	1.
20	0.3693E-04	0.1345E-03	-0.1527E-05	0.1248E 02	0.1336E 02	-0.6904E-02	0.1336E 02	0.1248E 02	13289.9	1.1	3.
21	0.1029E-04	0.1475E-03	0.1005E-03	0.1171E 02	0.1300E 02	0.4721E 00	0.1315E 02	0.1155E 02	13807.2	1.1	3.
22	-0.2799E-04	0.1824E-03	0.8576E-04	0.1066E 02	0.1255E 02	0.3867E 00	0.1263E 02	0.1058E 02	13258.0	1.2	3.
23	-0.7190E-04	0.2114E-03	0.5488E-04	0.8861E 01	0.1132E 02	0.2382E 00	0.1134E 02	0.8838E 01	12762.3	1.3	3.
24	-0.1085E-03	0.2336E-03	0.1777E-04	0.7382E 01	0.1028E 02	0.7528E-01	0.1028E 02	0.7380E 01	12458.3	1.4	3.
25	-0.1273E-03	0.2244E-03	-0.3874E-06	0.5381E 01	0.8370E 01	-0.1647E-02	0.8370E 01	0.5381E 01	12495.4	1.6	3.
26	-0.1291E-03	0.2054E-03	-0.7595E-05	0.4040E 01	0.6927E 01	-0.3277E-01	0.6927E 01	0.4039E 01	12686.9	1.7	3.
27	-0.1091E-03	0.1692E-03	-0.1078E-04	0.3214E 01	0.5689E 01	-0.4795E-01	0.5690E 01	0.3213E 01	13076.0	1.8	3.
28	-0.7541E-04	0.1167E-03	-0.8548E-05	0.2297E 01	0.4077E 01	-0.3961E-01	0.4078E 01	0.2296E 01	13624.4	1.8	3.
29	-0.4548E-04	0.7663E-04	-0.5934E-05	0.1902E 01	0.3071E 01	-0.2842E-01	0.3072E 01	0.1901E 01	14080.2	1.6	3.
30	-0.1577E-04	0.4121E-04	-0.2713E-05	0.1813E 01	0.2376E 01	-0.1340E-01	0.2376E 01	0.1813E 01	14522.2	1.3	3.
31	DISTANCE=	8.00	CURVATURE=	-0.37657E-04	MOMENT=	-0.10721E 06					
31	DISTANCE=	12.00	CURVATURE=	-0.33181E-04	MOMENT=	-0.94467E 05					
32	-0.1332E-03	0.7331E-04	0.1812E-03	-0.9233E 00	0.1542E-01	0.4118E 00	0.1709E 00	-0.1078E 01	6135.4	-0.2	1.
33	0.6351E-04	0.9442E-04	0.1330E-04	0.3971E 01	0.4467E 01	0.1066E 00	0.4488E 01	0.3949E 01	21637.2	1.1	1.
34	0.9589E-04	0.2128E-03	0.9638E-04	0.8733E 01	0.1097E 02	0.9229E 00	0.1130E 02	0.8402E 01	25856.0	1.3	1.
35	0.4886E-04	0.1181E-03	0.2306E-03	0.1331E 02	0.1399E 02	0.1132E 01	0.1494E 02	0.1247E 02	14428.4	1.2	3.
36	-0.3853E-05	0.1679E-03	0.2136E-03	0.1181E 02	0.1339E 02	0.9845E 00	0.1387E 02	0.1134E 02	13554.4	1.2	3.
37	-0.4209E-04	0.2010E-03	0.1405E-03	0.1062E 02	0.1277E 02	0.6204E 00	0.1293E 02	0.1045E 02	12979.0	1.2	3.
38	-0.8006E-04	0.2215E-03	0.8627E-04	0.8814E 01	0.1140E 02	0.3698E 00	0.1145E 02	0.8762E 01	12603.3	1.3	3.
39	-0.1121E-03	0.2377E-03	0.2844E-04	0.7349E 01	0.1030E 02	0.1200E 00	0.1030E 02	0.7344E 01	12401.4	1.4	3.
40	-0.1287E-03	0.2258E-03	-0.7339E-06	0.5365E 01	0.8375E 01	-0.3116E-02	0.8375E 01	0.5365E 01	12481.3	1.6	3.
41	-0.1295E-03	0.2057E-03	-0.1279E-04	0.4034E 01	0.6926E 01	-0.5517E-01	0.6927E 01	0.4033E 01	12685.9	1.7	3.
42	-0.1090E-03	0.1690E-03	-0.1801E-04	0.3211E 01	0.5685E 01	-0.8011E-01	0.5687E 01	0.3209E 01	13077.1	1.8	3.
43	-0.7520E-04	0.1164E-03	-0.1425E-04	0.2296E 01	0.4072E 01	-0.6603E-01	0.4075E 01	0.2294E 01	13625.7	1.8	3.
44	-0.4530E-04	0.7643E-04	-0.9881E-05	0.1902E 01	0.3068E 01	-0.4733E-01	0.3070E 01	0.1900E 01	14081.1	1.6	3.
45	-0.1570E-04	0.4113E-04	-0.4516E-05	0.1812E 01	0.2374E 01	-0.2230E-01	0.2375E 01	0.1811E 01	14522.5	1.3	3.
46	DISTANCE=	12.00	CURVATURE=	-0.33382E-04	MOMENT=	-0.95039E 05					
46	DISTANCE=	16.00	CURVATURE=	-0.28681E-04	MOMENT=	-0.81655E 05					
47	-0.2504E-04	0.4222E-03	0.1485E-02	0.1299E 01	0.2624E 01	0.2200E 01	0.4259E 01	-0.3366E 00	4000.0	-12.7	1.
48	0.8467E-05	0.3018E-03	0.9056E-03	0.6806E 01	0.1220E 02	0.8322E 01	0.1825E 02	0.7554E 00	24812.4	24.2	1.
49	-0.2491E-04	0.3405E-03	0.5763E-03	0.6453E 01	0.1332E 02	0.5418E 01	0.1630E 02	0.3473E 01	25383.3	4.7	1.
50	-0.2777E-04	0.2443E-03	0.5335E-03	0.1315E 02	0.1530E 02	0.2102E 01	0.1658E 02	0.1186E 02	11586.7	1.4	3.
51	-0.5007E-04	0.2346E-03	0.3258E-03	0.1153E 02	0.1368E 02	0.1345E 01	0.1449E 02	0.1092E 02	12140.3	1.3	3.
52	-0.6480E-04	0.2317E-03	0.1905E-03	0.1050E 02	0.1301E 02	0.8048E 00	0.1324E 02	0.1026E 02	12418.3	1.3	3.
53	-0.9139E-04	0.2354E-03	0.1129E-03	0.8732E 01	0.1148E 02	0.4755E 00	0.1156E 02	0.8653E 01	12378.3	1.3	3.
54	-0.1172E-03	0.2435E-03	0.3797E-04	0.7309E 01	0.1033E 02	0.1592E 00	0.1034E 02	0.7300E 01	12326.3	1.4	3.
55	-0.1308E-03	0.2280E-03	-0.1427E-05	0.5343E 01	0.8385E 01	-0.6048E-02	0.8385E 01	0.5343E 01	12462.2	1.6	3.
56	-0.1301E-03	0.2062E-03	-0.1824E-04	0.4024E 01	0.6925E 01	-0.7867E-01	0.6928E 01	0.4022E 01	12684.5	1.7	3.
57	-0.1089E-03	0.1688E-03	-0.2532E-04	0.3207E 01	0.5678E 01	-0.1127E 00	0.5683E 01	0.3202E 01	13078.9	1.8	3.

PART 3

PROGRAM LISTING

```
C
C
C    ******************************************************************
C    ******************************************************************
C    **                       PROGRAM ILLI-TRACK                     **
C    **     A COMPUTER PROGRAM FOR THE FINITE ELEMENT ANALYSIS OF    **
C    **     CONVENTIONAL RLWY TRACK SUPPORT SYSTEM(CRTSS), DEVELOPED BY **
C    **     SHIRAZ D. TAYABJI , CIVIL ENGINEERING DEPARTMENT, UNIVERSITY**
C    **     OF ILLINOIS, SPRING, 1975.                               **
C    ******************************************************************
C    ******************************************************************
C
C
C     DIMENSIONS MASTER REAL AND INTEGER ARRAY
      DIMENSION VARS(42000),INTS(12500)
      DATA IREAL,INTGR/42000,12500/
      CALL VRDIM(VARS,INTS,INTGR,IREAL)
      END
      SUBROUTINE AMESH(CORD,NONP,NPI,NUMEL)
```

```
C
      DIMENSION  CORD(2,NONP),NPI(4,NUMEL)
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/TEN/R(36),Z(30),NRR
C    PREPARES ELEMENT CONNECTIVIYY
      NNDEPT=NDEPTH+1
      DO 70 I=1,NONP
      JCOL=(I-1)/NNDEPT+1
      CORD(1,I)=R(JCOL)
   70 CONTINUE
C
C
      DO 110  I=1,NNDEPT
      J=I
      DO 120 K=J,NONP,NNDEPT
  120 CORD(2,K)=Z(J)
  110 CONTINUE
C
C    PREPARES NODAL COORDINANATES
C
      DO 200 I=1,NUMEL
      ANUM=(I-1)/NDEPTH
      JNUM=ANUM
      NPI(1,I)=I+JNUM
      NPI(2,I)=NPI(1,I)+1
      NPI(3,I)=NPI(2,I)+NDEPTH+1
      NPI(4,I)=NPI(3,I)-1
  200 CONTINUE
C
      RETURN
      END
      SUBROUTINE ASEMBL(NDEG,NGENS,SXX,NSXX,MAXCC,NAP,NPI,NUMEL,N1,NPNUM
     1,CORD,NP,MAXNP,NUME,NNODE,ET,DATA1,NNODE2,NONP,NCRD,PSR,DEN,TIEK,
     2 TYPE)
C
      DIMENSION SXX(NDEG,NDEG,NSXX),NUME(NUMEL),NPI(NNODE,NUMEL),
     1 ET(NUMEL),DATA1(NUMEL),NPNUM(NONP),CORD(NCRD,NONP),NP(NONP,MAXNP)
     2,MAXCO(NONP),NAP(NONP),PSR(NUMEL),DEN(NUMEL),TIEK(36),TYPE(NUMEL)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
C
C     ASSEMBLES THE STRUCTURAL STIFFNESS MATRIX
C     FROM THE ELEMENT STIFFNESS MACRO UNITS.
C     SXX  STRUCTURAL STIFFNESS ARRAY
C     NSXX  (MAXNP)*(NONP+1)  NO. OF MACRO UNITS IN SXX
C     MAXCO(I)  LAST NONZERO COLUMN IN ROW I
C     MAXNP  MAXIMUM SEMI-BANDWIDTH
C     OF STRUCTURAL STIFFNESS MATRIX
C     NAP(I)  SEMI-BANDWIDTH FOR ROW(I) OF
C     STRUCTURAL STIFFNESS MATRIX.
C     SK  ELEMENT STIFFNESS IN MACRO UNITS
```

```
C       NPNUM(N)   NODAL POINT NUMBER FOR NODE N
C       P(N,N1)   STORES N1 NONZERO ELEMENT OF NTH ROW OF THE STRUCTURAL
C       STIFFNESS MATRIX
C       NUME(N)   ELEMENT NUMBER
C       NNODE2   NNODE*NNODE
C       INITILIZE STRUCTURAL STIFFNESS MATRIX
C
        CALL SCLA(SXX,0.,NDEG*NDEG,NSXX,0)
C       INITILIZE MAXCO,NAP,AND NP ARRAYS
        DO 1 L=1,NONP
        NAP(L)=1
        MAXCO(L)=L
        DO 2 M=1,MAXNP
  2     NP(L,M)=0
  1     NP(L,1)=L
C       NP IS FILLED IN FOR THE DIAGONAL STIFFNESS
C       ELEMENTS SINCES THEY ARE STORED FIRST.
C
C     K IS A SUMNER FOR SPRING NUMBERS
        K=0
        DO 3 N=1,NUMEL
        DO 4 I=1,NNODE
  4     LM(I)=NPI(I,N)
        CALL ELEM(N,NDEG,NNODE,NGENS,NPI,ET(N),NUMEL,CORD,NONP,DATA1(N),
      1   N1,NCRD,NNODE2,PSR(N),DEN(N),TIEK,K,TYPE)
C       NEXT ROUTINE PUTS THE SK MACRO UNITS INTO A STRUCTURAL
C       STIFFNESS MATRIX
C       THIS ROUTINE ADDS THE ELEMENT MACRO UNITS SK TO THE STRUCTURAL
C       STIFFNESS SXX. IT ALSO FILLS IN THE 'POINTER' ARRAY NP.
        DO 21 L=1,NNODE
        LMSS=(L-1)*NNODE
        LX=LM(L)
        LMS1=(LX-1)*MAXNP
        DO 21 M=1,NNODE
        LMSS=LMSS+1
C       CHECK ON LAST COLUMN NUMBER
        IF(LM(M).GT.MAXCO(LX)) MAXCO(LX)=LM(M)
C       ONLY HALF OFF-DIAGONAL TERMS STORED
        IF(LM(M).GT.LX) GO TO 21
        MX=0
 22     MX=MX+1
        IF(NP(LX,MX).NE.LM(M).AND.NP(LX,MX).NE.0) GO TO 22
C       FILL IN NP ARRAY
        NP(LX,MX)=LM(M)
C       CHECK TO SEE IF MAX. SEMI-BANDWIDTH IS EXCEEDED
        IF(MX.GT.MAXNP) GO TO 26
        LMS=LMS1+MX
C       ADD IN ELEMENT MACRO UNIT
        DO 28 J1=1,NDEG
        DO 28 N2=1,NDEG
 28     SXX(J1,N2,LMS)=SXX(J1,N2,LMS)+SK(J1,N2,LMSS)
 21     CONTINUE
        GO TO 3
 26     WRITE(NOUT,27) LX
 27     FORMAT(' ','MORE THAN MAXNC JOINED TO NODE ',I5/)
  3     CONTINUE
```

```
C      COMPUTATION OF SEMI-BANDWIDTH FOR STRUCTURAL STIFFNESS
C      MATRIX--FILLS IN NAP ARRAY
       DO 5 M=1,NONP
       MX=1
    6  MX=MX+1
       IF(MX.LE.MAXNP.AND.NP(M,MX).GT.0) GO TO 6
    5  NAP(M)=MX-1
       RETURN
       END
       SUBROUTINE BETA(CORD,NONP,NCRD)
C     BETA PREPARES THE COEFFICIENT MATRIX USED TO EVALUATE STRAIN
C     FROM DISPLACEMENTS FOR THE PLANAR ELEMENTS
C
       DIMENSION CORD(NCRD,NONP)
C
       COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
       COMMON/THREE/DUMP(20),LM(4),IOUT
C
C     EVALUATED AT THE CENTER OF RECTANGLE
       N5=LM(1)
       N6=LM(2)
       N7=LM(3)
       N8=LM(4)
       A=ABS(CORD(1,N5)-CORD(1,N8))
       F=ABS(CORD(2,N5)-CORD(2,N6))
       X=A/2.
       Y=F/2.0
       C=A*F
       B(1,1)=-Y/C
       B(1,2)=0.
       B(1,3)=-(F-Y)/C
       B(1,4)=0.
       B(1,5)=-B(1,3)
       B(1,6)=0.
       B(1,7)=-B(1,1)
       B(1,8)=0.
       B(2,1)=0.
       B(2,2)=(A-X)/C
       B(2,3)=0.
       B(2,4)=-B(2,2)
       B(2,5)=0.
       B(2,6)=-X/C
       B(2,7)=0.
       B(2,8)=-B(2,6)
       B(3,1)=B(2,2)
       B(3,2)=B(1,1)
       B(3,3)=B(2,4)
       B(3,4)=B(1,3)
       B(3,5)=B(2,6)
       B(3,6)=B(1,5)
       B(3,7)=B(2,8)
       B(3,8)=B(1,7)
C
       RETURN
       END
```

```
      SUBROUTINE BSTIFF(CORD,NCRD,NONF,ET,PSR,DEN,DATA1,TIEK1,TIEK2)
C
      DIMENSION CORD(NCRD,NONP)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
C
C     ELEMENT STIFFNESS MATRIX FOR BEAM-SPRING TYPE ELEMENT
      N5=LM(1)
      N7=LM(3)
      AL=ABS(CORD(1,N7)-CORD(1,N5))
      C=ET*DATA1/(AL**3)
C
      SS(1,1)=4*AL*AL*C
      SS(1,2)=6*AL*C
      SS(1,7)=2*AL*AL*C
      SS(1,8)=-SS(1,2)
      SS(2,1)=6*AL*C
      SS(2,2)=TIEK1+12*C
      SS(2,4)=-TIEK1
      SS(2,7)=+SS(1,2)
      SS(2,8)=-12*C
      SS(4,2)=-TIEK1
      SS(4,4)=TIEK1
      SS(6,6)=TIEK2
      SS(6,8)=-TIEK2
      SS(7,1)=2*AL*AL*C
      SS(7,2)=6*AL*C
      SS(7,7)=4*AL*AL*C
      SS(7,8)=-6*AL*C
      SS(8,1)=-6*AL*C
      SS(8,2)=-12*C
      SS(8,6)=-TIEK2
      SS(8,7)=-6*AL*C
      SS(8,8)=TIEK2+12*C
C
      RETURN
      END
      SUBROUTINE BSTRES(N,NCRD,NDEG,NONP,CORD,ET,DATA1,TD)
C
      DIMENSION CORD(NCRD,NONP),TD(NDEG,NONP),X(2)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
C     CALC OF CURVATURE AND MOMENT AT THE END OF BEAM ELEMENT
      LX1=LM(1)
      LX2=LM(4)
      DISP(1)=TD(2,LX1)
      DISP(2)=TD(1,LX1)
      DISP(3)=TD(2,LX2)
```

```
      DISP(4)=TD(1,LX2)
      AL=ABS(CORD(1,LX1)-CORD(1,LX2))
      X(1)=0.
      X(2)=AL
      DO 10 I=1,2
      XX=X(I)
      CURV=(6./(AL*AL)-12.*XX/(AL**3))*DISP(1)
     1      +(4./AL-6.*XX/AL**2)*DISP(2)
     2      +(-6./AL**2+12.*XX/AL**3)*DISP(3)
     3      +(2./AL-6.*XX/AL**2)*DISP(4)
      AMOM=ET*DATA1*CURV
      XX=CORD(1,LX1)+XX
      IF(NSTP.NE.NSTEPS) GO TO 10
      WRITE(NOUT,20) N,XX,CURV,AMOM
   20 FORMAT(' ',I5,5X,'DISTANCE=',F6.2,5X,'CURVATURE=',E14.5,5X,
     1   'MOMENT=',E14.5)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE CHECK(ERROR)
      COMMON/ONE/SS(8,8),SK(2,2,16),C(3,3),B(3,8),DISP(8),DISPT(8),
     1   G(2,2),GI(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),ICUT
      COMMON/FOUR/ETS(10),PSRS(10),DATA11,DATA22,TIEKK
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/SIX/BONE1,BTWO1,BONE2,BTWO2,RMOD(8),DEV(8),UMOD(8),UDEV(8),
     1 EFAIL1,EFAIL2,EFAIL3,AMXSR1,SIGMN1,AMXSR2,SIGMN2,TAUSUB,NPOINT,
     2 JPCINT,EFAIL6,UTAUSB
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
      COMMON/EIGHT/RLCAD(36),PLOAD(36),DIST(36),MM(36),RDISP(36),
     1   PDISP(36),DIST1(36),MM1(36),NPT(36)
      COMMON/TEN/R(36),Z(30),NRR
      COMMON/ELEVEN/TTIEK(36)
C
      IF(RLTIE.LT.60.00.OR.RLTIE.GT.120.0)WRITE(NOUT,11) RLTIE
   11 FORMAT(' ','*****WARNING*****LENGTH OF TIE INPUT IS',F10.2,' CHECK
     1 IT'/)
      IF(WTIE.LT.4.00.OR.WTIE.GT.16.0)WRITE(NOUT,12) WTIE
   12 FORMAT(' ','*****WARNING*****WIDTH OF TIE INPUT IS',F10.2,' CHECK
     1IT'/)
      IF(TTHICK.LT.4.0.OR.TTHICK.GT.16.0) WRITE(NOUT,13) TTHICK
   13 FORMAT(' ','*****WARNING*****THICKNESS OF TIE INPUT IS',F10.2,' CH
     1ECK IT'/)
      IF(BDEPTH.LT.0.0)WRITE(NOUT,14) BDEPTH
   14 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1  ' ','BALLAST DEPTH OF',F10.2,' IS NEGATIVE'/)
      IF(BDEPTH.LT.0.0.OR.SBDEPT.LT.0.0.OR.PHI.LT.0..OR.PHI.GT.50.)ERROR
     1=1.0
      IF(SBDEPT.LT.0.0)WRITE(NOUT,15) SBDEPT
   15 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1  ' ','SUBBALLAST DEPTH OF',F10.2,' IS NEGATIVE'/)
      IF(TSPACE.LT.8.0.OR.TSPACE.GT.36.)WRITE(NOUT,16) TSPACE
   16 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1  ' ','TIE SPACING IS',F10.2,' CHECK IT'/)
```

```
      IF(BTHICK.LT.0.0.OR.BTHICK.GT.50.0)WRITE(NOUT,17) BTHICK
   17 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','EFFECTIVE TIE BEARING LENGTH IS',F10.2,' CHECK IT'/)
      IF(PHI.LT.0.00.OR.PHI.GT.50.0)WRITE(NOUT,18) PHI
   18 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','ANGLE OF DISTRIBUTION IS',F10.2,' CHECK IT'/)
      DO 111 I=1,6
      IF(ETS(I).LT.0.0) WRITE(NOUT,22) I,ETS(I)
   22 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','INITIAL MODULUS OF MATERIAL',I2,' IS',F14.0,' CHECK IT'/)
      IF(PSRS(I).LT.0.0)WRITE(NOUT,23) I,PSRS(I)
   23 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','POISSONS RATIO FOR MATERIAL',I2,' IS',F6.2,' CHECK IT'/)
      IF(ETS(I).LT.0.0.OR.PSRS(I).LT.0.0) ERROR=1.0
  111 CONTINUE
      IF(DATA11.LT.0..OR.DATA22.LT.0..OR.TIEKK.LT.0.)ERROR=1.0
      IF(DATA11.LT.0.)WRITE(NOUT,24) DATA11
   24 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','MOMENT OF INERTIA OF RAIL SECTION IS',F6.2,' CHECK IT'/)
      IF(DATA22.LT.0.)WRITE(NOUT,25) DATA22
   25 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','MOMENT OF INERTIA OF TIE SECTION IS',F6.2,' CHECK IT'/)
      IF(TIEKK.LT.0.0)WRITE(NOUT,26) TIEKK
   26 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','TIE SPRING RATE,TIEKK,IS',F10.1,' CHECK IT'/)
      IF(BONE1.LT.0..OR.BTWO1.LT.0..OR.BTWO1.GE.1.)ERROR=1.0
      IF(BONE1.LT.0..OR.BTWO1.LT.0..OR.BTWO1.GE.1.)WRITE(NOUT,27) BONE1,
     1BTWO1
   27 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1' ','BALLAST RESPONSE MODEL IS',F9.1,'(THETA)',F6.2,' CHECK IT'/)
      IF(BONE2.LT.0..OR.BTWO2.LT.0..OR.BTWO2.GE.1.)ERROR=1.0
      IF(BONE2.LT.0..OR.BTWO2.LT.0..OR.BTWO2.GE.1.)WRITE(NOUT,28) BONE2,
     1BTWO2
   28 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','SUBBALLAST RESPONSE MODEL IS',F10.2,'(THETA)',F6.2,' CHECK
     1IT'/)
      IF(NPOINT.LT.2.OR.NPOINT.GT.8) ERROR=1.0
      IF(NPOINT.LT.2.OR.NPOINT.GT.8)WRITE(NOUT,29) NPOINT
   29 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','NUMBER OF POINTS FOR LOWER SUBGRADE RESILIENT RESPONSE CURV
     2E IS ',I4,' CHECK IT'/)
      IF(JPOINT.LT.0.OR.JPOINT.EQ.1.OR.JPOINT.GT.8)ERROR=1.0
      IF(JPOINT.LT.0.OR.JPOINT.EQ.1.OR.JPOINT.GT.8) WRITE(NOUT,30)JPOINT
   30 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','NUMBER OF POINTS FOR UPPER SUBGRADE RESILIENT RESPONSE CURV
     2E IS',I4,' CHECK IT'/)
      DO 112 I=1,NPOINT
      IF(RMOD(I).LT.0.0.OR.DEV(I).LT.0.0) ERROR=1.0
      IF(RMOD(I).LT.0.0.OR.DEV(I).LT.0.0)WRITE(NOUT,31)I,RMOD(I),DEV(I)
   31 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','POINT',I3,' OF THE LOWER SUBGRADE RESILIENT RESPONSE CURVE
     2IS - MODULUS',F10.2,' DEVIATORIC STRESS',F6.2,' CHECK IT'/)
  112 CONTINUE
      IF(JPOINT.LE.0) GO TO 113
      DO 114 I=1,JPOINT
      IF(UMOD(I).LT.0..OR.UDEV(I).LT.0.) ERROR=1.0
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      IF(UMOD(I).LT.0..OR.UDEV(I).LT.0.)WRITE(NOUT,32)I,UMOD(I),UDEV(I)
   32 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','POINT',I3,' OF THE UPPER SUBGRADE RESILIENT RESPONSE CURVE
     2IS - MODULUS',F10.2,' DEVIATORIC STRESS',F6.2,' CHECK IT'/)
  114 CONTINUE
  113 CONTINUE
      IF(AMXSR1.LT.0.0.OR.AMXSR2.LT.0.0) ERROR=1.0
      IF(AMXSR1.LT.0.0.OR.AMXSR2.LT.0.0) WRITE(NOUT,33)AMXSR1,AMXSR2
   33 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','MAX STRESS RATIO FOR BALLAST IS',F6.1,' AND MAX STRESS RATI
     2O FOR SUBBALLAST IS',F6.1,' CHECK THEM'/)
      IF(EFAIL 1.LT.0.0.OR.EFAIL2.LT.0.0) ERROR=1.0
      IF(EFAIL 1.LT.0.0.OR.EFAIL2.LT.0.0) WRITE(NOUT,34)EFAIL1,EFAIL2
   34 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','FAILURE MODULUS FOR BALLAST IS',F10.1,' AND FAILURE MODULUS
     2 FOR SUBBALLAST IS',F10.1,' CHECK THEM'/)
      IF(TAUSUB.LT.0.0.OR.UTAUSB.LT.0.0) ERROR=1.0
      IF(TAUSUB.LT.0.0.OR.UTAUSB.LT.0.0)  WRITE(NOUT,35)TAUSUB,UTAUSB
   35 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','ALLOWABLE SHEAR STRESS FOR LOWER SUBGRADE IS',F6.1,' AND AL
     2LOWABLE SHEAR STRESS FOR UPPER SUBGRADE IS ',F6.1,' CHECK THEM'/)
      IF(EFAIL3.LT.0.0.OR.EFAIL6.LT.0.0) ERROR=1.0
      IF(EFAIL3.LT.0.0.OR.EFAIL6.LT.0.0)  WRITE(NOUT,36)EFAIL3,EFAIL6
   36 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','FAILURE MODULUS FOR LOWER SUBGRADE IS',F6.1,' AND FAILURE M
     2ODULUS FOR UPPER SUBGRADE IS',F6.1,' CHECK THEM'/)
      IF(NDSPEC.GT.36.OR.NFSPEC.GT.36) ERROR=1.0
      IF(NDSPEC.GT.36.OR.NFSPEC.GT.36) WRITE(NOUT,37)NDSPEC,NFSPEC
   37 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','NO. OF SPECIFIED DISPLACEMENTS ARE',I4,' AND NO. OF SPECIFI
     2ED FORCES ARE',I4,' CHECK THEM'/)
      RETURN
      END
      SUBROUTINE CONTRO(NNODE2,NCRD,NUMEL,NNODE,NDEG,NGENS,NONP,MAXNP,
     1  NSXX,N1,SXX,CORD,ET,DATA1,PL,TD,TF,EX,PSR,DEN,SIGXX,TX,PPSTRS,
     2  TYPE,MAXCO,NAP,NPI,NP,NUME,NPNUM,NPBC,ERROR,NEX)
C
      DIMENSION SXX(NDEG,NDEG,NSXX),CORD(NCRD,NONP),ET(NUMEL),
     1  DATA1(NUMEL),PL(NDEG,NONP),TD(NDEG,NONP),TF(NDEG,NONP),EX(NEX),
     2  SIGXX(NEX),PSR(NUMEL),DEN(NUMEL),MAXCO(NONP),NAP(NONP),
     3  NPI(NNODE,NUMEL),NP(NONP,MAXNP),NUME(NUMEL),NPNUM(NONP),
     4  NPBC(NDEG,NONP),TX(NDEG,NONP),TIEK(36),PPSTRS(NGENS,NONP),
     5  TYPE(NUMEL)
      DIMENSION  FD(2,800)
      DIMENSION TIED(36),TIER(36)
C     CONTRO IS THE CONTROL PROGRAM. IT CALLS ALL MAJOR SUBROUTINES
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
      COMMON/EIGHT/RLOAD(36),PLOAD(36),DIST(36),MM(36),RDISP(36),
     1   PDISP(36),DIST1(36),MM1(36),NPT(36)
      COMMON/NINE/FLAG,BFLAG,CFLAG,ABCD
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      COMMON/TEN/R(36),Z(30),NRR
      COMMON/ELEVEN/TTIEK(36)
C     INITIALIZE ARRAYS
      CALL SCLA(SIGXX,0.,NGENS,NUMEL,0)
      CALL SCLA(EX,0.,NGENS,NUMEL,0)
      CALL SCLA(TF,0.,NDEG,NONP,0)
      CALL SCLA(PPSTRS,0.,NGENS,NONP,0)
      CALL SCLA(FD,0.,2,800,0)
C     INITIALIZE CONTROLS
      NNDEPT=NDEPTH+1
      IASMBL=1
      FLAG=0.0
C     READ INPUT
C
      CALL INDATA(NDEG,NUMEL,NONP,NGENS,NCRD,NNODE,NUME,NPI,ET,DATA1,
     1 NPNUM,CORD,PSR,DEN,TIEK,TYPE,ERROR)
      IF(ERROR.EQ.1.0) RETURN
C     BEGIN SOLUTION OF PROBLEM
C     INCREMENTAL LOADING TECHNIQUE USED FOR SOLVING NON-LINEAR PROBLEMS.
C     LOAD IS ADDED IN SPECIFIED INCREMENTS AND SOLUTION IS SOUGHT FOR
C     EACH INCREMENT. THE STRESS STATE IS USED TO OBTAIN THE MODULI
C     VALUES TO BE USED IN THE NEXT INCREMENT STEP.AN ITERATIVE ANAL. IS
C     DONE AT THE END OF THE FINAL STEP(WITH FULL LOAD ACTING).
C     ABCD=1.0  FOR ITERATIVE SCHEME WITH FULL LOAD APPLIED AT ALL STEPS
C     ABCD=2.0 FOR STEP -INCREMENTAL LOADING SHEME WITH LOAD/NSTEPS
C       APPLIED AT EVERY STEP.DEFLECTIONS ARE ADDED CUMULATIVELY AT END
C       OF EACH STEP AND STRAINS AND STRESSES CALCULATED THEN
      DO 20 NSTP=1,NSTEPS
      WRITE(NOUT,25) NSTP,NSTEPS
   25 FORMAT(///' ','*********************************************** '/
     1   ' ','**  STEP NO.',I3,2X,'OF A TOTAL OF ',I3,2X,'STEPS      **'/
     2' ','***********************************************      '///)
      IF(ABCD.EQ.1.0) GO TO 301
      IF(ABCD.EQ.2.0) GO TO 302
      IF(NFSPEC.EQ.0) GO TO 233
      DO 22  JJ=1,NFSPEC
   22 PLOAD(JJ)=RLOAD(JJ)*NSTP/NSTEPS
  233 IF(NDSPEC.EQ.0) GO TO 23
      DO 222 JJ=1,NDSPEC
  222 PDISP(JJ)=RDISP(JJ)*NSTP/NSTEPS
      GO TO 23
  301 IF(NFSPEC.EQ.0) GO TO 333
      DO 322 JJ=1,NFSPEC
  322 PLOAD(JJ)=RLOAD(JJ)
  333 IF(NDSPEC.EQ.0) GO TO 23
      DO 323  JJ=1,NDSPEC
  323 PDISP(JJ)=RDISP(JJ)
      GO TO 23
  302 IF(NFSPEC.EQ.0) GO TO 341
      DO 342 JJ=1,NFSPEC
  342 PLOAD(JJ)=RLOAD(JJ)/NSTEPS
  341 IF(NDSPEC.EQ.0) GO TO 23
      DO 343  JJ=1,NDSPEC
  343 PDISP(JJ)=RDISP(JJ)/NSTEPS
      GO TO 23
C     FLAG=1.0 IS USED TO REPEAT THE FINAL CYCLE
```

```
 23   IF(FLAG.EQ.1.0) WRITE(NOUT,24)
 24   FORMAT(' ','****** FINAL CYCLE *********')
C     ASSEMBLE STIFFNESS
      CALL ASEMBL(NDEG,NGENS,SXX,NSXX,MAXCO,NAP,NPI,NUMEL,N1,NPNUM,CORD,
     1 NP,MAXNP,NUME,NNODE,ET,DATA1,NNODE2,NCNP,NCRD,PSR,DEN,TIEK,TYPE)
C     READ LOAD AND BOUNDARY CONDITIONS
      CALL READBC(NDEG,NGENS,NUMEL,N1,NCRD,NONP,NNODE,NPI,NPBC,PRESS,
     1PL,CORD,TD,TF)
C     TX IS USED INSTEAD OF TF IN SUBSEQUENT SOLUYION STEPS.
      DO 900 I=1,NONP
      DO 900 II=1,NDEG
 900  TX(II,I)=TF(II,I)
      IF(ERROR.EQ.1.0) RETURN
C     ADJUST STIFFNESS AND LOAD VECTOR FOR DISPLACEMENT
C       BOUNDART CONDITIONS
      CALL FIXBC(NONP,NDEG,MAXNP,NSXX,TD,NAP,NP,NPBC,SXX,TX,IASMBL)
C     SOLVE EQUATIONS
C     FIRST TIME THROUGH INCLUDE DECOMPOSITION,THUS CALL CROUTD
      IF(IASMBL.EQ.1) CALL CROUTD(NDEG,NONP,MAXNP,NSXX,NPBC,TD,TX,
     1 NP,SXX,NAP,MAXCO)
C     FOR SUBSEQUENT LOADING CASES WHERE ONLY BACK AND FORWARD
C       SUBSTITUTION IS NECESSARY ,CALL CROUTE
      IF(IASMBL.EQ.0) CALL CROUTE(NDEG,NONP,MAXNP,NSXX,NPBC,TD,TX,
     1 NP,SXX,NAP,MAXCO)
C
C     REPLACE THE GIVEN DISPLACEMENT INPUT, SINCE IT IS MADE EQUAL TO
C     ZERO IN FIXBC
      IF(NDSPEC.EQ.0) GO TO 202
      DO 201 L=1,NDSPEC
      MN=NPT(L)
      TD(2,MN)=PDISP(L)
 201  CONTINUE
 202  CONTINUE
      IF(ABCD.NE.2.0) GO TO 204
      IF(FLAG.EQ.1.0) GO TO 204
      DO 203 I=1,NONP
      DO 203 J=1,NDEG
      FD(J,I)=FD(J,I)+TD(J,I)
      TF(J,I)=TF(J,I)*NSTP
 203  TD(J,I)=FD(J,I)
 204  CONTINUE
C
C     PRINT DISPLACEMENT AND FORCE OUTPUT
C     TIERR IS THE TOTAL OF ALL THE TIE REACTIONS
C     TIED IS THE TIE/SPRING COMPRESSION
C     TIER IS THE TIE/SPRING REACTION
C
      TIERR=0.0
      KK=1
      IF(NSTP.NE.NSTEPS) GO TO 31
      WRITE(NOUT,1)
  1   FORMAT('1',16X,'DISPLACEMENT MATRIX',25X,'FORCE MATRIX'/,
     1  ' ',16X,'HORIZONTAL',7X,'VERTICAL',19X,'HORIZONTAL',7X,'VERTICAL
     2'//)
 31   CONTINUE
      DO 110 J=1,NONP
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      IF(ANAL.EQ.1.0) GO TO 112
      IF(CORD(2,J).LE.0.0) GO TO 112
      TIED(KK)=+(TD(2,J)-TD(2,J+1))
C     MULTIPLIED BY 2 TO GET THE EFFECT OF SPRING FOR BOTH ADJACENT BEAM
      TIEACT=TIEK(KK)*2.0
      TIER(KK)=TIED(KK)*TIEACT
      IF(J.EQ.1.OR.J.EQ.NONP) TIER(KK)=TIER(KK)/2.0
      TIERR=TIER(KK)+TIERR
      WRITE(NOUT,33) J,TIEACT,TIED(KK),TIER(KK)
   33 FORMAT(' ','AT NODE ',I3,' TIE SPRING RATE IS ',F12.0,', TIE SETTL
     1EMENT IS ',E14.5,', TIE REACTION IS ',F12.2)
C     +VE TIED MEANS COMPRESSION
C     NEGATIVE TIED IS NOT ALLOWED ,SO CORRESSPONDING TIE SPRINGRATES
C     (IE.,TIEK) IS MADE VERY SMALL
      IF(TIED(KK).LT.0.0) TIEK(KK)=1.00
      IF(TIED(KK).GE.0.0) TIEK(KK)=TTIEK(KK)
      IF(ANAL.EQ.3.0) TIEK(KK)=TTIEK(KK)
      KK=KK+1
  112 CONTINUE
      IF(NSTP.NE.NSTEPS) GO TO 110
      WRITE(NOUT,111) J,(TD(I,J),I=1,NDEG),(TF(I,J),I=1,NDEG)
  111 FORMAT(' ',8X,I3,5X,2E14.5,16X,2E14.5)
  110 CONTINUE
      WRITE(NOUT,113) TIERR
  113 FORMAT(' ','TOTAL TIE REACTION=',F12.2)
      IF(NSTP.NE.NSTEPS) GO TO 32
C
C     CALCULATION OF GENERALISED STRESS AND STRAINS AT CENTER OF ELEMENT
C
      WRITE(NOUT,30)
   30 FORMAT('1',2X,'ELEM',20X,'STRAIN',40X,'STRESS'//' ',08X,'EXXX',09X
     1,'EXYY',08X,'EXXY',08X,'SIGXX',8X,'SIGYY',8X,'TAUXY',6X,'SIG1',
     2  6X,'SIG3',6X,'MODULUS',3X,'STRS RATIO'//)
   32 CONTINUE
      DO 10 N=1,NUMEL
      DO 11 I=1,NNODE
   11 LM(I)=NPI(I,N)
      IF(TYPE(N).EQ.4.0.OR.TYPE(N).EQ.7.0.OR.TYPE(N).EQ.8.0) GO TO 612
       GO TO 12
C     BSTRESS CALCULATES CURVATURE AND MOMENTS IN BEAM SPRING ELEMENTS
  612 CALL BSTRES(N,NCRD,NDEG,NONP,CORD,ET(N),DATA1(N),TD)
      GO TO 10
C     GSTESS CALCULATES STRESS,STRAIN IN PLANAR ELEMENTS
   12 CALL GSTRES(N,NCRD,NNODE,NDEG,NGENS,NONP,N1,CORD,ET(N),DATA1(N),
     1 TD,EX,SIGXX,PSR(N),DEN(N),NEX,PPSTRS,TYPE,NUMEL)
   10 CONTINUE
C
C     WEIGH THE NODAL STRESSES ACCORDING TO ELEMENT AROUND IT, AND PRINT
C     OUT AVERAGE NODAL STRESSES FOR THE FINAL STEP ONLY
      IF(FLAG.NE.1.0) GO TO 13
      WRITE(NOUT,556)
  556 FORMAT(' ',//,' ','AVERAGE NODAL STRESSES FOR FINAL CYCLE',//,
     1 ' ',5X,'NODE',5X,'HORI STRESS',5X,'VERT STRESS',5X,'SHEAR STRESS'
     2,/)
      DO 555 I=1,NONP
      DO 555 II=1,3
```

```
      IF(CORD(2,I).GT.0.0) PPSTRS(II,I)=0.0
      IF(CORD(1,I).EQ.0.0.AND.CORD(2,I).EQ.0.0)PPSTRS(II,I)=PPSTRS(II,I)
      IF(CORD(1,I).EQ.0.0.AND.CORD(2,I).LT.0.0.AND.CORD(2,I).NE.Z(NNDEPT
     1)) PPSTRS(II,I)=PPSTRS(II,I)/2.0
      IF(CORD(1,I).EQ.0.0.AND.CORD(2,I).EQ.Z(NNDEPT))PPSTRS(II,I)=PPSTRS
     1(II,I)
      IF(CORD(1,I).EQ.R(NCOL).AND.CORD(2,I).EQ.Z(NNDEPT))PPSTRS(II,I)=PP
     1STRS(II,I)
      IF(CORD(1,I).EQ.R(NCOL).AND.CORD(2,I).LT.0.0.AND.CORD(2,I).NE.Z(NN
     1DEPT)) PPSTRS(II,I)=PPSTRS(II,I)/2.0
      IF(CORD(1,I).EQ.R(NCOL).AND.CORD(2,I).EQ.0.0)PPSTRS(II,I)=PPSTRS(I
     1I,I)
      IF(CORD(1,I).NE.0.0.AND.CORD(1,I).NE.R(NCOL).AND.CORD(2,I).EQ.0.0)
     1 PPSTRS(II,I)=PPSTRS(II,I)/2.0
      IF(CORD(1,I).NE.0.0.AND.CORD(1,I).NE.R(NCOL).AND.CORD(2,I).EQ.Z(NN
     1DEPT)) PPSTRS(II,I)=PPSTRS(II,I)/2.0
      IF(CORD(1,I).EQ.0.0.OR.CORD(1,I).EQ.R(NCOL).OR.CORD(2,I).EQ.0.0.OR
     1.CORD(2,I).EQ.Z(NNDEPT)) GO TO 559
      PPSTRS(II,I)=PPSTRS(II,I)/4.0
  559 IF(II.EQ.3) WRITE(NOUT,558) I,(PPSTRS(J,I),J=1,3)
  558 FORMAT(' ',5X,I4,3(7X,E12.4))
  555 CONTINUE
      RETURN
C
C
   13 IF(NSTP.EQ.NSTEPS) FLAG=FLAG+1.0
C     QUAD CALCULATES THE (NON-LINEAR) MODULI VALUES FOR EACH ELEMENT
      CALL QUAD(NUMEL,SIGXX,EX,PSR,ET,NGENS,ERROR,NEX,TYPE)
      IF(ERROR.EQ.1.0) RETURN
      IF(FLAG.EQ.1.0.AND.ABCD.EQ.2.0) GO TO 301
      IF(FLAG.EQ.1.0)  GO TO 23
   20 CONTINUE
      RETURN
      END
      SUBROUTINE CROUTD(NDEG,NUMNP,MAXNP,NSXX,NPBC,DSX,
     1TX,NP,SXX,NAP,MAXCO)
C
      DIMENSION NAP(NUMNP),SXX(NDEG,NDEG,NSXX),NP(NUMNP,MAXNP),
     1TX(NDEG,NUMNP),DSX(NDEG,NUMNP), MAXCO(NUMNP),NPBC(NDEG,NUMNP)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
C
C   SOLVES  SYSTEM OF SIMUL .EQS
C    DSX   DISPLACEMENTS
C    NPBC    SETS  BOUNDARY CONDITIONS
C     TX   LOAD  VECTOR
      A11=1.
      DETER=0.
      DO 120 N=1,NUMNP
      NU1=1
      NUM=NAP(N)
      IF(NUM.EQ.1) GO TO 120
      LMS=MAXNP*(N-1)
      LMSK=LMS+1
      LMSS=LMSK
```

```
      DO 121 L=2,NUM
      LMSK=LMSK+1
      IF(NP(N,L).GT.N) GO TO 121
      LMSS=LMSS+1
      NU1=NU1+1
      IF(L.EQ.NU1) GO TO 121
      NP(N,NU1)=NP(N,L)
      NP(N,L)=0
      DO 122 N1=1,NDEG
      DO 122 N2=1,NDEG
  122 SXX(N1,N2,LMSS)=SXX(N1,N2,LMSK)
  121 CONTINUE
  120 NAP(N)=NU1
  101 FORMAT(4HOROW,I5,22H  EXCEEDS MAXNP NEEDS ,I4)
      DO 10 I=1,NUMNP
      LMS=MAXNP*(I-1)
      NUM=NAP(I)
      IF(I.EQ.1) GO TO 102
      IF(MAXCO(I-1).GT.MAXCO(I))  MAXCO(I)=MAXCO(I-1)
  102 MAX=MAXCO(I)
      DO 10 J=I,MAX
      NU1=NAP(J)
      IF(J.EQ.I) L=1
      IF(J.EQ.I) GO TO 2
      DO 1 L=2,NU1
      IF(NP(J,L).EQ.I) GO TO 2
    1 CONTINUE
      L=NU1+1
      IF(L.GT.MAXNP) WRITE(6,101) J,L
      NAP(J)=L
      NP(J,L)=I
    2 LJS=MAXNP*(J-1)
      LJSI=LJS+L
      IF(L.LE.NU1) GO TO 2002
      DO 2001 N1=1,NDEG
      DO 2001 N2=1,NDEG
 2001 SXX(N1,N2,LJSI)=0.
 2002 IF(I.EQ.1.OR.NU1.EQ.1) GO TO 6
      DO 201 N1=1,NDEG
      DO 201 N2=1,NDEG
  201 G(N1,N2)=0.
      DO 5 LJ=2,NU1
      IF(NP(J,LJ).GE.I) GO TO 5
      K=NP(J,LJ)
      LJSK=LJS+LJ
      LMSK=MAXNP*NUMNP-K+I
      IF(I.NE.J) GO TO 3
      LLSK=MAXNP*(K-1)+1
      DO 25 N1=1,NDEG
      DO 25 N2=1,NDEG
      SXX(N1,N2,LMSK)=0.
      DO 25 N3=1,NDEG
   25 SXX(N1,N2,LMSK)=SXX(N1,N2,LMSK)+SXX(N1,N3,LLSK)*SXX(N2,N3,LJSK)
    3 DO 4 N1=1,NDEG
      DO 4 N2=1,NDEG
      DO 4 N3=1,NDEG
```

```
    4   G(N1,N2)=G(N1,N2)+SXX(N1,N3,LJSK)*SXX(N3,N2,LMSK)
    5   CONTINUE
        DO 51 N1=1,NDEG
        DO 51 N2=1,NDEG
   51   SXX(N1,N2,LJSI)=SXX(N1,N2,LJSI)-G(N1,N2)
    6   IF(J.NE.I) GO TO 10
        DO 61 N1=1,NDEG
   61   A11=A11*SXX(N1,N1,LJSI)
        CALL INVERT(SXX(1,1,LJSI),NDEG,G1,0,DETERM,NDEG)
        IF(DETERM.LE.0.) WRITE(NOUT,104) J
  104   FORMAT(35HONON POSITIVE DEF. STIFFNESS AT ROW,I4)
        IF(DETERM.LE.0)STOP
        DETERM=ABS(DETERM)
        DETER=DETER+ALOG(DETERM)
        A11=A11/DETERM
   10   CONTINUE
C       A11=4.*A11**(1./FLOAT(NUMNP*NDEG-1))
        A11=4.*A11**(1./DFLOAT(NUMNP*NDEG-1))
C       WRITE(NOUT,103) DETER,A11
C103   FORMAT(1H0,15X,15HUN(DETERMINANT),E14.4,18H      EIG. RATIO .GT. ,
C      1E14.4)
C       ENTRY CROUTE
        ENTRY CROUTE(NDEG,NUMNP,MAXNP,NSXX,NPBC,DSX,
       1TX,NP,SXX,NAP,MAXCO)
        DO 15 I=1,NUMNP
        LMS=MAXNP*(I-1)
        LMSS=LMS+1
        DO 11 N1=1,NDEG
   11   G(N1,1)=0.
        IF(I.EQ.1) GO TO 14
        NUM=NAP(I)
        IF(NUM.EQ.1) GO TO 14
        DO 13 K=2,NUM
        IF(NP(I,K).GE.I) GO TO 13
        LMSK=LMS+K
        NK=NP(I,K)
        DO 12 N1=1,NDEG
        DO 12 N2=1,NDEG
   12   G(N1,1)=G(N1,1)-SXX(N1,N2,LMSK)*DSX(N2,NK)
   13   CONTINUE
   14   DO 142 N1=1,NDEG
        IF(NPBC(N1,I).NE.0)GO TO 142
        G(N1,1)=G(N1,1)+TX(N1,I)
  142   CONTINUE
        DO 141 N1=1,NDEG
        DSX(N1,I)=0.
        DO 141 N2=1,NDEG
  141   DSX(N1,I)=SXX(N1,N2,LMSS)*G(N2,1)+DSX(N1,I)
   15   CONTINUE
        I=NUMNP+1
        DO 161 N=1,NUMNP
        DO 161 N1=1,NDEG
  161   TX(N1,N)=0.
   16   I=I-1
        NUM=NAP(I)
        LMS=MAXNP*(I-1)
```

```
      DO 19 N1=1,NDEG
      DO 19 N2=1,NDEG
   19 DSX(N1,I)=DSX(N1,I)+SXX(N1,N2,LMS+1)*TX(N2,I)
      IF(NUM.EQ.1) GO TO 20
      DO 18 K=2,NUM
      IF(NP(I,K).GE.I) GO TO 18
      LMSK=LMS+K
      NK=NP(I,K)
      DO 17 N1=1,NDEG
      DO 17 N2=1,NDEG
   17 TX(N1,NK)=TX(N1,NK)-SXX(N2,N1,LMSK)*DSX(N2,I)
   18 CONTINUE
   20 IF(I.GT.1) GO TO 16
      RETURN
      END
      SUBROUTINE ELEM(N,NDEG,NNODE,NGENS,NPI,ET,NUMEL,CORD,NONP,DATA1,
     1  N1,NCRD,NNODE2,PSR,DEN,TIEK,K,TYPE)
C
      DIMENSION CORD(NCRD,NONP),NPI(NNODE,NUMEL),TIEK(36),TYPE(NUMEL)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
C
C     ASEMBLY OF ELEMENT STIFFNESS MATRIX
C     NUMEL=NUMBER OF ELEMENTS
C     NPI CONTAINS THE NODE NUMBERS FOR EACH ELEMENT
C     E IS A WORK AREA-ARRAY
C     ET IS YOUNG MODULUS-MAY BE DIFFERENT FOR EACH ELEMENT
C     PSR IS POISSONS RATIO
C     DATA1=MOMENT OF INRRTIA OF RAIL  OR TIE
C     FIND NODAL NUMBERS FOR ELEMENT
C    LM STORES ELEMENT NODAL NUMBERS
C
      CALL SCLA(SS,0.,N1,N1,0)
      DO 1 I=1,NNODE
1     LM(I)=NPI(I,N)
      IF(TYPE(N).EQ.4.0.OR.TYPE(N).EQ.7.0.OR.TYPE(N).EQ.8.0) GO TO 31
      GO TO 30
   31 K=K+1
      TIEK1=TIEK(K)
      TIEK2=TIEK(K+1)
      CALL BSTIFF(CORD,NCRD,NONP,ET,PSR,DEN,DATA1,TIEK1,TIEK2)
      GO TO 21
   30 CALL STIFF(N1,CORD,NCRD,NONP,ET,PSR,DEN,DATA1)
      IF(TYPE(N).EQ.9.0) CALL TSTIFF(N1,CORD,NCRD,NONP,ET,PSR,DEN,DATA1)
   21 CONTINUE
C     PREPARES MACRO UNITS FOR THE ASSEMBLY OF
C     THE STRUCTURAL STIFFNESS MATRICE
      DO 2 L=1,NNODE
      DO 2 M=1,NNODE
      DO 2 NI=1,NDEG
      DO 2 N2=1,NDEG
      LMSS=(L-1)*NNODE+M
```

```
      LMS1=(L-1)*NDEG+N1
      LMS2=(M-1)*NDEG+N2
    2 SK(N1,N2,LMSS)=SS(LMS1,LMS2)
      RETURN
      END
      SUBROUTINE FIXBC(NUMNP,NDEG,MAXNP,NSXX,DSX,NAP,NP,NPBC,SXX,
     1TX,IASMBL)
C
      DIMENSION NPBC(NDEG,NUMNP),SXX(NDEG,NDEG,NSXX ),
     1 TX(NDEG,NUMNP),NAP(NUMNP),NP(NUMNP,MAXNP),DSX(NDEG,NUMNP)
C     MODIFIES THE OVERALL STIFFNESS MARRIX AND THE LOAD VECTOR FOR
C     THE GIVEN DISPLACEMENT BOUNDARY CONDITIONS
C     DSX  DISPLACEMENT  ARRAY
C    NPBC  BOUNDARY  CONDITIONS
C    TX  LOAD  VECTOR
C    IASEMBL=1  STIFFNESS NOT DECOMPOSED
C    IASEMBL=0   STIFFNESS DECOMPOSED IN CROUTD
C     EVALUATION OF STRESSES AND STRAINS FOR RECTANGULAR PLANE STRAIN ELM
      IF(IASMBL.EQ.0) GO TO 244
C     CORRECTS DIAGONAL TERMS OF THE OVERALL STIFFNESS MATRIX
      DO 32 M=1,NUMNP
      LMS=(M-1)*MAXNP+1
      DO 32 N1=1,NDEG
      IF(SXX(N1,N1,LMS).EQ.0.) SXX(N1,N1,LMS)=1.
   32 CONTINUE
  244 DO 34 M=1,NUMNP
      DO 34 N2=1,NDEG
      IF(NPBC(N2,M).EQ.0) GO TO 34
      IF(IASMBL.EQ.0) GO TO 34
C
C     ROW ADJUSTED FOR THE GIVEN DISPLACEMENTS
      TX(N2,M)=0.
      NUM=NAP(M)
      DO 38 MX=1,NUM
      LMS=MAXNP*(M-1)+MX
      IF(MX.EQ.1) RES=1./SXX(N2,N2,LMS)
      NN=NP(M,MX)
C
C     LLOAD VECTOR ADJUSTED FOR THE GIVEN DISPLACEMENT, AND ROW OF STIFFN
C     MATRIX MADE EQUAL TO ZERO
C
      DO 38 N3=1,NDEG
      TX(N3,NN)=TX(N3,NN)-SXX(N2,N3,LMS)*DSX(N2,M)
      SXX(N2,N3,LMS)=0.
   38 CONTINUE
      NBOT=M+1
      IF(NBOT.GT.NUMNP) GO TO 39
      IF(NBOT.LE.0)NBOT=1
      NTOP=M+MAXNP
      IF(NTOP.GT.NUMNP) NTOP=NUMNP
      DO 40 NN=NBOT,NTOP
      NU1=NAP(NN)
      DO 37 NX=1,NU1
      IF(NP(NN,NX).NE.M) GO TO 37
      LMSS=MAXNP*(NN-1)+NX
      DO 35 N3=1,NDEG
```

```
      TX(N3,NN)=TX(N3,NN)-SXX(N3,N2,LMSS)*DSX(N2,M)
      SXX(N3,N2,LMSS)=0.
   35 CONTINUE
   37 CONTINUE
   40 CONTINUE
   39 LMS=(M-1)*MAXNP+1
      DO 31 N1=1,NDEG
   31 SXX(N1,N2,LMS)=C.
      TX(N2,M)=-RES*TX(N2,M)
      SXX(N2,N2,LMS)=1.
   34 CONTINUE
      RETURN
      END
      SUBROUTINE GENS(ET,PSR,DATA1)
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),CISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
C
C  COMPUTATION OF GENERALISED STRESS/STRAIN MATRIX
C    USED IN CALCULATING STESSES FROM STRAINS
C
C
      EV=ET/((1.0+PSR)*(1.-2.*PSR))
C
      D(1,1)=EV*(1.-PSR)
      D(1,2)=EV*PSR
      D(1,3)=0.
      D(2,1)=EV*PSR
      D(2,2)=EV*(1.-PSR)
      D(2,3)=0.
      D(3,1)=0.
      D(3,2)=0.
      D(3,3)=EV*(1.-2.*PSR)/2.
      RETURN
      END
      SUBROUTINE GMPRD(A,B,R,N,M,L)
C
C    GMPRD ACCCNPLISHES MATRIX MULTIPLICATION,IE., A*B TO FORM R.
      DIMENSION A(1),E(1),R(1)
C
      IR=0
      IK=-M
      DO 10 K=1,L
      IK=IK+M
      DO 10 J=1,N
      IR=IR+1
      JI=J-N
      IB=IK
      R(IR)=0
      DO 10 I=1,M
      JI=JI+N
      IB=IB+1
   10 R(IR)=R(IR)+A(JI)*B(IB)
      RETURN
      END
      SUBROUTINE GSTRES(N,NCRD,NNODE,NDEG,NGENS,NONP,N1,CORD,ET,DATA1,
     1 TD,EX,SIGXX,PSR,DEN,NEX,PPSTRS,TYPE,NUMEL)
```

```
C
      DIMENSICN CORD(NCRD,NONP),TD(NDEG,NONP),EX(NEX),SIGXX(NEX),
     1  PPSTRS(NGENS,NONP),TYPE(NUMEL)
C
      COMMON/CNE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
      COMMON/NINE/FLAG,BFLAG,CFLAG,ABCD
C
C     CALCULATES STRESSES, STRAINS FOR PLANAR ELEMENTS
C     PUT DISPLACEMENT COMPONENTS FOR ELEMENT IN QUESTION INTO A 1-D
C     ARRAY DISP(N1), ARRANGED AS FOLLOWS- NODE1-HORI DISP,NODE1-VERT,
C     2-HORI,2-VERT,3-HORI,3-VERT,4-HORI,4-VERT.
C
      K=1
      DO 1 N3=1,NNODE
      LX=LM(N3)
      DO 1 N2=1,NDEG
      DISP(K)=TD(N2,LX)
      K=K+1
    1 CONTINUE
C
C     FIND D MATRIX - GENERALIZED CONSTITUTIVE RELATION -
      CALL GENS(ET,PSR,CATA1)
C
C     FIND B MATRIX - USED IN CALCULATINF STRAINS FROM NODAL DISPLACEMENT
      CALL BETA(CORD,NONP,NCRD)
      IF(TYPE(N).EQ.9.0) CALL TBETA(CCRD,NCNP,NCRD)
C     FIND POSITION OF CURRENT GEN. STRESS/STRAIN
C      IN STRAGE VECTCRS SIGXX/EX
      LSS=(N-1)*NGENS+1
C     COMPUTE GEN. STRAINS B*U AND PLACE IN EX - ARRANGED AS FOLLOWS
C     HORI STRAIN,VERT STRAIN,SHEAR STRAIN.
C
C
      CALL GMPRD(B,DISP,EX(LSS),NGENS,N1,1)
C     COMPUTE GEN. STRESSES D*EX AND PLACE IN SIGXX-ARRANGED AS FOLLOWS
C     HORI STRESS,VERT STRESS,SHEAR STRESS.
      CALL GMPRD(D,EX(LSS),SIGXX(LSS),NGENS,NGENS,1)
C     STRESS-STRAIN OUTPUT
      IF(NSTP.NE.NSTEPS) GO TO 2
      LSS=(N-1)*NGENS+1
      LSS1=LSS+1
      LSS2=LSS1+1
C
C     COMPUTE AVERAGE NODAL STRESSES AND STORE IN PPSTRS
      IF(FLAG.NE.1.0) GC TO 557
C     FOR TRANSVERSE ANALYSIS TIE STRESSES ARE NOT CONSIDERED WHEN
C      AVERAGING NODAL STRESSES
      IF(TYPE(N).EQ.5.0) GO TO 557
      LX=LM(1)
      IF(TYPE(N).EQ.1.0.AND.CORD(2,LX).GT.0.0) GO TO 557
      DO 556 II=1,4
      LLL=LM(II)
      DO 556 JJ=1,3
```

```
      PPSTRS(JJ,LLL)=PPSTRS(JJ,LLL)+SIGXX(LSS-1+JJ)
  556 CONTINUE
C
  557 CONTINUE
C    CALCULATE PRINCIPAL STRESSES AND STRESS RATIO
      CC=(SIGXX(LSS)+SIGXX(LSS1))/2.0
      BB=(SIGXX(LSS1)-SIGXX(LSS))/2.0
      CR=SQRT(BB*BB+SIGXX(LSS2)*SIGXX(LSS2))
      SIG1=CC+CR
      SIG3=CC-CR
      ASIG3=SIG3
      IF(ASIG3.EQ.0.0) ASIG3=0.001
      RATIO=SIG1/ASIG3
      IF(RATIO.GT.99.9) RATIO=99.9
      IF(RATIO.LT.-99.0) RATIO=-99.0
      N3=LSS+NGENS-1
      WRITE(NOUT,40) N,(EX(J),J=LSS,N3),(SIGXX(J),J=LSS,N3),SIG1,SIG3,ET
     1,RATIO,TYPE(N)
   40 FORMAT(' ',I3,1X,3E12.4,2X,5E12.4,2X,F09.1,1X,F5.1,F3.0)
    2 CONTINUE
      RETURN
      END
      SUBROUTINE INDATA(NDEG,NUMEL,NONP,NGENS,NCRD,NNODE,NUME,NPI,ET,
     1  DATA1,NPNUM,CORD,PSR,DEN,TIEK,TYPE,ERROR)
C
      DIMENSION NUME(NUMEL),NPI(NNODE,NUMEL),ET(NUMEL),DATA1(NUMEL),
     1  NPNUM(NONP),CORD(NCRD,NONP),DEN(NUMEL),PSR(NUMEL),TIEK(36),
     2  TYPE(NUMEL)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/FOUR/ETS(10),PSRS(10),DATA11,DATA22,TIEKK
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/SIX/BONE1,BTWO1,BONE2,BTWO2,RMOD(8),DEV(8),UMOD(8),UDEV(8),
     1 EFAIL1,EFAIL2,EFAIL3,AMXSR1,SIGMN1,AMXSR2,SIGMN2,TAUSUB,NPOINT,
     2 JPOINT,EFAIL6,UTAUSB,NSUBL,NSUBU
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
      COMMON/EIGHT/RLOAD(36),PLOAD(36),DIST(36),MM(36),RDISP(36),
     1   PDISP(36),DIST1(36),MM1(36),NPT(36)
      COMMON/NINE/FLAG,BFLAG,CFLAG,ABCD
      COMMON/TEN/R(36),Z(30),NRR
      COMMON/ELEVEN/TTIEK(36)
C
C    SUBROUTINE INDATA READS ELEMENT PROPERTIES AND ALLOCATES ELEMENT
C    PROPERTIES TO CORRESPONDING ELEMENTS
      K=0
      DATA11=0.0
      DATA22=0.0
      TIEKK=0.0
      CALL AMESH(CORD,NONP,NPI,NUMEL)
C
      READ(NIN,301) ETS(4),DATA11,ETS(5),PSRS(5),DATA22,TIEKK,PSRS(4)
      READ(NIN,301)BONE1,BTWO1,ETS(1),PSRS(1),BONE2,BTWO2,ETS(2),PSRS(2)
```

```
301   FORMAT(8F10.2)
      READ(NIN,302) NPOINT,JPOINT,NCST, NSUBL, NSUBU
302   FORMAT(10I5)
      READ(NIN,303) (RMOD(I),DEV(I),I=1,NPOINT)
303   FORMAT(2F10.2)
      IF(JPOINT.GT.0) READ(NIN,303) (UMOD(I),UDEV(I),I=1,JPOINT)
      READ(NIN,301) ETS(3),PSRS(3),ETS(6),PSRS(6)
      READ(NIN,301)AMXSR1,SIGMN1,EFAIL1,AMXSR2,SIGMN2,EFAIL2,BFLAG,CFLAG
      READ(NIN,301) TAUSUB,EFAIL3,UTAUSB,EFAIL6
C
C
      WRITE(NOUT,701) ETS(4),DATA11,ETS(5),DATA22,PSRS(5),TIEKK
701   FORMAT(/' ','MATERIAL DATA',/' ','--------------',//
     1   ' ','RAIL',/' ',2X,'RAIL MODULUS OF ELASTICITY=',F14.2/
     2   ' ',2X,'RAIL SECTION MOMENT OF INERTIA=',F10.2/
     3   ' ','TIES',/' ',2X,'TIE COMPRESSIVE MODULUS=',F14.2/
     4   ' ',2X,'TIE SECTION MOMENT OF INERTIA=',F10.2/
     5   ' ',2X,'TIE POISSONS RATIO=',F10.2/
     6   ' ',2X,'SPRING CONSTANT USED FOR TRANSVERSE ANALYSIS=',F14.2)
      WRITE(NOUT,702)BONE1,BTWO1,ETS(1),PSRS(1),BONE2,BTWO2,ETS(2),PSRS(
     12),NPOINT,(RMOD(I),DEV(I),I=1,NPOINT)
702   FORMAT(' ','BALLAST'/
     1   ' ',2X,'BALLAST RESILIENT RESPONSE MODEL - ',F10.2,'(THETA)**',
     2   F04.2/
     3   ' ',2X,'BALLAST INITIAL MODULUS=',F10.2/
     3   ' ',2X,'BALLAST POISSONS RATIO=',F10.2/
     4   ' ','SUBBALLAST'/
     5   ' ',2X,'SUBBALLAST RESILIENT RESPONSE MODEL - ',F10.2,
     6   '(THETA)**',F04.2/
     7   ' ',2X,'SUBBALLAST INITIAL MODULUS=',F10.2/
     8   ' ',2X,'SUBBALLAST POISSONS RATIO=',F10.2/
     9   ' ','SUBGRADE'/
     1   ' ',2X,I2,' POINTS FOR THE SUBGRADE RESILIENT RESPONSE CURVE'/
     2   ' ',10X,'RMOD          DEV'/
     3   (' ',8X,F10.2,2X,F10.2))
      WRITE(NOUT,703) ETS(3),PSRS(3)
703   FORMAT(' ',2X,'SUBGRADE INITIAL MODULUS=',F10.2/
     1   ' ',2X,'SUBGRADE POISSONS RATIO=',F10.2)
      IF(JPOINT.GT.0)WRITE(NOUT,704)JPOINT,(UMOD(I),UDEV(I),I=1,JPOINT)
704   FORMAT(' ','UPPER SUBGRADE LAYER'/
     1   ' ',2X,I2,' POINTS FOR THE UPPER SUBGRADE LAYER RESILIENT MODUL
     2US CURVE'/
     3   ' ',10X,'UMOD          UDEV'/
     4   (' ',8X,F10.2,2X,F10.2))
      IF(JPOINT.GT.0)WRITE(NOUT,705) ETS(6),PSRS(6)
705   FORMAT(' ',2X,'UPPER SUBGRADE LAYER INITIAL MODULUS=',F10.2/
     1   ' ',2X,'UPPER SUBGRADE LAYER POISSONS RATIO=',F10.2)
      WRITE(NOUT,706) AMXSR1,SIGMN1,EFAIL1,AMXSR2,SIGMN2,EFAIL2,TAUSUB,
     1   EFAIL3
706   FORMAT(/' ','FAILURE CRITERIA'/' ','----------------',//
     1   ' ','BALLAST'/
     2   ' ',2X,'MAXIMUM ALLOWABLE PRINCIPAL STRESS RATIO=',F10.2/
     3   ' ',2X,'MINIMUM ALLOWABLE MINIMUM PRINCIPAL STRESS=',F10.2/
     3   ' ',2X,'FAILURE MODULUS=',F10.2/
     4   ' ','SUBBALLAST'/
     5   ' ',2X,'MAXIMUM ALLOWABLE PRINCIPAL STRESS RATIO=',F10.2/
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     7     ' ',2X,'MINIMUM ALLOWABLE MINIMUM PRINCIPAL STRESS=',F10.2/
     8     ' ',2X,'FAILURE MODULUS=',F10.2/
     9     ' ','SUBGRADE'/
     1     ' ',2X,'MAXIMUM ALLOWABLE SHEAR STRESS=',F10.2/
     2     ' ',2X,'FAILURE MODULUS=',F10.2)
      IF(JPOINT.GT.0) WRITE(NOUT,707) UTAUSB,EFAIL6
  707 FORMAT(' ','UPPER SUBGRADE LAYER'/
     1     ' ',2X,'MAXIMUM ALLOWABLE SHEAR STRESS=',F10.2/
     2     ' ',2X,'FAILURE MODULUS=',F10.2)
C  EACH TIE SPRING IS DIVIDED BY TWO FOR THE TWO ADJACENT BEAM ELEMENTS
      TIKKK=BTHICK*WTIE*ETS(5)/(TTHICK*2.0)
      TK=TIKKK/3.0
C
      CDEPTH=BDEPTH+SBDEPT
      BBBDEP=-BDEPTH
      CCCDEP=-CDEPTH
C   UPPER IS THICKNESS OF UPPER SUBGRADE SOIL LAYER
      DDDDEP=-CDEPTH-UPPER
      DO 555 I=1,NUMEL
      N7=NPI(3,I)
      IF(ANAL.EQ.1.0) GO TO 554
      IF(ANAL.EQ.3.0) GO TO 561
      IF(CORD(2,N7).LT.0.0) GO TO 553
      K=K+1
      ET(I)=ETS(4)
      PSR(I)=PSRS(4)
      DATA1(I)=DATA11
      TYPE(I)=4.0
      TIEK(K)=TIKKK
      GO TO 555
  554 IF(CORD(2,N7).LT.0.0) GO TO 553
      RLTIE2=RLTIE/2.0
      IF(CORD(1,N7).GT.RLTIE2) GO TO 553
      ET(I)=ETS(5)
      PSR(I)=PSRS(5)
      DATA1(I)=DATA22
      TYPE(I)=5.0
      GO TO 555
C
  561 IF(CORD(2,N7).LT.0.0) GO TO 553
      K=K+1
      RLTIE2=RLTIE/2.0
      ET(I)=ETS(5)
      PSR(I)=PSRS(5)
      DATA1(I)=DATA22
      TYPE(I)=7.0
      IF(CORD(1,N7).GT.RLTIE2) ET(I)=ETS(5)/100.0
      IF(CORD(1,N7).GT.RLTIE2) TYPE(I)=8.0
      GO TO 555
C
  553 IF(CORD(2,N7).LT.BBBDEP) GO TO 556
      ET(I)=ETS(1)
      PSR(I)=PSRS(1)
      TYPE(I)=1.0
      GO TO 555
  556 IF(CORD(2,N7).LT.CCCDEP) GO TO 557
```

```
      ET(I)=ETS(2)
      PSR(I)=PSRS(2)
      TYPE(I)=2.0
      GO TO 555
  557 IF(CORD(2,N7).LT.DDDDEP) GO TO 558
      ET(I)=ETS(6)
      PSR(I)=PSRS(6)
      TYPE(I)=6.0
      GO TO 555
  558 ET(I)=ETS(3)
      PSR(I)=PSRS(3)
      TYPE(I)=3.0
  555 CONTINUE
C
C    TIE SPRING RATES ARE SPECIFIED AT APROPRIATE TIES
      TIEK(K+1)=TIKKK
      KKK=K+1
      TIEK(3)=0.0
      TIEK(4)=C.0
      TIEK(8)=0.0
      TIEK(9)=0.0
      TIEK(13)=0.0
      TIEK(15)=0.0
      TIEK(17)=0.0
      TIEK(19)=0.0
      TIEK(21)=0.0
      TIEK(1)=TK
      TIEK(2)=TK
      TIEK(5)=TK
      TIEK(6)=TK
      TIEK(7)=TK
      TIEK(10)=TK
      TIEK(11)=TK
      TIEK(12)=TK
      IF(ANAL.NE.3.0) GO TO 562
      KKK=K+1
C    ALL TIEK(I) DIVIDED BY TWO FOR THE TWO ADJACENT BEAM ELEMENTS
      DO 563 I=2,K
  563 TIEK(I)=TIEKK*(R(I)-R(I-1)+R(I+1)-R(I))/2.0/2.0
      TIEK(1)=TIEKK*(R(2)-R(1))/2.0
      TIEK(KKK)=TIEKK*(R(KKK)-R(K))/2.0
  562 CONTINUE
C
C    TTIEK(I) SAVES TIEK(I) VALUES FOR LATER USE IN CONTRO
      DO 559 I=1,KKK
  559 TTIEK(I)=TIEK(I)
C    ELEMENT CONNECTIVITY AND PROPERTIES PRINTED OUT
      WRITE(NOUT,1)
    1 FORMAT(//' ','ELEMENT CONNECTIVITY'/' ','--------------------'//
     1 ' ','ELEM NO. NODE PTS ANTI-CLOCK   INITIAL MOD.  P. RATIO   EL
     2EM TYPE'//)
      DO 2 N=1,NUMEL
      NUME(N)=N
    2 WRITE(NOUT,3)NUME(N),(NPI(NI,N),NI=1,NNODE),ET(N),PSR(N),TYPE(N)
    3 FORMAT(' ',5I5,5X,E10.3,2(5X,F6.2))
C    NODAL COORDINATES PRINTED OUT
```

```
      WRITE(NOUT,11)
   11 FORMAT(//' ','NODE NO.    COORDINATES(HORI-VERT)'//)
      DO 12 M=1,NONP,4
      NPNUM(M)=M
      NPNUM(M+1)=M+1
      NPNUM(M+2)=M+2
      NPNUM(M+3)=M+3
   12 WRITE(NOUT,15)NPNUM(M),(CORD(NI,M),NI=1,NCRD),NPNUM(M+1),(CORD(NI,
     1M+1),NI=1,NCRD),NPNUM(M+2),(CORD(NI,M+2),NI=1,NCRD),NPNUM(M+3),(CO
     2RD(NI,M+3),NI=1,NCRD)
   15 FORMAT(' ',4(I5,4X,2F10.5))
      WRITE(NOUT,62)
   62 FORMAT(//' ','BOUNDARY CONDITIONS'/' ','-------------------'//)
      WRITE(NOUT,63)
   63 FORMAT(' ',' DISPLACEMENTS SPEC     FORCES SPEC  NO. STEPS SPEC')
      READ(NIN,64) NDSPEC,NFSPEC,NSTEPS,NFIX,NLOAD
   64 FORMAT(8I5)
      WRITE(NOUT,65) NDSPEC,NFSPEC,NSTEPS,NFIX,NLOAD
   65 FORMAT(' ',5(I10,8X))
      IF(NFSPEC.EQ.0) GO TO 993
C
C    INPUT OF VERT LOADS AND THEIR DISTANCES FROM CENTER LINE
      DO 68 J=1,NFSPEC
      READ(NIN,66) RLOAD(J),DIST(J)
   66 FORMAT(2F10.2)
   68 CONTINUE
      WRITE(NOUT,67) (RLOAD(J),DIST(J),J=1,NFSPEC)
   67 FORMAT(' ','FORCES SPECIFIED ARE '/
     1 (' ',F10.2,'  POUNDS AT ',F10.2,'  INCHES FROM CENTER LINE'))
C
C    DETERMINATION OF VERTICAL LINE NUMBERS ON WHICH LOAD ACTS
C    MM(J) IS THE VERTICAL LINE NUMBER ON WHICH RLOAD(J) IS ACTING
C
      NDIST=1
      DO 992 J=1,NFSPEC
      DO 991  JK=NDIST,40
      A=R(JK)
      C=(R(JK+1)-R(JK))/2.0
      F=DIST(J)-A
      IF(DIST(J).EQ.A) MM(J)=JK-1
      IF(DIST(J).GT.R(JK+1)) GO TO 991
      IF(F.GE.C) MM(J)=JK
      IF(F.LT.C) MM(J)=JK-1
      GO TO 990
  991 CONTINUE
  990 NDIST=JK
  992 CONTINUE
C
C    INPUT OF VERTICAL DISPLACEMENTS AND TFEIP DISTANCES FROM CENTER LIN
  993 IF(NDSPEC.EQ.0) GO TO 1000
      DO 998 J=1,NDSPEC
      READ(NIN,66) RDISP(J),DIST1(J)
  998 CONTINUE
      WRITE(NOUT,994) (RDISP(J),DIST1(J),J=1,NDSPEC)
  994 FORMAT(' ','DISPLACEMENTS SPECIFIED ARE'/
     1 (' ',F10.6,'  INCHES AT ',F10.2,' INCHES FROMCENTER LINE'))
```

```
C
C     DETERMINATION OF VERTICAL LINE NO. ON WHICH DISPLACEMENTS ACTS
C     MM1(J) IS THE VERT.LINE NO. ON WHICH RDISP(J) ACTS
C
      NDIST=1
      DO 995 J=1,NDSPEC
      DO 996 JK=NDIST,20
      A=R(JK)
      C=(R(JK+1)-R(JK))/2.0
      F=DIST1(J)-A
      IF(DIST1(J).EQ.A) MM1(J)=JK-1
      IF(DIST1(J).GT.R(JK+1)) GO TO 996
      IF(F.GE.C) MM1(J)=JK
      IF(F.LT.C) MM1(J)=JK-1
      GO TO 997
  996 CONTINUE
  997 NDIST=JK
  995 CONTINUE
 1000 IF(NCST.EQ.0) GO TO 851
      WRITE(NOUT,854) NCST
  854 FORMAT(' '//' ',I5,2X,'ELEMENT TYPE OR PROPERTIES MODIFIED'//)
      DO 852  I=1,NCST
      READ(NIN,853) NECST,TYPE(NECST),ETMM
  853 FORMAT(I5,2F10.0)
      IF(TYPE(NECST).EQ.10.0) ET(NECST)=ETMM
      WRITE(NOUT,3) NUME(NECST),(NPI(NI,NECST),NI=1,NNODE),ET(NECST),
     1  PSR(NECST),TYPE(NECST)
  852 CONTINUE
  851 CONTINUE
      CALL CHECK(ERROR)
      RETURN
      END
      SUBROUTINE INVERT(A,N,B,M,DETERM,IDIM)
C
      DIMENSION IPIVOT( 150),A(IDIM,IDIM),B(IDIM,M),INDEX( 150,2)
     1,PIVOT( 150)
C
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C      INITIALIZATION
C
   10 DETERM=1.0
      IF(N.EQ.1)A(N,N)=1./A(N,N)
      IF(N.EQ.1)RETURN
      DO 20  J=1,IDIM
      IPIVOT(J)=0
      INDEX(J,1)=0
      INDEX(J,2)=0
      PIVOT(J)=0.0
   20 CONTINUE
      SWAP=0.0
      L1=0
      L=0
      T=0.0
   30 DO 550 I=1,N
C
   40 AMAX=0.0
```

```
C
C         SEARCH FOR PIVOT ELEMENT
   41     IROW=0
   42     ICOLUM=0
   45     DO 105 J=1,N
   50     IF (IPIVOT(J)-1) 60, 105, 60
   60     DO 100 K=1,N
   70     IF (IPIVOT(K)-1) 80, 100, 740
   80     IF (ABS(AMAX)-ABS(A(J,K))) 85, 100, 100
   85     IROW=J
   90     ICOLUM=K
   95     AMAX=A(J,K)
  100     CONTINUE
  105     CONTINUE
  106     IF(IROW) 110,750,110
  110     IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C         INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
  130     IF (IROW-ICOLUM) 140, 260, 140
  140     DETERM=-DETERM
  150     DO 200 L=1,N
  160     SWAP=A(IROW,L)
  170     A(IROW,L)=A(ICOLUM,L)
          A(ICOLUM,L)=SWAP
  200     CONTINUE
  205     IF(M) 260, 260, 210
  210     DO 250 L=1,M
  220     SWAP=B(IROW,L)
  230     B(IROW,L)=B(ICOLUM,L)
          B(ICOLUM,L)=SWAP
  250     CONTINUE
  260     INDEX(I,1)=IROW
  270     INDEX(I,2)=ICOLUM
  310     PIVOT(I)=A(ICOLUM,ICOLUM)
  320     DETERM=DETERM*PIVOT(I)
C
C         DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  330     A(ICOLUM,ICOLUM)=1.0
  340     DO 350 L=1,N
          A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
  350     CONTINUE
  355     IF(M) 380, 380, 360
  360     DO 370 L=1,M
          B(ICOLUM,L)=B(ICOLUM,L)/PIVOT(I)
  370     CONTINUE
C
C         REDUCE NON-PIVOT ROWS
C
  380     DO 550 L1=1,N
  390     IF(L1-ICOLUM) 400, 550, 400
  400     T=A(L1,ICOLUM)
  420     A(L1,ICOLUM)=0.0
  430     DO 450 L=1,N
          A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
```

```
  450 CONTINUE
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
      B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  500 CONTINUE
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
  740 RETURN
  750 DETERM=0.0
  760 GO TO 740
      END
      SUBROUTINE MESH(DEPTH,NOUT,NIN)
C
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/TEN/R(36),Z(30),NRR
C
C    MESH PREPARES STANDARD GRID FOR TRANSVERSE OR LONGITUDINAL ANALYSIS
C    MINIMUN DEPTH OF SUB-BALLAST IS 0.0 INCHES
C    MINIMUN DEPTH OF BALLAST IS 0.0 INCHES
C    RLTIE=LENGTH OF TIE,GREATER THAN OR EQUAL TO 84 INCHES
C    RLTIE2=HALF THE LENGTH OF TIE
C   WTIE=WIDTH OF TIE
C   TSPACE=TIE SPACING
C    TTHICK=TIE THICKNESS
C    ANAL=1.0 FOR TRANSVERSE ANALYSIS
C    ANAL=2.0 FOR LONGITUDINAL ANALYSIS
C    ANAL=3.0 FOR TRANSVERSE ANALYSIS - TIE AS BEAM
      R(1)=0.0
      R(2)=10.0
      R(3)=18.0
      R(4)=22.0
      R(5)=26.0
      R(6)=30.0
      R(7)=34.0
      R(8)=42.0
      IF(NRR.GT.0) READ(NIN,900) (R(I),I=1,NRR)
  900 FORMAT(8F10.2)
C
      IF(ANAL.EQ.2.0) GO TO 500
C    VERTICAL BOUNDARY LINES FOR TRANSVERSE ANALYSIS
      RLTIE2=RLTIE/2.0
```

```
      IF(RLTIE.EQ.84.0) GO TO 10
      A=RLTIE2-42.
      IF(A.GT.2.0) GO TO 5
      R(8)=RLTIE2
      GO TO 10
    5 IF(A.GT.8.0) GO TO 6
      R(9)=RLTIE2
      GO TO 11
    6 R(9)=R(8)+4.0
      R(10)=RLTIE2
      GO TO 12
C
C
   10 R(9)=R(8)+6.0
   11 R(10)=R(9)+12.0
   12 R(11)=R(10)+12.0
      R(12)=R(11)+24.0
      R(13)=R(12)+24.0
      R(14)=R(13)+24.0
      R(15)=R(14)+24.0
      R(16)=R(15)+24.0
      R(17)=R(16)+48.0
      R(18)=R(17)+48.0
      R(19)=R(18)+48.0
      R(20)=R(19)+100.0
      GO TO 510
C
C    VERTICAL BOUNDARY LINES FOR LONGITUDINAL ANALYSIS
  500 T2=WTIE/2.0
      TS3=(TSPACE-WTIE)/3.0
      TS2=TSPACE/2.
      TS4=(TSPACE-WTIE)/2.0
C
      R(1)=0.0
      R(2)=T2
      R(3)=R(2)+TS3
      R(4)=R(3)+TS3
      R(5)=R(4)+TS3
      R(6)=R(5)+T2
      R(7)=R(6)+T2
      R(8)=R(7)+TS3
      R(9)=R(8)+TS3
      R(10)=R(9)+TS3
      R(11)=R(10)+T2
      R(12)=R(11)+T2
      R(13)=R(12)+(TSPACE-T2)/2.0
      R(14)=R(13)+(TSPACE-T2)/2.0
      R(15)=R(14)+TS2
      R(16)=R(15)+TS2
      R(17)=R(16)+TS2
      R(18)=R(17)+TS2
      R(19)=R(18)+TS2
      R(20)=R(19)+TS2
      R(21)=R(20)+TS2
      R(22)=R(21)+TS2
      R(23)=R(22)+TSPACE
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      R(24)=R(23)+TSPACE
      R(25)=R(24)+TSPACE
      R(26)=R(25)+TSPACE
      R(27)=R(26)+TSPACE
      R(28)=R(27)+TSPACE
      R(29)=R(28)+TSPACE
      R(30)=R(29)+TSPACE
      R(31)=R(30)+TSPACE
      R(32)=R(31)+TSPACE
C    LAST COLUMN WIDTH IS MADE EQUAL TO TWICE TIE SPACING
      R(NCOL)=R(NCOL)+TSPACE
C
C     HORIZONTAL BOUNDARY LINES CALCULATED IN THE SAME MANNER FOR BOTH
C     TRANSVERSE AND LONGITUDINAL ANALYSIS
 510  M=1
      Z(M)=-TTHICK
      M=M+1
       Z(M)=0.C
      IF(BDEPTH.EQ.0.0)  GO TO 610
      M=M+1
      Z(M)=4.0
      IF(BDEPTH.EQ.4.0) GO TO 610
      B=BDEPTH-4.0
      IF(B.GT.2.0) GO TO 511
      Z(M)=BDEPTH
      GO TO 610
 511  IF(B.GT.6.0) GO TO 512
 605  M=M+1
      Z(M)=BDEPTH
      GO TO 610
 512  M=M+1
      Z(M)=8.0
      IF(B.GT.12.0) GO TO 513
      GO TO 605
 513  M=M+1
      Z(M)=12.0
      IF(B.GT.18.0) GO TO 514
      GO TO 605
 514  M=M+1
      Z(M)=18.C
      IF(B.GT.24.0) GO TO 515
      GO TO 605
 515  M=M+1
      Z(M)=24.0
      M=M+1
      Z(M)=BDEPTH
 610  IF(SBDEPT.EQ.0.0) GO TO 40
      M=M+1
      Z(M)=Z(M-1)+4.0
      C=SBDEPT-4.0
      IF(C.GT.2.0) GO TO 635
      Z(M)=Z(M-1)+SBDEPT
      GO TO 40
 635  IF(C.GT.8.0) GO TO 636
      M=M+1
      Z(M)=Z(M-2)+SBDEPT
```

```
      GO TO 40
  636 M=M+1
      Z(M)=Z(M-1)+6.0
      M=M+1
      Z(M)=Z(M-3)+SBDEPT
C     TO SOLVE BEAB ON ELASTIC FOUNDATION TYPE PROBLEMS.IE.,
C         IE., BDEPTH=SBDEPT=DEPTH=0.0
   40 IF(DEPTH.EQ.(BDEPTH+SBDEPT)) GO TO 290
      IF(UPPER.EQ.0.0) GO TO 140
      M=M+1
      Z(M)=Z(M-1)+6.0
      DD=UPPER-6.0
      IF(DD.GT.2.0) GO TO 141
      Z(M)=Z(M-1)+UPPER
      GO TO 140
  141 IF(DD.GT.8.0) GO TO 142
      M=M+1
      Z(M)=Z(M-2)+UPPER
      GO TO 140
  142 M=M+1
      Z(M)=Z(M-1)+6.0
      M=M+1
      Z(M)=Z(M-3)+UPPER
  140 CONTINUE
      M=M+1
      Z(M)=Z(M-1)+6.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+6.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+12.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+12.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+24.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+24.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+24.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+50.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+50.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+50.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
```

```
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
      IF(Z(M).GE.DEPTH) GO TO 290
       M=M+1
      Z(M)=Z(M-1)+100.0
C  Z'S ARE MADE NEG. DOWNEWARDS TO CORR. TO DIRECTIONS OF ELEMENT DIRCTN
 290  DO 291 I=1,M
 291  Z(I)=-Z(I)
C
C    NDEPTH=TOTAL NO. OF ROWS
C    NNDEPT=TOTAL NO. OF HORI. LINES=TOTAL NOS. OF ROWS +1
C    NCOL=TOTAL NO. OF VERT. LINES=TOTAL NO. OF COLUMNS +1
C
      NDEPTH=M-1
      NNDEPT=NDEPTH+1
C
      WRITE(NOUT,32)
   32 FORMAT(' '//' ','VERTICAL GRID LINES'//)
      WRITE(NOUT,30) (I,R(I),I=1,NCOL)
   30 FORMAT(' ',5X,'R(',I2,')=',F8.2)
      WRITE(NOUT,33)
   33 FORMAT(' '//' ','HORIZONTAL GRID LINES'//)
      WRITE(NOUT,31) (I,Z(I),I=1,NNDEPT)
   31 FORMAT(' ',5X,'Z(',I2,')=',F8.2)
      RETURN
      END
      SUBROUTINE QUAD(NUMEL,SIGXX,EX,PSR,ET,NGENS,ERROR,NEX,TYPE)
C
      DIMENSION SIGXX(NEX),EX(NEX),PSR(NUMEL),ET(NUMEL),TYPE(NUMEL)
C
      COMMON/SIX/BONE1,BTWO1,BONE2,BTWO2,RMOD(8),DEV(8),UMOD(8),UDEV(8),
     1 EFAIL1,EFAIL2,EFAIL3,AMXSR1,SIGMN1,AMXSR2,SIGMN2,TAUSUB,NPOINT,
     2 JPOINT,EFAIL6,UTAUSB,NSUBL,NSUBU
      COMMON/NINE/FLAG,BFLAG,CFLAG,ABCD
C    CALCULATION OF ELEMENT  MODULUS VALUE TO BE USED FOR THE NEXT
C    LOAD INCREMENT STEP
C    COMPRESSIVE STRESSES ARE POSITIVE
C    DOWNWARD DISPLACEMENTS ARE POSITIVE
C    POSITIVE HORI. DISPLACEMENTS ARE T OWARDS LEFT
C
      DO 10 N=1,NUMEL
      LSS=(N-1)*NGENS+1
      LSS1=LSS+1
      LSS2=LSS1+1
      CC=(SIGXX(LSS)+SIGXX(LSS1))/2.0
      BB=(SIGXX(LSS1)-SIGXX(LSS))/2.0
```

```
      CR=SQRT(BB*BB+SIGXX(LSS2)*SIGXX(LSS2))
      SIG1=CC+CR
      SIG3=CC-CR
      ASIG3=SIG3
C     SIGD IS THE DEVIATORIC STRESS FOR PLANE STRAIN CASE,VIZ, SIG1-SIG3
      SIGD=SIG1-SIG3
      IF(SIG3.LE.0.0) ASIG3=0.001
      RATIO=SIG1/ASIG3
      IF(TYPE(N).EQ.4.0.OR.TYPE(N).EQ.5.0.OR.TYPE(N).EQ.7.0.OR.TYPE(N).E
     1Q.8.0.OR.TYPE(N).EQ.10.) GO TO 10
      IF(TYPE(N).EQ.1.0.OR.TYPE(N).EQ.9.0)  GO TO 11
      IF(TYPE(N).EQ.2.0) GO TO 12
      IF(TYPE(N).EQ.6.0) GO TO 13
C     FOR SUBGRADE SOIL - TYPE(N)=3.0
      IF(NSUBL.EQ.1) GO TO 14
      IF(SIGD.LT.DEV(1)) SIGD=DEV(1)
      IF(SIGD.GT.DEV(NPOINT)) SIGD=DEV(NPOINT)
      DO 20 JJD=1,NPOINT
      IF(SIGD.EQ.DEV(JJD))ET(N)=RMOD(JJD)
      IF(JJD.EQ.NPOINT) GO TO 20
      IF(SIGD.GT.DEV(JJD).AND.SIGD.LT.DEV(JJD+1)) GO TO 24
      GO TO 20
   24 DIFF=RMOD(JJD)-RMOD(JJD+1)
      TOP=SIGD-DEV(JJD)
      BOT=DEV(JJD+1)-DEV(JJD)
      ET(N)=RMOD(JJD)-DIFF*TOP/BOT
      IF(CR.GE.TAUSUB)  ET(N)=EFAIL3
   20 CONTINUE
      GO TO 10
C
C     FOR SUBGRADE SOIL - TYPE(N)=3.0 WITH ER=K1(THETA)K2 RESPONSE
   14 CONTINUE
      BONE=RMOD(1)
      BTWO=DEV(1)
      EFAIL=EFAIL3
      DFLAG=RMOD(2)
      AMXSR=RMOD(3)
      SIGMN=DEV(3)
      GO TO 111
C
C     FOR THE UPPER SOIL LAYER - TYPE(N)=6.0
   13 CONTINUE
      IF(NSUBU.EQ.1) GO TO 15
      IF(SIGD.LT.UDEV(1)) SIGD=UDEV(1)
      IF(SIGD.GT.UDEV(JPOINT))SIGD=UDEV(JPOINT)
      DO 30 JJD=1,JPOINT
      IF(SIGD.EQ.UDEV(JJD)) ET(N)=UMOD(JJD)
      IF(JJD.EQ.JPOINT) GO TO 30
       IF(SIGD.GT.UDEV(JJD).AND.SIGD.LT.UDEV(JJD+1)) GO TO 34
      GO TO 30
   34 DIFF=UMOD(JJD)-UMOD(JJD+1)
      TOP=SIGD-UDEV(JJD)
      BOT=UDEV(JJD+1)-UDEV(JJD)
      ET(N)=UMOD(JJD)-DIFF*TOP/BOT
      IF(CR.GE.UTAUSB) ET(N)=EFAIL6
   30 CONTINUE
```

```
      GO TO 10
C
C     FOR UPER SUBGRACE LAYER- TYPE(N)=6.0 WITH ER=K1(THETA)K2 RESPCNSE
   15 CONTINUE
      BONE=UMOD(1)
      BTWO=UDEV(1)
      EFAIL=EFAIL6
      DFLAG=UMOD(2)
      AMXSR=UMOD(3)
      SIGMN=UDEV(3)
      GO TO 111
C     FLAG=1.0 ISA MARKER FOR THE FINAL CYCLE
C     BFLAG=1.0 ID A MARKER FOR USING BALLAST          L FAILURE CRITERIA
C     IN THE FINAL  CYCLE ONLY
C     BFLAG=2.0 IS A MARKER FOR NCT USING BALLAST FAILURE CRITERIA AT ALL
C     CFLAG=1.0 ID A MARKER FOR USING   SUBBALLST      FAILURE CRITERIA
C     IN THE FINAL CYCLE ONLY
C     CFLAG=2.0 IS A MARKER FOR NCT USING SUBBALL FAILURE CRITERIA AT ALL
C     FOR BALLAST MATERIAL - TYPE(N)=1.0 OR 9.0(FOR CST)
   11 CONTINUE
      BONE=BONE1
      BTWO=BTWO1
      EFAIL=EFAIL1
      DFLAG=BFLAG
      AMXSR=AMXSR1
      SIGMN=SIGMN1
      GO TO 111
  111 SIGZ=PSR(N)*(SIGXX(LSS)+SIGXX(LSS1))
      THETA=SIGZ+SIGXX(LSS)+SIGXX(LSS1)
      IF (BTWO.EQ.0.0) ET(N)=BONE
      IF (BTWO.EQ.0.0) GO TO 10
      IF(THETA.LE.0.0) THETA=0.0
      IF(THETA.LE.0.0) GO TO 112
      IF(RATIO.GT.AMXSR.OR.SIG3.LT.SIGMN) GO TO 112
      ET(N)=BONE*(THETA)**BTWO
      GO TO 10
  112 ET(N)=EFAIL
      IF(DFLAG.EQ.1.0.AND.FLAG.NE.1.0)ET(N)=BONE*(THETA)**BTWO
      IF(DFLAG.EQ.2.0) ET(N)=BONE*(THETA)**BTWO
      GO TO 10
C     FOR SUB-BALLAST MATERIAL - TYPE(N)=2.0
   12 CONTINUE
      BONE=BONE2
      BTWO=BTWO2
      EFAIL=EFAIL2
      DFLAG=CFLAG
      AMXSR=AMXSR2
      SIGMN=SIGMN2
      GO TO 111
   10 CONTINUE
C
      RETURN
      END
      SUBROUTINE READEC(NDEG,NGENS,NUMEL,N1,NCRD,NONP,NNODE,NPI,NPBC,
     1 PRESS,PL,CORD,TD,TF)
C
```

```
      DIMENSION CORD(NCRD,NONP),NPI(NNODE,NUMEL),PL(NDEG,NONP),
     1          NPBC(NDEG,NONP),TD(NDEG,NONP),TF(NDEG,NONP)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),GI(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),ICUT
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/SEVEN/NDSPEC,NFSPEC,NSTEPS,NSTP,NFIX,NLOAD
      COMMON/EIGHT/RLOAD(36),PLOAD(36),DIST(36),MM(36),RDISP(36),
     1   PDISP(36),DIST1(36),MM1(36),NPT(36)
C
C     THIS SUBROUTINE IS CALLED FROM CONTRO
C     SUBROUTINE READEC READS THE DISPLACEMENT BOUNDARY CONDITION
C     AND LOAD INPUT TO THE PROBLEM
C
C     NPBC(I,J)=0 MEANS THAT DEGREE OF FREEDOM I FOR
C     NODE J IS NOT FIXED
C     NPBC(I,J)=1 MEANS THAT DEGREE OF FREEDOM I FOR
C     NODE J IS FIXED.THE VALUE OF THE DISPLACEMENT CAN BE ZERO OR SOME
C     FINITE VALUE
C     TF=TOTAL LOADS, PL=PRESSURE LOADS
C     INITIALIZE NPBC ARRAY
      DO 1 J=1,NONP
      DO 1 I=1,NDEG
      TF(I,J)=0.0
    1 NPBC(I,J)=0
C
C     SET NPBC MATRIX
C    (FORCE AND DISPLACEMENT CONDITIONS NOT SPECIFIED FOR THE SAME
C    DEGREE OF FREEDOM.)
C
C     DISPLACEMENT BOUNDARY CONDITIONS ARE CONSIDERED FIRST
C
    2 WRITE(NOUT,21)
   21 FORMAT(' ',25H  SPECIFIED DISPLACEMENTS,//19H   ND PT   DIR    DIS)
      NN=1
      NNN=2
      NONP=NCOL*(NDEPTH+1)
      NONP1=NONP-1
      NCOL1=NCOL+1
      NDEPT1=NDEPTH+1
C
C     HORI. DISPLACEMENTS ALONG TWO OUTER SIDES ARE MADE ZERO EXCEPT FOR
C     LOWERMOST NODES. THUS AT THE SURFACE NODES IT IS ACTUALLY ROTATION
C     THAT IS MADE ZEROFOR THE BEAM ELEMENT
C
      DO 50 I=1,NDEPTH
      TD(1,I)=0.0
      TD(1,NONP1)=0.0
      WRITE(NOUT,13) I,NN,TD(NN,I),NONP1,NN,TD(NN,NONP1)
   13 FORMAT(2I5,E15.7,5X,2I5,E15.7)
      NPBC(1,I)=1
      NPBC(1,NONP1)=1
   50 NONP1=NONP1-1
```

```
C     VERT. DISPLACEMENT OF BEAM ELEMENT AT THE SURFACE END NODE MADE
C     EQUAL TO ZERO
C      NONP2=NONP-NDEPTH
C      TD(2,NONP2)=0.0
C      NPBC(2,NONP2)=1
C      WRITE(NOUT,13) NONP2,NNN,TD(2,NONP2)
C
C     HORI. AND VERT. DISPLACEMENTS ALONG BOTTOM SIDE ARE MADE ZERO
       DO 60 I=NDEPT1,NONP,NDEPT1
       TD(1,I)=0.0
       TD(2,I)=0.0
       WRITE(NOUT,13) I,NN,TD(NN,I),I,NNN,TD(NNN,I)
       NPBC(1,I)=1
       NPBC(2,I)=1
   60  CONTINUE
C
C     FOR OTHER FIXED POINTS IN ANY DIRECTION - N=DIRECTION,M=NODE  NUMBE
C     THESE DATA CARDS ARE REPEATED NSTEPS TIMES
       IF(NFIX.EQ.0) GO TO 201
       DO 202  I=1,NFIX
       READ(NIN,203) M,N, TD(N,M)
  203  FORMAT(2I5,F10.2)
       WRITE(NOUT,13) M,N,TD(N,M)
       NPBC(N,M)=1
  202  CONTINUE
  201  CONTINUE
C     CHECK FOR ANY OTHER SPECIFIED DISPLACEMENTS
       IF(NDSPEC.EQ.0) GO TO 17
C     READS SPECIFIED DISPLACEMENTS AND MAKES  NPBC(N,M)=1
       N=2
       DO 118 L=1,NDSPEC
       M=MM1(L)*(NDEPTH+1)
       M=M+1
       NPT(L)=M
       TD(N,M)=PDISP(L)
       NPBC(N,M)=1
       WRITE(NOUT,13) M,N,TD(N,M)
  118  CONTINUE
C
   17  CONTINUE
       IF(NFSPEC.EQ.0) RETURN
       WRITE(NOUT,20)
   20  FORMAT(' ',18H  SPECIFIED FORCES,//,21H  ND PT  DIR    FORCE)
C
C     VERTICAL LOADING ONLY CONSIDERED,IE,Y DIRECTION
C     MM(L) DENOTES VERTICAL LINE NUMBER ALONG WHICH FORCE NO. L ACTS
C     MIS THE NODE NO. AT WHICH VERT. FORCE ACTS
        N=2
       DO 18 L=1,NFSPEC
       M=MM(L)*(NDEPTH+1)
       M=M+1
       TF(N,M)=PLOAD(L)
       IF(NPBC(N,M).EQ.0) GO TO 15
       IV=0
       WRITE(NOUT,14) IV,NPBC(N,M),M,N
   14  FORMAT(I5,5H  AND,I5,23H BOTH SPECIFIED AT NODE,I5,
```

```
     110H DIRECTION,I5)
      STOP
C
   15 NPBC(N,M)=0
      WRITE(NOUT,13) M,N,TF(N,M)
   18 CONTINUE
      RETURN
      END
      SUBROUTINE SCLA(W,C,N,M,MS)
C
      DIMENSION W(1)
C
C    CLEARS MATRIX W(N,M) AND PUTS C IN ALL LOCATIONS
      NM=N*M
      DO 1 I=1,NM
    1 W(I)=C
      RETURN
      END
      SUBROUTINE STIFF(N1,CORD,NCRD,NCNP,ET,PSR,DEN,DATA1)
C
      DIMENSION CORD(NCRD,NONP)
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
C    EVALUATES ELEMENT STIFFNESS MATRIX FOR RECTANGULAR PLANE STRAIN ELM
C
      THICK=WTIE
      IF(ANAL.EQ.2.0) THICK=BTHICK
      N5=LM(1)
      N6=LM(2)
      N7=LM(3)
      N8=LM(4)
      A=ABS(CORD(1,N5)-CORD(1,N8))
      C=ABS(CORD(2,N5)-CORD(2,N6))
      A1=C*(1.-PSR)/(3.*A)
      A2=A*(1.-2.*PSR)/(6.*C)
      A3=A1/2.
      A4=A2/2.
      A5=A*(1.-PSR)/(3.*C)
      A6=C*(1.-2.*PSR)/(6.*A)
      A7=A6/2.
      A8=A5/2.
      C=1./8.
      CC=(4.*PSR-1.)/8.
      EV=ET/((1.0+PSR)*(1.-2.*PSR))
C
C
C    THICKNESS OF PLANAR ELEMENTS INCREASED WITH DEPTH,TO ACCOUNT FOR
C    ADEQUATE DISTRIBUTION OF LOAD,USING PSEUDO PLAIN STRAIN TECHNIQUE
C    SUBTRACTION BECAUSE DEPTHS ARE NEGATIVE
      IF(CORD(2,N5).GE.0.0) GO TO 1
      THICK=THICK-(2.0*CORD(2,N5)*TAN(PHI))
    1 CONTINUE
```

```
C
C
      SS(1,1)=A1+A2
      SS(1,2)=-C
      SS(1,3)=A3-A2
      SS(1,4)=CC
      SS(1,5)=-A3-A4
      SS(1,6)=C
      SS(1,7)=-A1+A4
      SS(1,8)=-CC
      SS(2,1)=SS(1,2)
      SS(2,2)=A5+A6
      SS(2,3)=-CC
      SS(2,4)=-A5+A7
      SS(2,5)=C
      SS(2,6)=-A8-A7
      SS(2,7)=CC
      SS(2,8)=A8-A6
      SS(3,1)=SS(1,3)
      SS(3,2)=SS(2,3)
      SS(3,3)=SS(1,1)
      SS(3,4)=C
      SS(3,5)=SS(1,7)
      SS(3,6)=CC
      SS(3,7)=SS(1,5)
      SS(3,8)=-C
      SS(4,1)=SS(1,4)
      SS(4,2)=SS(2,4)
      SS(4,3)=SS(3,4)
      SS(4,4)=SS(2,2)
      SS(4,5)=-CC
      SS(4,6)=SS(2,8)
      SS(4,7)=-C
      SS(4,8)=SS(2,6)
      SS(5,1)=SS(1,5)
      SS(5,2)=SS(2,5)
      SS(5,3)=SS(3,5)
      SS(5,4)=SS(4,5)
      SS(5,5)=SS(1,1)
      SS(5,6)=-C
      SS(5,7)=SS(1,3)
      SS(5,8)=CC
      SS(6,1)=SS(1,6)
      SS(6,2)=SS(2,6)
      SS(6,3)=SS(3,6)
      SS(6,4)=SS(4,6)
      SS(6,5)=SS(5,6)
      SS(6,6)=SS(2,2)
      SS(6,7)=-CC
      SS(6,8)=SS(2,4)
      SS(7,1)=SS(1,7)
      SS(7,2)=SS(2,7)
      SS(7,3)=SS(3,7)
      SS(7,4)=SS(4,7)
      SS(7,5)=SS(5,7)
      SS(7,6)=SS(6,7)
```

```
      SS(7,7)=SS(1,1)
      SS(7,8)=C
      SS(8,1)=SS(1,8)
      SS(8,2)=SS(2,8)
      SS(8,3)=SS(3,8)
      SS(8,4)=SS(4,8)
      SS(8,5)=SS(5,8)
      SS(8,6)=SS(6,8)
      SS(8,7)=SS(7,8)
      SS(8,8)=SS(2,2)
      DO 230 I=1,8
      DO 230 J=1,8
  230 SS(I,J)=SS(I,J)*EV*THICK
C
C
      RETURN
      END
      SUBROUTINE  TBETA(CORD,NONP,NCRD)
C
      DIMENSION  CORD(NCRD,NONP)
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/THREE/DUMP(20),LM(4),IOUT
C    EVALUATES B MATRIX FOR THE CST  ELEMENT
C
      N5=LM(1)
      N6=LM(2)
      N7=LM(3)
      N8=LM(4)
      Y23=CORD(2,N6)-CORD(2,N7)
      Y31=CORD(2,N7)-CORD(2,N5)
      Y12=CORD(2,N5)-CORD(2,N6)
      X32=CORD(1,N7)-CORD(1,N6)
      X13=CORD(1,N5)-CORD(1,N7)
      X21=CORD(1,N6)-CORD(1,N5)
      AREA=(CORD(1,N5)*Y23+CORD(1,N6)*Y31+CORD(1,N7)*Y12)/2.0
      AREAH=1.0/(2.0*AREA)
C
C
      B(1,1)=Y23*AREAH
      B(1,2)=0.0
      B(1,3)=Y31*AREAH
      B(1,4)=0.0
      B(1,5)=Y12*AREAH
      B(1,6)=0.0
      B(1,7)=0.0
      B(1,8)=0.0
      B(2,1)=0.0
      B(2,2)=X32*AREAH
      B(2,3)=0.0
      B(2,4)=X13*AREAH
      B(2,5)=0.0
      B(2,6)=X21*AREAH
      B(2,7)=0.0
      B(2,8)=0.
      B(3,1)=X32*AREAH
```

```
      B(3,2)=Y23*AREAH
      B(3,3)=X13*AREAH
      B(3,4)=Y31*AREAH
      B(3,5)=X21*AREAH
      B(3,6)=Y12*AREAH
      B(3,7)=0.
      B(3,8)=0.
C
      RETURN
      END
      SUBROUTINE  TSTIFF(N1,CORD,NCRD,NONP,ET,PSR,DEN,DATA1)
C
      DIMENSION  CORD(NCRD,NONP)
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
C
      THICK=WTIE
      N5=LM(1)
      N6=LM(2)
      N7=LM(3)
      N8=LM(4)
      Y23=CORD(2,N6)-CORD(2,N7)
      Y31=CORD(2,N7)-CORD(2,N5)
      Y12=CORD(2,N5)-CORD(2,N6)
      X32=CORD(1,N7)-CORD(1,N6)
      X13=CORD(1,N5)-CORD(1,N7)
      X21=CORD(1,N6)-CORD(1,N5)
      AREA=(CORD(1,N5)*Y23+CORD(1,N6)*Y31+CORD(1,N7)*Y12)/2.0
      ETM=ET/(1.0-PSR*PSR)
      PSRM=PSR/(1.0-PSR)
      IF(CORD(2,N5).GE.0.0) GO TO 1
      THICK=THICK-(2.0*CORD(2,N5)*TAN(PHI))
    1 CONTINUE
      EV=ETM*THICK/(4.0*AREA*(1.0-PSRM*PSRM))
      A1=(1.0-PSRM)/2.0
      A2=(1.0+PSRM)/2.0
C
C
      SS(1,1)=Y23*Y23+A1*X32*X32
      SS(1,2)=A2*X32*Y23
      SS(1,3)=Y31*Y23+A1*X13*X32
      SS(1,4)=PSRM*X13*Y23+A1*X32*Y31
      SS(1,5)=Y12*Y23+A1*X21*X32
      SS(1,6)=PSRM*X21*Y23+A1*X32*Y12
      SS(2,1)=SS(1,2)
      SS(2,2)=X32*X32+A1*Y23*Y23
      SS(2,3)=PSRM*X32*Y31+A1*X13*Y23
      SS(2,4)=X13*X32+A1*Y23*Y31
      SS(2,5)=PSRM*X32*Y12+A1*X21*Y23
      SS(2,6)=X21*X32+A1*Y12*Y23
      SS(3,1)=SS(1,3)
      SS(3,2)=SS(2,3)
```

```
      SS(3,3)=Y31*Y31+A1*X13*X13
      SS(3,4)=A2*X13*Y31
      SS(3,5)=Y12*Y31+A1*X13*X21
      SS(3,6)=PSRM*X21*Y31+A1*X13*Y12
      SS(4,1)=SS(1,4)
      SS(4,2)=SS(2,4)
      SS(4,3)=SS(3,4)
      SS(4,4)=X13*X13+A1*Y31*Y31
      SS(4,5)=PSRM*X13*Y12+A1*X21*Y31
      SS(4,6)=X13*X21+A1*Y12*Y31
      SS(5,1)=SS(1,5)
      SS(5,2)=SS(2,5)
      SS(5,3)=SS(3,5)
      SS(5,4)=SS(4,5)
      SS(5,5)=Y12*Y12+A1*X21*X21
      SS(5,6)=A2*X21*Y12
      SS(6,1)=SS(1,6)
      SS(6,2)=SS(2,6)
      SS(6,3)=SS(3,6)
      SS(6,4)=SS(4,6)
      SS(6,5)=SS(5,6)
      SS(6,6)=X21*X21+A1*Y12*Y12
      DO  230  I=1,8
      DO  230  J=1,8
  230 SS(I,J)=SS(I,J)*EV
C
C
      RETURN
      END
      SUBROUTINE VRDIM(VARS,INTS,INTGR,IREAL)
C
      DIMENSION VARS(IREAL),INTS(INTGR),ASTER(30)
C
      COMMON/ONE/SS(8,8),SK(2,2,16),D(3,3),B(3,8),DISP(8),DISPT(8),
     1 G(2,2),G1(2,2),E(3,8),NOUT,NIN
      COMMON/TWO/NDEPTH,NCOL,TITLE(20),RLTIE,WTIE,BDEPTH,SBDEPT,TSPACE,
     1UPPER
      COMMON/THREE/DUMP(20),LM(4),IOUT
      COMMON/FIVE/ANAL,TTHICK,BTHICK,PHI
      COMMON/NINE/FLAG,BFLAG,CFLAG,ABCD
      COMMON/TEN/R(36),Z(30),NRR
      DATA ASTER/30*'****'/
C
C    VRDIM READS THE CONTROL INPUT DATA AND SUB ALLOCATES THE ARRAYS
C    VARS AND INTS ACCORDING TO INPUT PARAMETERS
C    NIN IS THE UNIT NO. FOR THE READER
C    NOUT IS THE UNIT NO. FOR THE PRINTER
      NIN=5
      NOUT=6
      READ(NIN,10) NPROB
   10 FORMAT(I5)
      WRITE(NOUT,110) ASTER,ASTER,NPROB
  110 FORMAT('1',30A4//
     1  ' ','STRUCTURAL ANALYSIS PROGRAM FOR CONVENTIONAL RAILWAY TRACK
     2SYSTEM - ILLI-TRACK - VERSION 2'/
     3  ' ','DEVELOPED BY THE TRANSPORTATION GROUP, CIVIL ENGINEERING DE
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     4PARTMENT,'/
     5   ' ','UNIVERSITY OF ILLINCIS, URBANA,'//
     6   ' ',30A4////' ','NUMBER OF PROBLEMS IN THIS RUN=',I3)
      DO 20 K=1,NPRCB
C
      ERROR=0.0
      READ(NIN,7) (TITLE(I),I=1,20)
    7 FORMAT(20A4)
      READ(NIN,22) ANAL,ABCD
      READ(NIN,22) RLTIE,WTIE,TTHICK,BDEPTH,SBDEPT,TSPACE,BTHICK,PHI
   22 FORMAT(8F10.2)
C    UPPPER=THICKNESS OF UPPER SUBGRADE LAYER
      READ(NIN,23) DEPTH,UPPER,LCOL,NRR
   23 FORMAT(2F10.2,2I5)
      IF(DEPTH.LT.0..OR.UPPER.LT.0..OR.LCOL.LT.0) ERROR=1.0
      IF(DEPTH.LT.0.0) WRITE(NOUT,59) DEPTH
   59 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1   ' ','TCTAL DEPTH OF SECTION IS',F10.2,' CHECK IT'/)
      IF(UPPER.LT.0.0)WRITE(NOUT,60) UPPER
   60 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1   ' ','DEPTH OF UPPER SUBGRADE LAYER IS',F10.2,' CHECK IT'/)
      IF(LCOL.LT.0)WRITE(NOUT,61) LCCL
   61 FORMAT(' ','*****ERROR*****PROBLEM WILL NOT BE SOLVED'/
     1 ' ','NUMBER OF VERTICAL BCUNDARIES IS',I6,' CHECK IT'/)
      WRITE(NOUT,8) (TITLE(I),I=1,20)
    8 FORMAT('1','*****',20A4,'*****'//)
      WRITE(NOUT,33) ANAL,RLTIE,WTIE,TTHICK,TSPACE,BDEPTH,SBDEPT
   33 FORMAT(' ','TYPE OF ANALYSIS=',F7.2//
     *   ' ','GEOMETRICAL DATA'/' ','----------------'//
     1    ' ','TIE LENGTH=',F7.2,5X,'TIE WIDTH=',F7.2,5X,'TIE THICKNESS='
     2,F7.2,5X,'TIE SPACING=',F7.2/
     3   ' ','BALLAST DEPTH GIVEN=',F7.2/
     4   ' ','SUBBALLAST DEPTH GIVEN=',F7.2/)
      WRITE(NOUT,888) PHI,BTHICK,DEPTH,UPPER
  888 FORMAT(' ','*** ANGLE OF SPREAD ,PHI IS',F6.2/
     1     ' ','*** EFFECTIVE LENGTH OF TIE UNCER EACH RAIL IS',F10.2/
     2       ' ','***TCTAL DEPTH OF SECTION REQUIRED IS ',F8.2/
     3   ' ','*** DEPTH OF UPPER LAYER OF SUBGRADE IS ',F8.2/)
C    CONVERT PHI TO RADIANS
      PHI=PHI*22.0/(7.0*180.0)
      NCOL=27
      IF(ANAL.EQ.1.0) NCOL=13
      IF(ANAL.EQ.3.0) NCOL=13
      IF(LCOL.GT.0) NCOL=LCOL
  201 FORMAT(I5)
C    MESH IS CALLED TO PREPARE THE STANDARD GRID USING THE NCOL AND
C    DEPTH VALUES FOR EITHER TRANSVERSE OR LONGITUDINAL ANALYSIS
      CALL MESH(DEPTH,NCUT,NIN)
C    INTEGER INPUT CONTROLS
C
      NNDEPT=NDEPTH+1
      IOUT=1
      NCRD=2
      NGENS=3
      NNODE=4
      NDEG=2
```

```
      NONP=NCOL*NNDEPT
      NUMEL=(NNDEPT-1)*(NCOL-1)
      NEX=NGENS*NUMEL
      MAXNP=NDEPTH+2+1
      WRITE(NOUT,21) NNDEPT,NCOL,NUMEL,NONP
   21 FORMAT(' ',/' ','NO. OF HORIZONTAL BOUNDARY LINES=',I5/
     1    ' ','NO. OF VERTICAL BOUNDARY LINES=',I5/
     2     ' ','NO. OF ELEMENTS USED=',I5/
     3     ' ','NO. OF NODE POINTS USED=',I5//)
C
      NNODE2=NNODE*NNODE
      NSXX=MAXNP*(NONP+1)
      N1=NDEG*NNODE
      ISXX=1
      ICORD=ISXX+NDEG*NDEG*NSXX
      IET=ICORD+NCRD*NONP
      IDATA1=IET+NUMEL
      IPL=IDATA1+NUMEL
      ITD=IPL+NDEG*NONP
      ITF=ITD+NDEG*NONP
      IEX=ITF+NDEG*NONP
      IPSR=IEX+NGENS*NUMEL
      IDEN=IPSR+NUMEL
      ISIGXX=IDEN+NUMEL
      ITX=ISIGXX+NGENS*NUMEL
      IPPSTR=ITX+NDEG*NONP
      ITYPE=IPPSTR+NGENS*NONP
      IFVARS=ITYPE+NUMEL
C     COMPUTATION AND ADDRESSING OF INTEGER ARRAY
      IMAXCO=1
      INAP=IMAXCO+NONP
      INPI=INAP+NONP
      INP=INPI+NNODE*NUMEL
      INUME=INP+MAXNP*NONP
      INPNUM=INUME+NUMEL
      INPBC=INPNUM+NONP
      IFINTS=INPBC+NDEG*NONP
C
C     WRITE(NOUT,9) IFVARS,IFINTS
C   9 FORMAT(' ','FLOAT VECTOR LENGTH=',I7,5X,'INTEGER VECTOR LENGTH=',
C    1  I7/)
      IF(IFVARS.LT.IREAL.AND.IFINTS.LT.INTGR) GO TO 31
      WRITE(NOUT,32) IREAL,INTGR
   32 FORMAT(//' ','***** PROBLEM WILL NOT BE SOLVED '/
     1  ' ','DIMENSIONS OF VARS AND INTS IN MAIN OF ',2I7,5X,'ARE LESS T
     2HAN REQUIRED'//)
      ERROR=1.0
C     CALL CONTROL PROGRAM
   31 CALL CONTRO(NNODE2,NCRD,NUMEL,NNODE,NDEG,NGENS,NONP,MAXNP,NSXX,
     1 N1,VARS(ISXX),VARS(ICORD),VARS(IET),VARS(IDATA1),VARS(IPL),
     2 VARS(ITD),VARS(ITF),VARS(IEX),VARS(IPSR),VARS(IDEN),VARS(ISIGXX),
     3 VARS(ITX),VARS(IPPSTR),VARS(ITYPE),
     4 INTS(IMAXCO),INTS(INAP),INTS(INPI),INTS(INP),INTS(INUME),
     5 INTS(INPNUM),INTS(INPBC),ERROR,NEX)
C
      WRITE(NOUT,11)
```

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 11   FORMAT(////,1X,'***** END CF PRCBLEM *****')
 20   CONTINUE
C
      RETURN
      END
    1
STANCARD TRACK, LONG.ANALYSIS
  2.0
   96.        8.           7.       12.00                    20.    18.0     10.0
  275.0
30000000.     94.9       1250000.   0.20       229.0   999999.
 5082.0     0.58         30000.0    0.35       50000.0    0.0   50000.0    0.25
    3
 14820.0       0.1
  8000.0        6.2
  2900.0      36.2
  5000.0      0.47
  10.0        0.0        4000.0     999999.0   -20.0      4000.0
  25.0        100.0
         2      3
   30000.0     40.0
  30000.0      110.0
/*
//
```