A FINITE-ELEMENT METHOD OF ANALYSIS FOR COMPOSITE BEAMS

by

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Development of Methods for Computer Simulation
of Beam-Columns and Grid-Beam and Slab Systems

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PREFACE

This report describes an analytical tool for the solution of composite beam and slab problems. It may be used as a guide for the study and analysis of shear interaction between highway bridge decks and their supporting girders.

The program described in this report is written for the Control Data Corporation 1604 or 6600 computers. It is in FORTRAN language and only minor changes would be necessary to make it operable on other systems.

This is the tenth in a series of reports that describe the work in Research Project No. 3-5-63-56 entitled "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems." The reader may find it advantageous to review Report No. 56-1 (see List of Reports) as it provides background for this report.

The support of this work by the Texas Highway Department and the Bureau of Public Roads is gratefully acknowledged. The continued assistance and advice of Mr. Larry G. Walker, contact representative, and others in the Bridge Division of the Texas Highway Department is appreciated. Support for a portion of this study was provided by the National Science Foundation in the form of a graduate student fellowship, and approximately two hours of computer time were donated by the Computation Center at The University of Texas.

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LIST OF REPORTS

Report No. 56-1, "A Finite-Element Method of Solution for Linearly Elastic Beam-Columns" by Hudson Matlock and T. Allan Haliburton, presents a finite-element solution for beam-columns that is a basic tool in subsequent reports.

Report No. 56-2, "A Computer Program to Analyze Bending of Bent Caps" by Hudson Matlock and Wayne B. Ingram, describes the application of the beam-column solution to the particular problem of bent caps.

Report No. 56-3, "A Finite-Element Method of Solution for Structural Frames" by Hudson Matlock and Berry Ray Grubbs, describes a solution for frames with no sway.

Report No. 56-4, "A Computer Program to Analyze Beam-Columns under Movable Loads" by Hudson Matlock and Thomas P. Taylor, describes the application of the beam-column solution to problems with any configuration of movable non-dynamic loads.

Report No. 56-5, "A Finite-Element Method for Bending Analysis of Layered Structural Systems" by Wayne B. Ingram and Hudson Matlock, describes an alternating-direction iteration method for solving two-dimensional systems of layered grids-over-beams and plates-over-beams.

Report No. 56-6, "Discontinuous Orthotropic Plates and Pavement Slabs" by W. Ronald Hudson and Hudson Matlock, describes an alternating-direction iteration method for solving complex two-dimensional plate and slab problems with emphasis on pavement slabs.

Report No. 56-7, "A Finite-Element Analysis of Structural Frames" by T. Allan Haliburton and Hudson Matlock, describes a method of analysis for rectangular plane frames with three degrees of freedom at each joint.

Report No. 56-8, "A Finite-Element Method for Transverse Vibrations of Beams and Plates" by Harold Salani and Hudson Matlock, describes an implicit procedure for determining the transient and steady-state vibrations of beams and plates, including pavement slabs.

Report No. 56-9, "A Direct Computer Solution for Plates and Pavement Slabs" by C. Fred Stelzer, Jr., and W. Ronald Hudson, describes a direct method for solving complex two-dimensional plate and slab problems.

Report No. 56-10, "A Finite-Element Method of Analysis for Composite Beams" by Thomas P. Taylor and Hudson Matlock, describes a method of analysis for composite beams with any degree of horizontal shear interaction.

ABSTRACT

A method of analysis for composite beams with any degree of horizontal shear interaction is presented. The method is very versatile; it is applicable to composite beams that have abrupt, point-by-point variations in their structural properties. Also, the beam may be subjected to any configuration of transverse or longitudinal load, and it may be supported in any reasonable manner.

There are three important features in the method of analysis presented. First, a finite-element model is substituted for the real structure. Second, algebraic equations which describe the load-deflection behavior are written for the model. Finally, the equations are solved for the unknown deflections by a modified form of Gaussian elimination.

The solution of practical problems is facilitated by the use of the computer program, COMBM 1, which utilizes the method of analysis presented herein. A series of example problems are included to demonstrate the use of the program and the generality of the method.

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NOMENCLATURE

Symbol	Typical Units	Definition
A^s, A^b	in^2	Cross-sectional areas
a^s, a^b	in	Distance from interface to horizontal spring restraints
a^1 - a^{14}	-	Terms in coefficient and load matrices
b^1 - b^9	-	Terms in coefficient and load matrices
C^s, C^b	in	Distance from neutral axis to interface
c^1 - c^{14}	-	Terms in coefficient and load matrices
γ	in	Slip at interface
d^s, d^b	in	Component of slip due to slope of bars
δ^c	in	Change in horizontal displacement between adjacent one-half stations
E^s, E^b	lb/in^2	Modulus of elasticity
F^s, F^b	$lb\text{-}in^2$	Flexural stiffness = EI
h	in	Increment length
θ	rad	Central-difference slope
I^s, I^b	in^4	Moment of inertia
i	-	Station number
K^c	lb/in	Shear connector modulus
K^s, K^b	lb/in	Horizontal spring stiffness
L	-	Dummy index used in summation process
M^s, M^b	in-lb	Bending moment
N^s, N^b	lb	Axial tension or compression

Note: The superscripts "s" and "b" are used throughout the study to refer to slab and beam respectively.

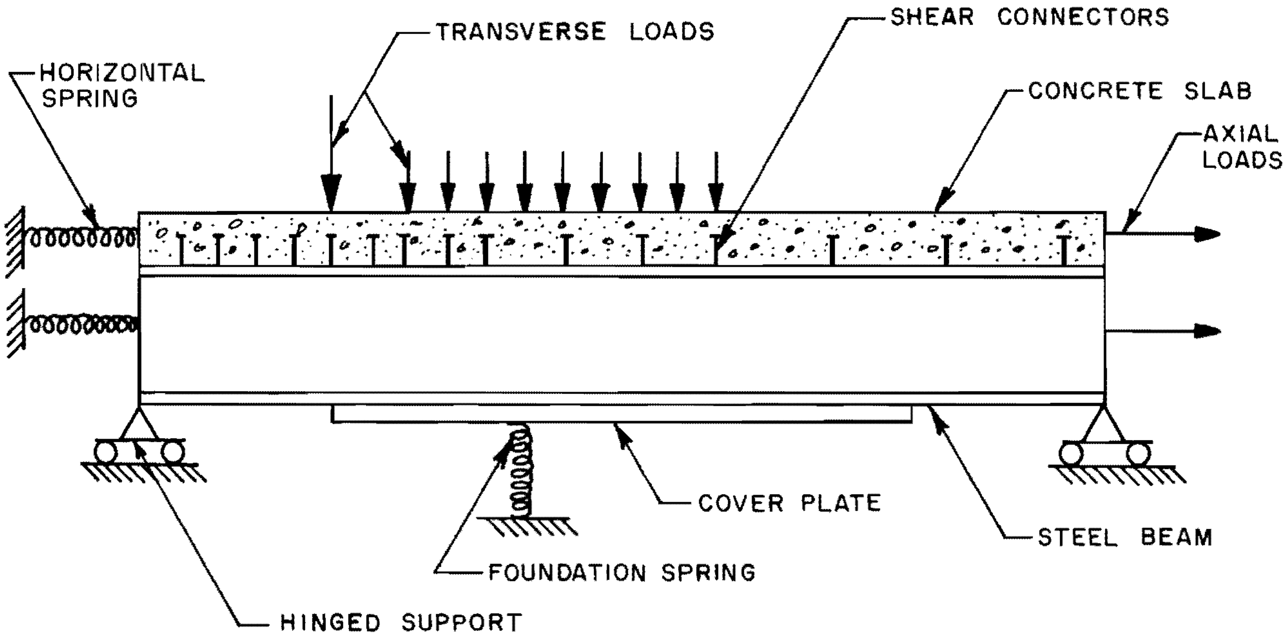
Symbol	Typical Units	Definition
P^s, P^b	lb	Applied longitudinal loads
Q	lb	Transverse load
R^s, R^b	in-lb/rad	Rotational restraints
S	lb/in	Transverse spring support
S^A	lb/in	Axial spring stiffness
S^A_E	lb/in	Equivalent axial spring stiffness
T^s, T^b	in-lb	Applied transverse couples
U^s, U^b	in	Horizontal displacement
V^s, V^b	lb	Shear
W	in	Vertical deflection
x	in	Longitudinal distance along composite beam

CHAPTER 1. INTRODUCTION

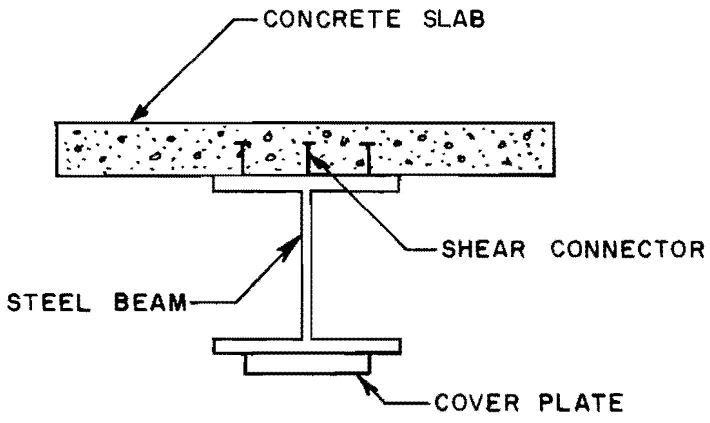
Statement of Problem

This study is concerned with the development of an efficient method for the analysis of composite beams. In this text, the term "composite beam" refers to structural systems consisting of two separate members that are joined at their interface by a shear connection. A practical example is a highway bridge girder that acts compositely with the floor slab. A typical composite beam is shown in Fig 1. The top member is a concrete slab and the bottom member is a steel I-beam. Shear connection is provided between the two members by studs which were welded to the top of the beam prior to placement of the concrete. The method of analysis presented is not limited to concrete-steel combinations such as shown in Fig 1 but is applicable to any similar composite system.

The stiffness and strength characteristics of a composite system are greatly affected by the amount of interaction between the slab and the beam. Number, location, and strength of the shear connectors are the factors that determine the degree of interaction between the two members. A complete absence of shear connectors causes the most flexible system. At the other extreme, the stiffest possible system is obtained when sufficient connectors are provided to insure that there is no slip between the two members. It is possible to determine the moment of inertia of the system for both of the extreme cases; therefore, conventional methods of analysis may be applied to them. For intermediate cases, it is not possible to calculate the moment of inertia of the system; hence, a new method of analysis is needed. Special-case solutions for partial-interaction problems may be found in the technical



a. Elevation.



b. Cross section.

Fig 1. One possible composite structure.

literature, but a general method of analysis for the full range of composite structures has not been found.

Brief Description of the Method of Analysis

The method of analysis presented in this text is free of many of the severe limitations that are found in conventional methods. The method presented herein allows wide variations in loads, supports, shear connectors, and characteristics of the members. Development of this method was made possible by the advent of the digital computer with its ability to do repetitive arithmetic operations rapidly. A basic requirement of the method is the ability to solve a large number of simultaneous equations, an ability not practical without the aid of a computer.

There are three steps in the analysis presented herein. First, the real physical problem is replaced by a finite-element model which enables a person who is not familiar with techniques of numerical analysis to understand the equations that describe the behavior of the system. Second, three equations which describe the load-deflection behavior of the system are derived from a free-body diagram of the model. The load-deflection equations are written in terms of three unknowns: horizontal displacement of the upper member, horizontal displacement of the lower member, and vertical deflection, which is the same for both members. When the three governing equations are written for each station in the model, a diagonally-banded set of equations results. Solution of this set of equations is the final step of the analysis.

The three steps outlined above have been incorporated into a computer program which makes the solution of practical problems a routine matter. All that is required of the user is to describe the physical problem according to a data input form that is provided, and the program completes the analysis automatically.

Limitations of the Method

While the analysis presented in this text is applicable to a wide range of problems, certain assumptions and limitations are built in. A detailed list of the pertinent assumptions is given in a later chapter; hence, only a summary will be given at this point. The method is valid only for static loads on the system; dynamic response is not considered. Also, the assumptions of conventional beam mechanics, linear stress-strain properties, small deflections, etc., are included. In addition, only linearly elastic shear connectors are presently considered.

Organization of the Report

A summary of the previous developments which have contributed to this report is given in Chapter 2. In Chapter 3, the finite-element model is presented and the load-deflection equations are derived. Chapter 4 is devoted to the solution of the system of equations. The computer program is described in Chapter 5. Example problems which illustrate correct usage of the computer program are given in Chapter 6. The final chapter includes a summary and recommendations for further research.

CHAPTER 2. A SURVEY OF IMPORTANT DEVELOPMENTS

History of Composite Construction

One of the first composite structures was built in 1922 by the Dominion Bridge Company of Canada. Two I-beams with a concrete slab were tested. At about the same time, tests of composite beams were carried out in the United States and England. All of the tests indicated good interaction between the two materials. In 1926, the patent "Composite Beam Construction" was issued to J. Kahn. By the early forties, several composite bridges had been built. The first specification for design of composite highway bridges was published by the American Association of State Highway Officials (AASHO) in 1944. The presentation of design principles in a specification stimulated a great deal of interest in composite construction.

Conventional Methods of Analysis

In 1912, E. S. Andrews (Ref 2) published one of the first articles on the theory of composite concrete and steel beams. Andrews presented equations for the computation of stresses that were based on the theory of a transformed section. In the transformed section theory, the concrete properties are multiplied by the modular ratio in order to convert the concrete to an equivalent section of steel. The modular ratio is simply the modulus of elasticity of concrete divided by the modulus of elasticity of steel. After the concrete has been transformed, the section is treated like a homogeneous steel section. Andrews' analysis assumed straight-line stress distributions and no slip between the concrete and steel.

The transformed section theory has been compared with tests of composite beams by many investigators. These experiments have shown that the transformed section theory is applicable as long as the bond between the steel and concrete is unbroken. The tests have also shown that the theory gives a good approximation even after bond failure if there is a sufficient number of very stiff mechanical shear connectors. For design purposes, the transformed section theory has generally been accepted.

Tests have also shown that, except in the case of complete bond, some slip between the slab and the beam is bound to occur and therefore the interaction between the beam and slab is not complete. Several theories have been developed to consider the effect of slip on the behavior of the system. The most widely known of the partial-interaction theories was developed by N. M. Newmark (Ref 12).

Newmark derived a differential equation which relates the force transmitted through the shear connectors to the applied bending moment. The equation is applicable to a system composed of different materials joined by an imperfect shear connection. It is assumed that:

(1) the shear connection between the slab and I-beam is continuous along the length of the beam,

(2) the amount of slip permitted by the shear connection is directly proportional to the load transmitted,

(3) the distribution of strains is linear within each of the members,

(4) the beam and the slab are assumed to deflect equal amounts at all points along their length.

The differental equation developed by Newmark is a general expression, but it is solved only for one special case, a simply-supported beam with a concentrated load. Once the axial load caused by the shear connectors has been determined, it is possible to determine the desired design information such as deflections and strains. The objection to this analytical procedure is that the governing differential equation must be resolved for each different type of load or support condition. For many common cases a solution to the equation would be extremely difficult to obtain.

A Finite-Element Method of Analysis for Beam-Columns

The method of analysis presented in this text has been greatly influenced by Matlock's numerical solutions to beam-column on elastic foundation problems (Ref 10). Matlock's approach to these problems is to replace the real physical system by an appropriate finite-element model. The model used by Matlock is composed of rigid, weightless bars hinged at their ends. The beam stiffness of each finite beam element is concentrated in the springs at the hinges. In Fig 2 the development of a bar-and-spring model from a section of a beam element subjected to pure bending is shown. Figure 2b shows the stresses acting on the beam element. The distributed stresses may be replaced by concentrated forces as shown in Fig 2c. In Fig 2d the deformed beam element is replaced by a pair of plates hinged at the center and restrained by springs at the top and bottom. A beam could be represented by a series of such beam-element models as in Fig 2e. Finally, a cruder model could be made by using rigid bars and springs as shown in Fig 2f.

Based on the model, a set of equations which describes the deflections as a function of the applied loads is derived. This set of equations forms a five-wide, diagonally-banded matrix which is solved by a direct elimination procedure.

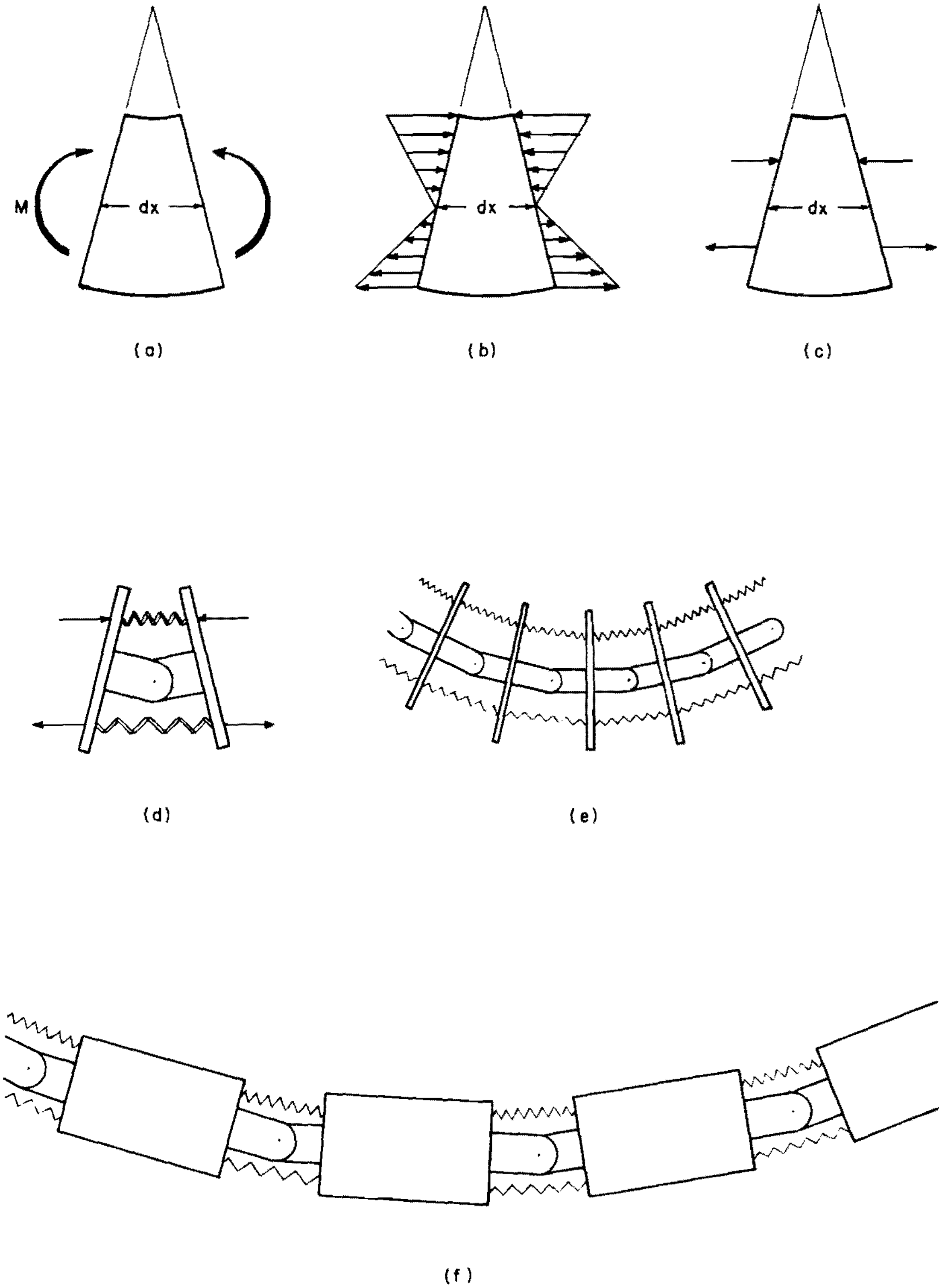


Fig 2. Finite mechanical representation of a conventional beam (after Matlock, Ref 10).

CHAPTER 3. METHOD OF SOLUTION

General Remarks on the Method of Solution

In this chapter, three equations which describe the load-deflection behavior of the system are derived. The three equations are written in terms of three unknowns: vertical deflection, horizontal displacement of the upper member, and horizontal displacement of the lower member. The vertical deflections are measured from any convenient horizontal reference line to the interface of the two members. There is no common reference line for the horizontal displacements; instead, the displacement of each point is measured from its own initial equilibrium position. For convenience, the upper member will hereafter be called the "slab" and the lower member will be called the "beam." A list of the assumptions that were made in the derivation of the equations is given below:

(1) vertical deflections of the slab and beam are equal,

(2) the slab and the beam interface is a straight line,

(3) deflections are small compared to the length of the structure,

(4) linearly-elastic shear connectors are used,

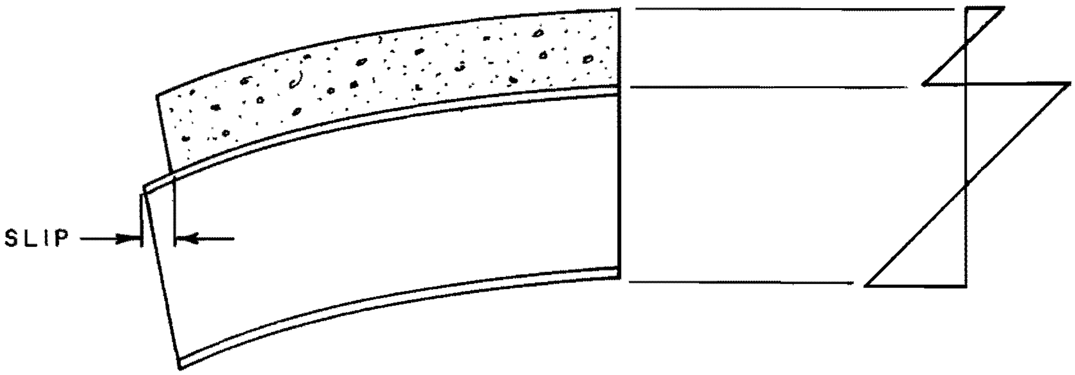
(5) slab and beam have linear stress-strain properties,

(6) the strain distribution throughout the cross section of both the beam and slab is linear; however, the strain distribution for the entire composite section may have a discontinuity at the interface as shown in Fig 3d,

(7) transverse shear deformations are negligible within each member,

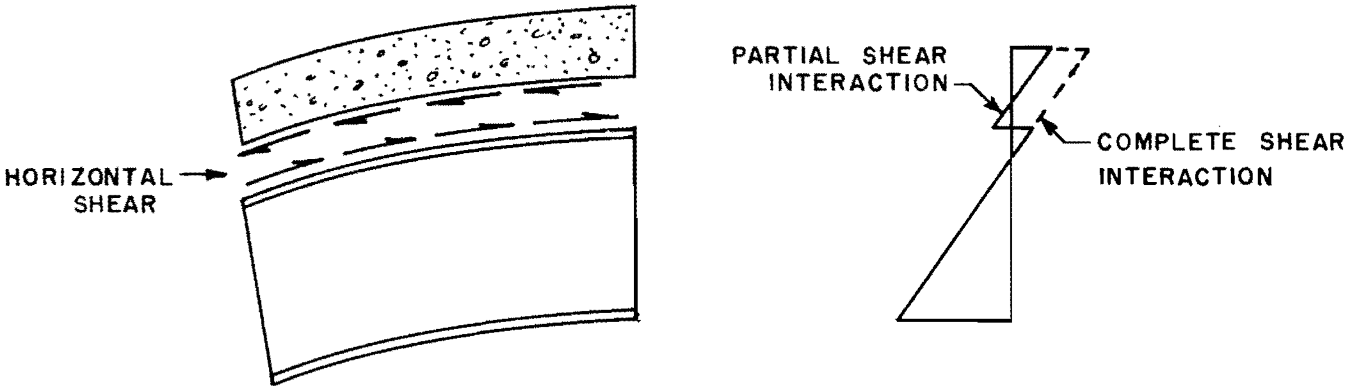
(8) the cross sections of both members are symmetrical about the vertical axis and loads are applied only in the plane of the vertical axis.

A numerical solution to a composite structural system may be obtained by either of two approaches. One method, as explained in Chapter 2, is to replace



a. Segment of a composite beam with no shear connectors.

b. Strain distribution.



c. Segment of a composite beam with shear connectors.

d. Strain distribution.

Fig 3. The effect of shear connectors in a composite structure.

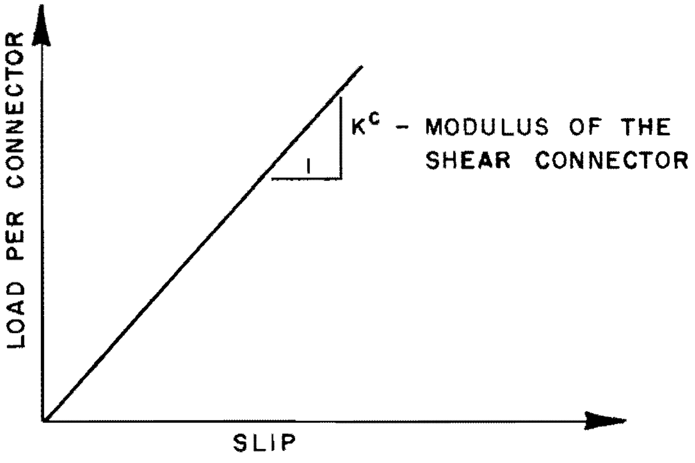


Fig 4. A typical load-slip curve.

the physical system by an appropriate bar-and-spring model. Equations can then be derived which describe the load-deflection behavior of the model. Another approach is to base the derivations on an infinitesimal, or differential, element of the real beam. Finite differences may then be used to convert the resulting differential equations to difference equations. Identical equations are obtained by either of the two methods. In this chapter, a bar-and-spring model approach to the problem is presented because the mathematics involved are simpler in this method. The infinitesimal element approach was investigated by the author and used to check the equations presented in this chapter.

Bending of a Composite Section

When a composite section is subjected to an upward load, the bottom fibers of the slab tend to shorten while the top fibers of the beam tend to lengthen. If there are no shear connectors to bind the slab and beam together, slip occurs at the interface of the beam and the slab as shown in Fig 3a. If shear connectors have been installed, they prevent, at least partially, the slip from occurring. The shear connectors cause horizontal shear to be transferred across the interface, inducing a tension force in the slab and a compressive force in the beam when deflected upward. This action is shown in Fig 3c. If enough shear connectors are provided to transfer all of the shear that is developed, no slip occurs and the upper limit of the strength of the member is reached. Stiffness, number, and location of the shear connectors are the factors that determine the amount of interaction between the beam and slab.

Stiffness of the individual connectors is measured by their load-slip modulus which is simply the slope of their load-slip curve (see Fig 4). Load-slip curves for a particular shear connection can be determined in the laboratory from a push-out test. In a push-out test, shear connectors are placed on each flange of steel beam. The length of the beam is variable, but is usually about two feet. Concrete with the same characteristics as the concrete to be used in the real structure is poured in the form of a slab against each flange. Bond is destroyed between the steel and concrete by lubrication with cup grease. After the concrete has set, a series of axial loads are applied to the beam and the resulting slips are measured.

The Bar-and-Spring Model

Figure 5 shows the model that is used to replace the real system. Each member (slab and beam) is represented by a system of bars and springs. All of the bending characteristics for each of the two layers of the system are lumped in the springs which act at the hinges of the bars. The weightless bars possess an infinite resistance to bending, but they are axially deformable. Pin-connected vertical spacer rods are included between the slab model and the beam model to insure that their vertical deflections are equal. The horizontal shear transfer mechanism is modeled by a pointer rod and spring system. To the center of each bar is attached an infinitely stiff cantilever pointer rod that extends to the interface. A linear spring which represents a shear connector is attached to each pair of slab and beam pointer rods.

An important feature of the model shown is that it permits a completely general description of the system. The properties of the system are defined only at discrete points; some properties are related to the joints while others are related to the bars. Therefore, abrupt variations in the properties along the member are allowable. The following quantities are defined at the joints: vertical deflection W, bending moments M^s and M^b, accumulated axial tensions N^s and N^b, transverse loads Q, applied torques T^s and T^b, rotational restraints R^s and R^b, support springs S, cross-section areas A^s and A^b, moments of inertia I^s and I^b, and distances from the neutral axis to the

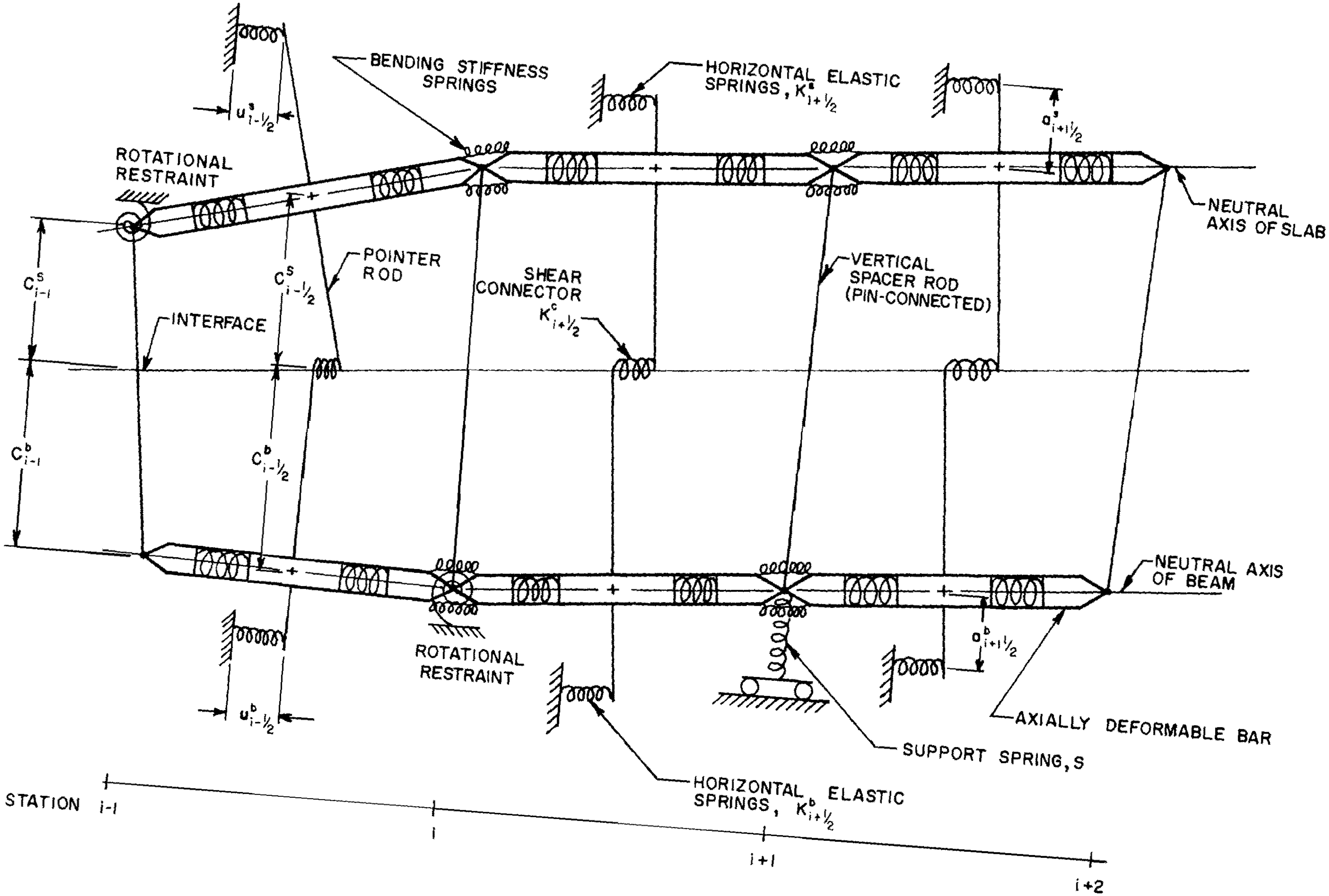


Fig 5. The bar-and-spring model.

interfaces C^s and C^b. In the symbols above as well as in the remainder of the text, the superscript "s" refers to the slab and the superscript "b" refers to the beam. The following quantities are related to the bars and are defined at the half-station: horizontal displacements U^s and U^b, slip γ, shears V^s and V^b, shear connector modulus K^c, horizontal elastic springs K^s and K^b, distances from the neutral axes to the horizontal springs a^s and a^b, and concentrated longitudinal loads P^s and P^b. The quantities listed above are shown acting in the positive sense in Fig 6.

Derivation of Equations

The relationship between the horizontal displacement and the axial tension of the slab can be determined by examination of Fig 7. Between Stations $i-\frac{1}{2}$ and $i+\frac{1}{2}$ the elongation is given by

$$\delta_i^c = -U_{i-1/2}^s + U_{i+1/2}^s \tag{3.1}$$

The axial tension is equal to the elongation multiplied by the axial spring constant

$$\left(-U_{i-1/2}^s + U_{i+1/2}^s\right) A_i^s E_i^s / h = N_i^s \tag{3.2}$$

Similarly, for Station i-1

$$\left(-U_{i-3/2}^s + U_{i-1/2}^s\right) A_{i-1}^s E_{i-1}^s / h = N_{i-1}^s \tag{3.3}$$

Subtract Eq 3.3 from Eq 3.2

$$-\left(-U_{i-3/2}^s + U_{i-1/2}^s\right) A_{i-1}^s E_{i-1}^s / h + \left(-U_{i-1/2}^s + U_{i+1/2}^s\right) A_i^s E_i^s / h$$
$$= -N_{i-1}^s + N_i^s \tag{3.4}$$

Sum the horizontal forces on Bar $i-\frac{1}{2}$ (Fig 8).

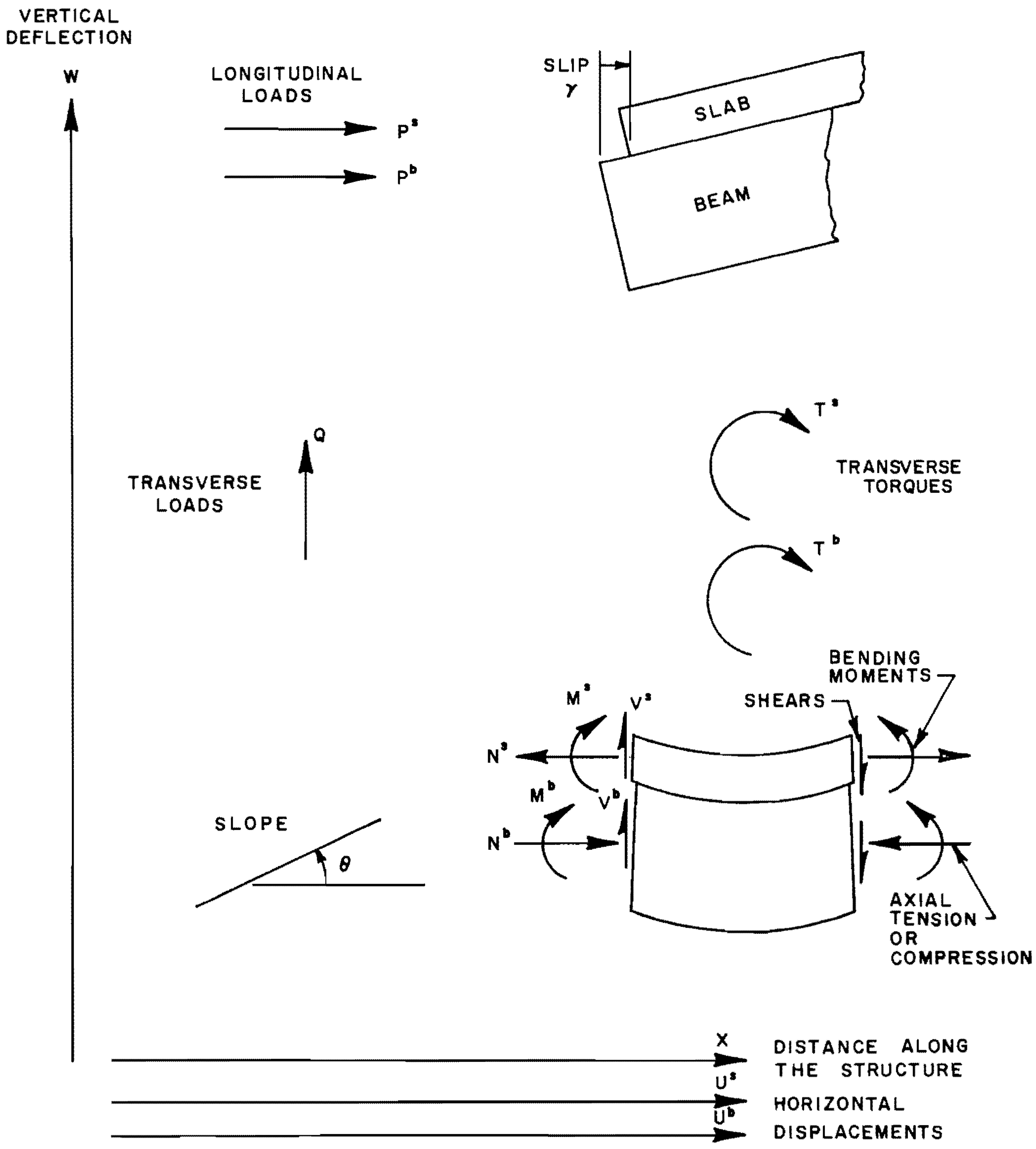


Fig 6. The sign convention. All quantities are shown in the positive sense with respect to distance along the beam, x .

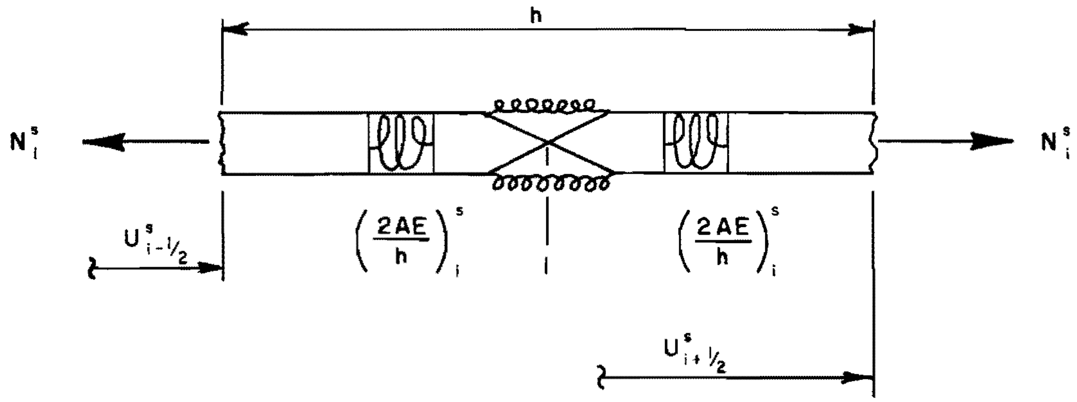


Fig 7. A slab joint.

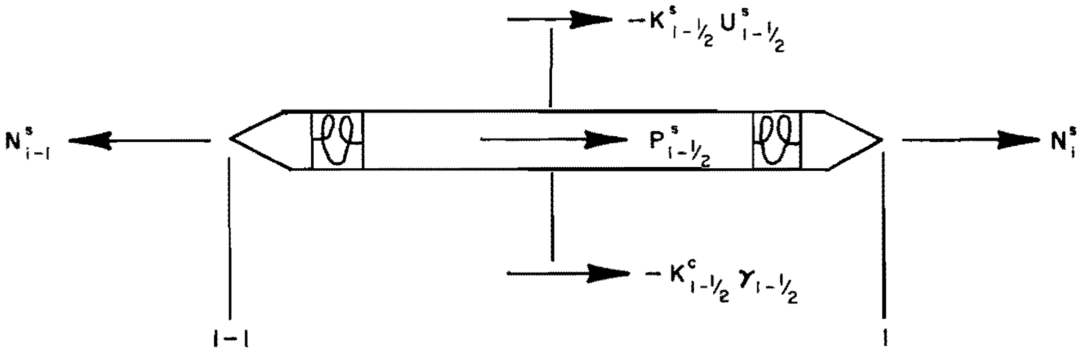


Fig 8. A slab bar.

$$- N^s_{i-1} + N^s_i - K^s_{i-1/2}U^s_{i-1/2} - K^c_{i-1/2}\gamma_{i-1/2} + P^s_{i-1/2} = 0 \quad (3.5)$$

Equation 3.5 may be substituted into Eq 3.4

$$- \left(- U^s_{i-3/2} + U^s_{i-1/2}\right) A^s_{i-1}E^s_{i-1}/h + \left(- U^s_{i-1/2} + U^s_{i+1/2}\right) A^s_iE^s_i/h$$
$$- K^s_{i-1/2}U^s_{i-1/2} - K^c_{i-1/2}\gamma_{i-1/2} = - P^s_{i-1/2} \quad (3.6)$$

The term $\gamma_{i-\frac{1}{2}}$ must be eliminated from Eq 3.6 in order that U^s , U^b , and W will be the only unknowns. An expression for $\gamma_{i-\frac{1}{2}}$ may be obtained by examination of Fig 9. The amount of slip at each half-station is measured by two pointer rods that are rigidly connected to the slab and beam bars. Slip at Station $i-\frac{1}{2}$ is simply the horizontal distance between the tip of the slab pointer and the tip of the beam pointer. The pointers are stiff cantilevers; therefore, they have the same slope as the bars. It can be seen that the component of slip that is due to the slope of the slab bar is

$$d^s_{i-1/2} = C^s_{i-1/2} \left(\frac{-W_{i-1} + W_i}{h}\right) \quad (3.7)$$

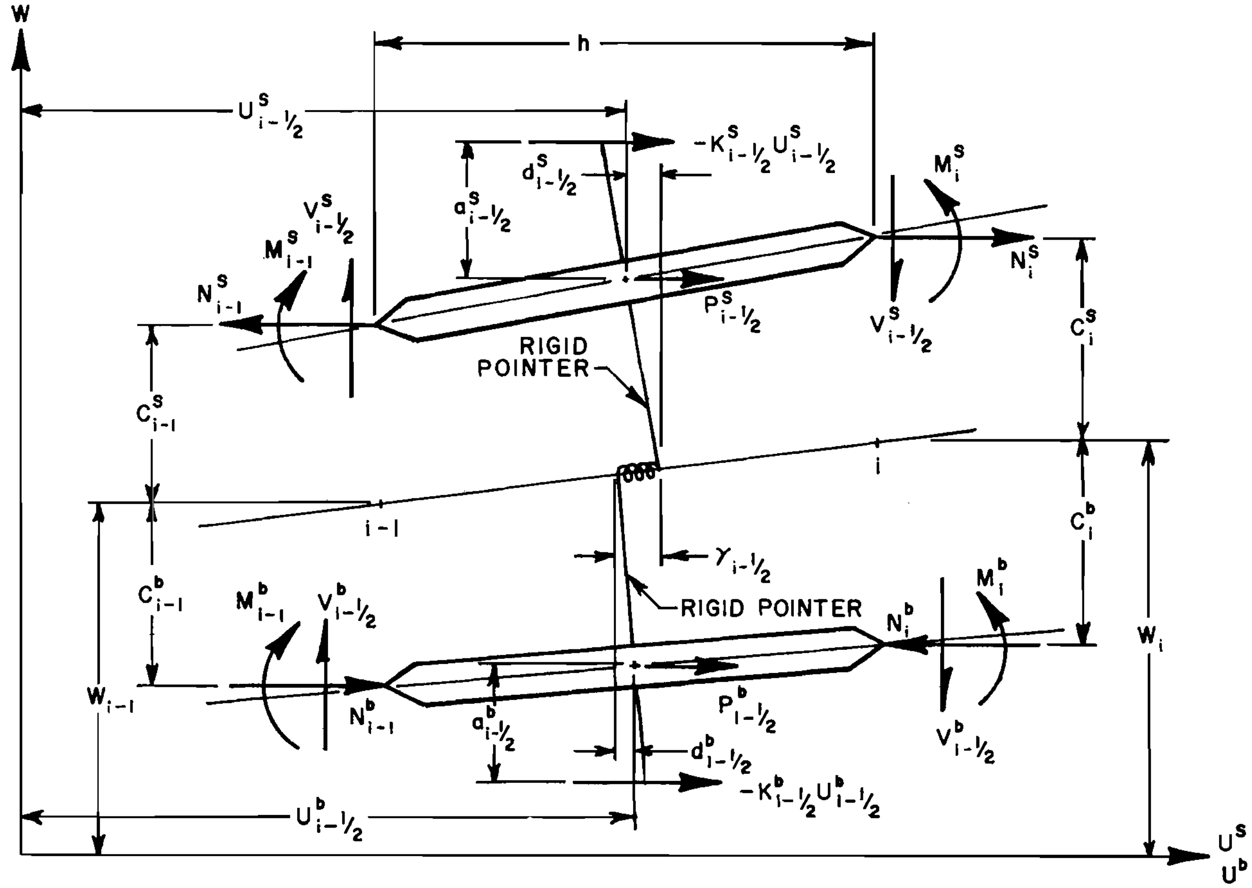
Similarly,

$$d^b_{i-1/2} = C^b_{i-1/2} \left(\frac{-W_{i-1} + W_i}{h}\right) \quad (3.8)$$

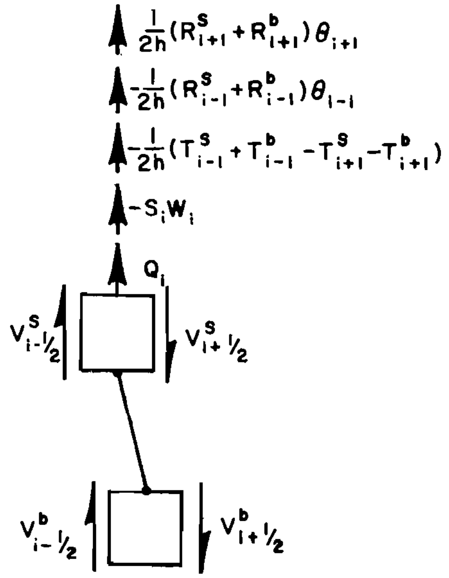
Examination of Fig 9 shows that the total slip is composed of the difference in horizontal displacement plus the slip components due to bar slopes given by Eqs 3.7 and 3.8.

$$\gamma_{i-1/2} = U^s_{i-1/2} + C^s_{i-1/2} \left(\frac{-W_{i-1} + W_i}{h}\right) - U^b_{i-1/2}$$
$$+ C^b_{i-1/2} \left(\frac{-W_{i-1} + W_i}{h}\right) \quad (3.9)$$

Equation 3.9 may be written



a. Free-body diagram of bars at Station i-1/2.



b. Free-body diagram of joints at Station i.

Fig 9. Free-body diagrams.

$$\gamma_{i-1/2} = U^s_{i-1/2} - U^b_{i-1/2} + \left(C^s_{i-1/2} + C^b_{i-1/2}\right) \left(\frac{-W_{i-1} + W_i}{h}\right) \qquad (3.10)$$

When Eq 3.10 is substituted into Eq 3.6, one of the three governing difference equations is produced.

$$\begin{aligned} - \left(- U^s_{i-3/2} + U^s_{i-1/2}\right) A^s_{i-1}E^s_{i-1}/h + \left(- U^s_{i-1/2} + U^s_{i+1/2}\right) A^s_i E^s_i/h \\ - K^s_{i-1/2}U^s_{i-1/2} - K^c_{i-1/2} \Big[U^s_{i-1/2} - U^b_{i-1/2} + \frac{1}{h} \left(C^s_{i-1/2} + C^b_{i-1/2}\right) \\ \left(- W_{i-1} + W_i\right)\Big] = - P^b_{i-1/2} \end{aligned} \qquad (3.11)$$

A derivation similar to the one just outlined yields the second governing difference equation which applies to the beam.

$$\begin{aligned} - \left(- U^b_{i-3/2} + U^b_{i-1/2}\right) A^b_{i-1}E^b_{i-1}/h + \left(- U^b_{i-1/2} + U^b_{i+1/2}\right) A^b_i E^b_i/h \\ - K^b_{i-1/2}U^b_{i-1/2} + K^c_{i-1/2} \Big[U^s_{i-1/2} - U^b_{i-1/2} + \frac{1}{h} \left(C^s_{i-1/2} + C^b_{i-1/2}\right) \\ \left(- W_{i-1} + W_i\right)\Big] = - P^b_{i-1/2} \end{aligned} \qquad (3.12)$$

Equations 3.11 and 3.12 are thus derived from a summation of horizontal forces and the axial deformation properties of the slab and beam. The third governing differential equation is a moment-equilibrium equation. It also involves a summation of vertical forces and the moment-curvature relationship.

A free-body diagram of a portion of the system is shown in Fig 9a. It should be noted that the applied torques and rotational restraints are felt by the system as transverse loads one station away from where the torque or rotational restraint is applied (see Fig 9b). For example, if a rotational restraint is applied at Station i, then transverse loads equal to the product of the rotational restraint and the slope θ_i are felt at Stations i-1 and i+1.

Sum moments about the interface at Station i are shown in Fig 9a.

$$\begin{aligned}
& - M^s_{i-1} - M^b_{i-1} + M^s_i + M^b_i - h\left(V^s_{i-1/2} + V^b_{i-1/2}\right) - \left(- W_{i-1} + W_i \right. \\
& \quad \left. - C^s_{i-1}\right) N^s_{i-1} + \left(- W_{i-1} + W_i + C^b_{i-1}\right) N^b_{i-1} - C^s_i N^s_i - C^b_i N^b_i \\
& \quad - \left[\frac{1}{2}\left(- W_{i-1} + W_i\right) - C^s_{i-1/2} - a^s_{i-1/2}\right] K^s_{i-1/2} U^s_{i-1/2} \\
& \quad - \left[\frac{1}{2}\left(- W_{i-1} + W_i\right) + C^b_{i-1/2} + a^b_{i-1/2}\right] K^b_{i-1/2} U^b_{i-1/2} \\
& \quad + \left[\frac{1}{2}\left(- W_{i-1} + W_i\right) + C^b_{i-1/2}\right] P^b_{i-1/2} + \left[\frac{1}{2}\left(- W_{i-1} + W_i\right) \right. \\
& \quad \left. - C^s_{i-1/2}\right] P^s_{i-1/2} = 0 \qquad (3.13)
\end{aligned}$$

A similar equation can be obtained from a summation of moments about the interface at Station i+1.

$$\begin{aligned}
& -M^s_i - M^b_i + M^s_{i+1} + M^b_{i+1} - h\left(V^s_{i+1/2} + V^b_{i+1/2}\right) - \left(- W_i + W_{i+1} \right. \\
& \quad \left. - C^s_i\right) N^s_i + \left(- W_i + W_{i+1} + C^b_i\right) N^b_i - C^s_{i+1} N^s_{i+1} - C^b_{i+1} N^b_{i+1} \\
& \quad - \left[\frac{1}{2}\left(- W_i + W_{i+1}\right) - C^s_{i+1/2} - a^s_{i+1/2}\right] K^s_{i+1/2} U^s_{i+1/2} \\
& \quad - \left[\frac{1}{2}\left(- W_i + W_{i+1}\right) + C^b_{i+1/2} + a^b_{i+1/2}\right] K^b_{i+1/2} U^b_{i+1/2} \\
& \quad + \left[\frac{1}{2}\left(- W_i + W_{i+1}\right) + C^b_{i+1/2}\right] P^b_{i+1/2} + \left[\frac{1}{2}\left(- W_i + W_{i+1}\right) \right. \\
& \quad \left. - C^s_{i+1/2}\right] P^s_{i+1/2} = 0 \qquad (3.14)
\end{aligned}$$

Subtract Eq 3.13 from Eq 3.14 and rearrange the terms

$$\begin{aligned}
& M^s_{i-1} + M^b_{i-1} - 2\left(M^s_i + M^b_i\right) + M^s_{i+1} + M^b_{i+1} - \left[N^s_{i-1} C^s_{i-1} + N^b_{i-1} C^b_{i-1} \right. \\
& \quad \left. - 2\left(N^s_i C^s_i + N^b_i C^b_i\right) + N^s_{i+1} C^s_{i+1} + N^b_{i+1} C^b_{i+1}\right] - \left(- W_{i-1} + W_i\right)
\end{aligned}$$

$$\begin{aligned}
&\left(N^b_{i-1} - N^s_{i-1} - \frac{1}{2}K^b_{i-1/2}U^b_{i-1/2} - \frac{1}{2}K^s_{i-1/2}U^s_{i-1/2} + \frac{1}{2}P^b_{i-1/2}\right. \\
&\left.+ \frac{1}{2}P^s_{i-1/2}\right) + \left(-W_i + W_{i+1}\right)\left(N^b_i - N^s_i - \frac{1}{2}K^b_{i+1/2}U^b_{i+1/2}\right. \\
&\left.- \frac{1}{2}K^s_{i+1/2}U^s_{i+1/2} + \frac{1}{2}P^b_{i+1/2} + \frac{1}{2}P^s_{i+1/2}\right) - \left(C^s_{i-1/2} + a^s_{i-1/2}\right) \\
&K^s_{i-1/2}U^s_{i-1/2} + \left(C^b_{i-1/2} + a^b_{i-1/2}\right) K^b_{i-1/2}U^b_{i-1/2} + \left(C^s_{i+1/2}\right. \\
&\left.+ a^s_{i+1/2}\right) K^s_{i+1/2}U^s_{i+1/2} - \left(C^b_{i+1/2} + a^b_{i+1/2}\right) K^b_{i+1/2}U^b_{i+1/2} \\
&= -h\left(V^s_{i-1/2} + V^b_{i-1/2} - V^s_{i+1/2} - V^b_{i+1/2}\right) - P^s_{i-1/2}C^s_{i-1/2} \\
&+ P^b_{i-1/2}C^b_{i-1/2} + P^s_{i+1/2}C^s_{i+1/2} - P^b_{i+1/2}C^b_{i+1/2} \qquad (3.15)
\end{aligned}$$

An expression for the shear terms which appear in Eq 3.15 may be obtained by the the summation of vertical forces on Station i.

$$\begin{aligned}
&V^s_{i-1/2} + V^b_{i-1/2} - V^s_{i+1/2} - V^b_{i+1/2} + Q_i - S_iW_i - \frac{1}{2h}\left(T^s_{i-1} + T^b_{i-1} - T^s_{i+1}\right. \\
&\left.- T^b_{i+1}\right) - \frac{1}{2h}\left(R^s_{i-1} + R^b_{i-1}\right)\theta_{i-1} + \frac{1}{2h}\left(R^s_{i+1} + R^b_{i+1}\right)\theta_{i+1} = 0 \qquad (3.16)
\end{aligned}$$

An expression for N^s_{i-1} may be obtained by summation of horizontal forces along the length of the slab.

$$N^s_{i-1} - \sum_{L=1}^{i-1}\left(K^c_{L-1/2}\gamma_{L-1/2} + K^s_{L-1/2}U^s_{L-1/2} - P^s_{L-1/2}\right) = 0 \qquad (3.17)$$

Similarly for the beam

$$N^b_{i-1} - \sum_{L=1}^{i-1}\left(+ K^c_{L-1/2}\gamma_{L-1/2} - K^b_{L-1/2}U^b_{L-1/2} + P^b_{L-1/2}\right) = 0 \qquad (3.18)$$

Subtract Eq 3.17 from Eq 3.18

$$N^b_{i-1} - N^s_{i-1} = \sum_{L=1}^{i-1}\left(P^s_{L-1/2} + P^b_{L-1/2} - K^s_{L-1/2}U^s_{L-1/2} - K^b_{L-1/2}U^b_{L-1/2}\right) \qquad (3.19)$$

A similar equation may be written at Station i

$$N^b_i - N^s_i = \sum_{L=1}^{i} \left(P^s_{L-1/2} + P^b_{L-1/2} - K^s_{L-1/2}U^s_{L-1/2} - K^b_{L-1/2}U^b_{L-1/2}\right) \quad (3.20)$$

Substitute Eqs 3.16, 3.19, and 3.20 into Eq 3.15

$$\begin{aligned}
&M^s_{i-1} + M^b_{i-1} - 2\left(M^s_i + M^b_i\right) + M^s_{i+1} + M^b_{i+1} - \Big[N^s_{i-1}C^s_{i-1} + N^b_{i-1}C^b_{i-1} \\
&\quad - 2\left(N^s_iC^s_i + N^b_iC^b_i\right) + N^s_{i+1}C^s_{i+1} + N^b_{i+1}C^b_{i+1}\Big] - \left(- W_{i-1} + W_i\right) \\
&\quad \left[\sum_{L=1}^{i-1}\left(P^s_{L-1/2} + P^b_{L-1/2}\right) + \frac{1}{2}\left(P^s_{i-1/2} + P^b_{i-1/2}\right)\right] + \left(- W_{i-1} + W_i\right) \\
&\quad \Big[\sum_{L=1}^{i-1}\left(K^s_{L-1/2}U^s_{L-1/2} + K^b_{L-1/2}U^b_{L-1/2}\right) + \frac{1}{2}\Big(K^s_{i-1/2}U^s_{i-1/2} \\
&\quad + K^b_{i-1/2}U^b_{i-1/2}\Big)\Big] + \left(- W_i + W_{i+1}\right)\Big[\sum_{L=1}^{i}\Big(P^s_{L-1/2} + P^b_{L-1/2} \\
&\quad + \frac{1}{2}\left(P^s_{i+1/2} + P^b_{i+1/2}\right)\Big] - \left(- W_i + W_{i+1}\right)\Big[\sum_{L=1}^{i}\Big(K^s_{L-1/2}U^s_{L-1/2} \\
&\quad + K^b_{L-1/2}U^b_{L-1/2}\Big) + \frac{1}{2}\left(K^s_{i+1/2}U^s_{i+1/2} + K^b_{i+1/2}U^b_{i+1/2}\right)\Big] \\
&\quad - \left(C^s_{i-1/2} + a^s_{i-1/2}\right)K^s_{i-1/2}U^s_{i-1/2} + \left(C^b_{i-1/2} + a^b_{i-1/2}\right)K^b_{i-1/2}U^b_{i-1/2} \\
&\quad + \left(C^s_{i+1/2} + a^s_{i+1/2}\right)K^s_{i+1/2}U^s_{i+1/2} - \left(C^b_{i+1/2} + a^b_{i+1/2}\right)K^b_{i+1/2}U^b_{i+1/2} \\
&\quad = hQ_i - hS_iW_i - \frac{1}{2}\left(T^s_{i-1} + T^b_{i-1} - T^s_{i+1} - T^b_{i+1}\right) - \frac{1}{2}\Big(R^s_{i-1} \\
&\quad + R^b_{i-1}\Big)\theta_{i-1} + \frac{1}{2}\left(R^s_{i+1} + R^b_{i+1}\right)\theta_{i+1} - P^s_{i-1/2}C^s_{i-1/2}
\end{aligned}$$

$$+ P^b_{i-1/2}C^b_{i-1/2} + P^s_{i+1/2}C^s_{i+1/2} - P^b_{i+1/2}C^b_{i+1/2} \qquad (3.21)$$

The N^s and N^b terms in Eq 3.21 can be eliminated by substitution of equations of the form of Eq 3.2. Also, the M^s and M^b terms can be eliminated by using the moment-curvature relationship which is given in Eqs 3.22 and 3.23. The terms F^s and F^b are equal to the products E^sI^s and E^bI^b respectively.

$$M^s_i = \frac{F^s_i}{h^2}\left(W_{i-1} - 2W_i + W_{i+1}\right) \qquad (3.22)$$

$$M^b_i = \frac{F^b_i}{h^2}\left(W_{i-1} - 2W_i + W_{i+1}\right) \qquad (3.23)$$

When Eqs 3.22 and 3.23 are substituted into Eq 3.21, the third governing difference equation is obtained.

$$\begin{aligned}
&\left(F^s_{i-1} + F^b_{i-1}\right)\left(W_{i-2} - 2W_{i-1} + W_i\right) - 2\left(F^s_i + F^b_i\right)\left(W_{i-1} - 2W_i + W_{i+1}\right) \\
&\quad + \left(F^s_{i+1} + F^b_{i+1}\right)\left(W_i - 2W_{i+1} + W_{i+2}\right) - \left(- U^s_{i-3/2} + U^s_{i-1/2}\right) \\
&\quad A^s_{i-1}E^s_{i-1}C^s_{i-1}h + \left(- U^b_{i-3/2} + U^b_{i-1/2}\right) A^b_{i-1}E^b_{i-1}C^b_{i-1}h + 2\,(- U^s_{i-1/2} \\
&\quad + U^s_{i+1/2})\, A^s_iE^s_iC^s_ih - 2\left(- U^b_{i-1/2} + U^b_{i+1/2}\right) A^b_iE^b_iC^b_ih - (- U^s_{i+1/2} \\
&\quad + U^s_{i+3/2})\, A^s_{i+1}E^s_{i+1}C^s_{i+1}h + \left(- U^b_{i+1/2} + U^b_{i+3/2}\right) A^b_{i+1}E^b_{i+1}C^b_{i+1}h \\
&\quad - \left(- W_{i-1} + W_i\right)\left[\sum_{L=1}^{i-1}\left(P^s_{L-1/2} + P^b_{L-1/2}\right) + \frac{1}{2}\left(P^s_{i-1/2} + P^b_{i-1/2}\right)\right] h^2 \\
&\quad + \left(- W_{i-1} + W_i\right)[\sum_{L=1}^{i-1}\left(K^s_{L-1/2}U^s_{L-1/2} + K^b_{L-1/2}U^b_{L-1/2}\right) + \frac{1}{2}\,(K^s_{i-1/2}U^s_{i-1/2} \\
&\quad + K^b_{i-1/2}U^b_{i-1/2})] \, h^2 + \left(- W_i + W_{i+1}\right) [\sum_{L=1}^{i}\left(P^s_{L-1/2} + P^b_{L-1/2}\right)
\end{aligned}$$

$$+ \frac{1}{2}\left(P^s_{i+1/2} + P^b_{i+1/2}\right)\Big] h^2 - \left(- W_i + W_{i+1}\right) \Big[\sum_{L=1}^{i} \Big(K^s_{L-1/2}U^s_{L-1/2}$$

$$+ K^b_{L-1/2}U^b_{L-1/2}\Big) + \frac{1}{2}\left(K^s_{i+1/2}U^s_{i+1/2} + K^b_{i+1/2}U^b_{i+1/2}\right)\Big] h^2 - \Big(C^s_{i-1/2}$$

$$+ a^s_{i-1/2}\Big) h^2 K^s_{i-1/2}U^s_{i-1/2} + \left(C^b_{i-1/2} + a^b_{i-1/2}\right) h^2 K^b_{i-1/2}U^b_{i-1/2}$$

$$+ \left(C^s_{i+1/2} + a^s_{i+1/2}\right) h^2 K^s_{i+1/2}U^s_{i+1/2} - \left(C^b_{i+1/2} + a^b_{i+1/2}\right) h^2 K^b_{i+1/2}$$

$$U^b_{i+1/2} = h^3 Q_i - h^3 S_i W_i - \frac{h^2}{2}\left(T^s_{i-1} + T^b_{i-1} - T^s_{i+1} - T^b_{i+1}\right)$$

$$- \frac{h^2}{2}\left(R^s_{i-1} + R^b_{i-1}\right)\theta_{i-1} + \frac{h^2}{2}\left(R^s_{i+1} + R^b_{i+1}\right)\theta_{i+1} + h^2\Big(- P^s_{i-1/2}C^s_{i-1/2}$$

$$+ P^b_{i-1/2}C^b_{i-1/2} + P^s_{i+1/2}C^s_{i+1/2} - P^b_{i+1/2}C^b_{i+1/2}\Big) \qquad (3.24)$$

Nonlinear Terms in the Moment-Equilibrium Equation

In Eq 3.24, the terms $\left(- W_{i-1} + W_i\right) \Big[\sum_{L=1}^{i-1} \left(K^s_{L-1/2}U^s_{L-1/2} + K^b_{L-1/2}U^b_{L-1/2}\right)$ $+ \frac{1}{2}\left(K^s_{i-1/2}U^s_{i-1/2} + K^b_{i-1/2}U^b_{i-1/2}\right)\Big] h^2$ and $\left(- W_i + W_{i+1}\right) \Big[\sum_{L=1}^{i} \Big(K^s_{L-1/2}U^s_{L-1/2}$ $+ K^b_{L-1/2}U^b_{L-1/2}\Big) + \frac{1}{2}\left(K^s_{i+1/2}U^s_{i+1/2} + K^b_{i+1/2}U^b_{i+1/2}\right)\Big] h^2$ are nonlinear because they involve products of two unknowns. The nonlinearity occurs because the horizontal springs cause the final axial load distribution to be dependent on both vertical deflections and horizontal displacements. For problems in which there are no horizontal springs, the terms drop out and the equation is linear. For many practical problems this will be the case. In Chapter 5, example problems will be shown in which the presence of horizontal springs does not affect the linearity of Eq 3.24. In these problems, the horizontal spring fixes the structure's location in space and does not affect the axial load distribution.

An iterative solution must be used when Eq 3.24 is nonlinear. In the iterative solution, the products of the horizontal spring constants and the horizontal displacements are computed and treated as known stiffness terms in Eq 3.24. Zero horizontal displacements are assumed for the first iteration. In each successive iteration, the horizontal displacements from the previous iteration are used. The process is continued until the computed displacements from two successive iterations agree to within a specified tolerance.

CHAPTER 4. COMPUTATION OF RESULTS

Contents of the Chapter

In this chapter the load-deflection equations that have been derived are converted to a form that is convenient for a computer solution. The system of equations that results when the load-deflection equations are written about every station in the structure is shown in matrix form, and the elimination procedure used to solve the set of equations is described. Boundary conditions are discussed and the accuracy of the solution is evaluated. The formulas used to compute bending moment, axial load, slip, force per connector, shear, and support reaction are presented.

Conversion of Equations to Standard Form

In this section the three load-deflection equations are converted to a standard form that facilitates visualization of the elimination procedure used to solve the equations.

Equation 3.11 may be written in the form

$$a_i^1 U^s_{i-3/2} + a_i^2 U^b_{i-3/2} + a_i^3 W_{i-1} + a_i^4 U^s_{i-1/2} + a_i^5 U^b_{i-1/2} + a_i^6 W_i$$

$$+ a_i^7 U^s_{i+1/2} + a_i^8 U^b_{i+1/2} + a_i^9 W_{i+1} = a_i^{10} \tag{4.1}$$

In this equation the coefficients are defined

$$a_i^1 = \frac{1}{h} A^s_{i-1} E^s_{i-1}$$

$$a_i^2 = 0$$

$$a_i^3 = \frac{1}{h}\left(C^s_{i-1/2} + C^b_{i-1/2}\right) K^c_{i-1/2}$$

$$a_i^4 = -\left[\frac{1}{h}\left(A^s_{i-1}E^s_{i-1} + A^s_i E^s_i\right) + K^s_{i-1/2} + K^c_{i-1/2}\right]$$

$$a_i^5 = K^c_{i-1/2} \tag{4.2}$$

$$a_i^6 = -\frac{1}{h}\left(C^s_{i-1/2} + C^b_{i-1/2}\right) K^c_{i-1/2}$$

$$a_i^7 = \frac{1}{h} A_i^s E_i^s$$

$$a_i^8 = 0$$

$$a_i^9 = 0$$

$$a_i^{10} = -P^s_{i-1/2}$$

Equation 3.12 may be written

$$b_i^1 U^b_{i-3/2} + b_i^2 W_{i-1} + b_i^3 U^s_{i-1/2} + b_i^4 U^b_{i-1/2} + b_i^5 W_i + b_i^6 U^s_{i+1/2} + b_i^7 U^b_{i+1/2} + b_i^8 W_{i+1} = b_i^9 \tag{4.3}$$

The coefficients in Eq 4.3 have the following values

$$b_i^1 = \frac{1}{h} A^b_{i-1} E^b_{i-1}$$

$$b_i^2 = -\frac{1}{h}\left(C^s_{i-1/2} + C^b_{i-1/2}\right) K^c_{i-1/2}$$

$$b_i^3 = K^c_{i-1/2}$$

$$b_i^4 = -\left[\frac{1}{h}\left(A^b_{i-1}E^b_{i-1} + A^b_i E^b_i\right) + K^b_{i-1/2} + K^c_{i-1/2}\right]$$

$$b_i^5 = \frac{1}{h}\left(C^s_{i-1/2} + C^b_{i-1/2}\right) K^c_{i-1/2} \tag{4.4}$$

$$b_i^6 = 0$$

$$b_i^7 = \frac{1}{h} A_i^b E_i^b$$

$$b_i^8 = 0$$

$$b_i^9 = - P^b_{i-1/2}$$

Equation 3.24 may be written in a similar form

$$\begin{aligned} & c_i^1 W_{i-2} + c_i^2 U^s_{i-3/2} + c_i^3 U^b_{i-3/2} + c_i^4 W_{i-1} + c_i^5 U^s_{i-1/2} + c_i^6 U^b_{i-1/2} \\ & + c_i^7 W_i + c_i^8 U^s_{i+1/2} + c_i^9 U^b_{i+1/2} + c_i^{10} W_{i+1} + c_i^{11} U^s_{i+3/2} \\ & + c_i^{12} U^b_{i+3/2} + c_i^{13} W_{i+2} = c_i^{14} \end{aligned} \tag{4.5}$$

The coefficients are defined

$$c_i^1 = F^s_{i-1} + F^b_{i-1} - 0.25h \left(R^s_{i-1} + R^b_{i-1}\right)$$

$$c_i^2 = hC^s_{i-1}A^s_{i-1}E^s_{i-1}$$

$$c_i^3 = - hC^b_{i-1}A^b_{i-1}E^b_{i-1}$$

$$\begin{aligned} c_i^4 = & - 2 \left(F^s_{i-1} + F^b_{i-1} + F^s_i + F^b_i\right) + \sum_{L=1}^{i-1} \left(P^s_{L-1/2} + P^b_{L-1/2}\right) h^2 \\ & + \frac{1}{2} \left(P^s_{i-1/2} + P^b_{i-1/2}\right) h^2 - \sum_{L=1}^{i-1} \left(K^s_{L-1/2}U^s_{L-1/2} + K^b_{L-1/2}U^b_{L-1/2}\right) h^2 \\ & - \frac{1}{2} \left(K^s_{i-1/2}U^s_{i-1/2} + K^b_{i-1/2}U^b_{i-1/2}\right) h^2 \end{aligned}$$

$$c_i^5 = - h \left[C^s_{i-1}A^s_{i-1}E^s_{i-1} + 2C^s_iA^s_iE^s_i + h \left(C^s_{i-1/2} + a^s_{i-1/2}\right) K^s_{i-1/2}\right]$$

$$c_i^6 = h \left[C^b_{i-1}A^b_{i-1}E^b_{i-1} + 2C^b_iA^b_iE^b_i + h \left(C^b_{i-1/2} + a^b_{i-1/2}\right) K^b_{i-1/2}\right]$$

$$\begin{aligned} c_i^7 = & F^s_{i-1} + F^b_{i-1} + 4 \left(F^s_i + F^b_i\right) + F^s_{i+1} + F^b_{i+1} + h^3 S_i + 0.25h \Big(R^s_{i-1} \\ & + R^b_{i-1} + R^s_{i+1} + R^b_{i+1}\Big) - 2 \sum_{L=1}^{i-1} h^2 \left(P^s_{L-1/2} + P^b_{L-1/2}\right) - \frac{3}{2} h^2 \Big(P^s_{i-1/2} \end{aligned}$$

$$+ P^b_{i-1/2}\Big) - \frac{h^2}{2}\left(P^s_{i+1/2} + P^b_{i+1/2}\right) + 2\sum_{L=1}^{i-1} h^2\Big(K^s_{L-1/2}U^s_{L-1/2}$$

$$+ K^b_{L-1/2}U^b_{L-1/2}\Big) + \frac{3}{2}\left(K^s_{i-1/2}U^s_{i-1/2} + K^b_{i-1/2}U^b_{i-1/2}\right) h^2$$

$$+ \frac{1}{2}\left(K^s_{i+1/2}U^s_{i+1/2} + K^b_{i+1/2}U^b_{i+1/2}\right) h^2 \qquad (4.6)$$

$$c^8_i = h\left[2C^s_i A^s_i E^s_i + C^s_{i+1}A^s_{i+1}E^s_{i+1} + h\left(C^s_{i+1/2} + a^s_{i+1/2}\right) K^s_{i+1/2}\right]$$

$$c^9_i = -h\left[2C^b_i A^b_i E^b_i + C^b_{i+1}A^b_{i+1}E^b_{i+1} + h\left(C^b_{i+1/2} + a^b_{i+1/2}\right) K^b_{i+1/2}\right]$$

$$c^{10}_i = -2\left(F^s_i + F^b_i + F^s_{i+1} + F^b_{i+1}\right) + \sum_{L=1}^{i}\left(P^s_{L-1/2} + P^b_{L-1/2}\right) h^2$$

$$+ \frac{1}{2}\left(P^s_{i+1/2} + P^b_{i+1/2}\right) h^2 - \sum_{L=1}^{i}\left(K^s_{L-1/2}U^s_{L-1/2} + K^b_{L-1/2}U^b_{L-1/2}\right) h^2$$

$$- \frac{1}{2}\left(K^s_{i+1/2}U^s_{i+1/2} + K^b_{i+1/2}U^b_{i+1/2}\right) h^2$$

$$c^{11}_i = -hC^s_{i+1}A^s_{i+1}E^s_{i+1}$$

$$c^{12}_i = hC^b_{i+1}A^b_{i+1}E^b_{i+1}$$

$$c^{13}_i = F^s_{i+1} + F^b_{i+1} - 0.25h\left(R^s_{i+1} + R^b_{i+1}\right)$$

$$c^{14}_i = h^3 Q_i - 0.5h^2\left(T^s_{i-1} + T^b_{i-1} - T^s_{i+1} - T^b_{i+1}\right) + h^2\Big(-C^s_{i-1/2}P^s_{i-1/2}$$

$$+ C^b_{i-1/2}P^b_{i-1/2} + C^s_{i+1/2}P^s_{i+1/2} - C^b_{i+1/2}P^b_{i+1/2}\Big)$$

The Pattern of the Equations

Each of the three equations (Eqs 4.1, 4.3, and 4.5) is a valid expression for each station in the model. When the equations are written about every station, a system of simultaneous equations results which can be written in matrix form as shown in Fig 10. All of the terms in the coefficient matrix are grouped in a thirteen-element wide diagonal band.

The set of simultaneous equations is solved by Gaussian elimination. An extremely fast and efficient solution is obtained because of the large number of zeroes in the square coefficient matrix. Those terms that are zeroes before the solution begins are not even considered during the elimination process. Therefore, the number of algebraic operations that must be performed is greatly reduced. It is not possible to take advantage of the zero coefficients a_i^8, a_i^9, and b_i^8 because the value of these coefficients is altered by the elimination procedure. There are three sets of coefficients used in the matrix; therefore, three back-substitution formulas are used. These formulas are also simplified by the diagonal banding of the matrix. The back-substitution formulas are

$$\begin{aligned} W_i = & -\frac{1}{c_i^7}\Big(c_i^8 U^s_{i+1/2} + c_i^9 U^b_{i+1/2} + c_i^{10} W_{i+1} + c_i^{11} U^s_{i+3/2} + c_i^{12} U^b_{i+3/2} \\ & + c_i^{13} W_{i+2} - c_i^{14}\Big) \end{aligned} \tag{4.7}$$

$$U^b_{i-1/2} = -\frac{1}{b_i^4}\left(b_i^5 W_i + b_i^6 U^s_{i+1/2} + b_i^7 U^b_{i+1/2} + b_i^8 W_{i+1} - b_i^9\right) \tag{4.8}$$

$$\begin{aligned} U^s_{i-1/2} = & -\frac{1}{a_i^4}\Big(a_i^5 U^b_{i-1/2} + a_i^6 W_i + a_i^7 U^s_{i+1/2} + a_i^8 U^b_{i+1/2} \\ & + a_i^9 W_{i+1} - a_i^{10}\Big) \end{aligned} \tag{4.9}$$

Boundaries and Specified Conditions

The method of solution presented in this text is extremely versatile with regard to boundary conditions. Some of the most common types are discussed in this section.

A zero bending moment occurs at a point when the curvature and axial loads

COEFFICIENT MATRIX

DEFLECTION MATRIX

LOAD MATRIX

$$\begin{bmatrix}
 & a^{1}_{i-1} & a^{2}_{i-1} & a^{3}_{i-1} & a^{4}_{i-1} & a^{5}_{i-1} & a^{6}_{i-1} & a^{7}_{i-1} & a^{8}_{i-1} & a^{9}_{i-1} & & & & & & & & & & & & \\
 & & b^{1}_{i-1} & b^{2}_{i-1} & b^{3}_{i-1} & b^{4}_{i-1} & b^{5}_{i-1} & b^{6}_{i-1} & b^{7}_{i-1} & b^{8}_{i-1} & & & & & & & & & & & & \\
c^{1}_{i-1} & c^{2}_{i-1} & c^{3}_{i-1} & c^{4}_{i-1} & c^{5}_{i-1} & c^{6}_{i-1} & c^{7}_{i-1} & c^{8}_{i-1} & c^{9}_{i-1} & c^{10}_{i-1} & c^{11}_{i-1} & c^{12}_{i-1} & c^{13}_{i-1} & & & & & & & & & \\
 & & & & a^{1}_{i} & a^{2}_{i} & a^{3}_{i} & a^{4}_{i} & a^{5}_{i} & a^{6}_{i} & a^{7}_{i} & a^{8}_{i} & a^{9}_{i} & & & & & & & & & \\
 & & & & & b^{1}_{i} & b^{2}_{i} & b^{3}_{i} & b^{4}_{i} & b^{5}_{i} & b^{6}_{i} & b^{7}_{i} & b^{8}_{i} & & & & & & & & & \\
 & & & c^{1}_{i} & c^{2}_{i} & c^{3}_{i} & c^{4}_{i} & c^{5}_{i} & c^{6}_{i} & c^{7}_{i} & c^{8}_{i} & c^{9}_{i} & c^{10}_{i} & c^{11}_{i} & c^{12}_{i} & c^{13}_{i} & & & & & & \\
 & & & & & & & a^{1}_{i+1} & a^{2}_{i+1} & a^{3}_{i+1} & a^{4}_{i+1} & a^{5}_{i+1} & a^{6}_{i+1} & a^{7}_{i+1} & a^{8}_{i+1} & a^{9}_{i+1} & & & & & & \\
 & & & & & & & & b^{1}_{i+1} & b^{2}_{i+1} & b^{3}_{i+1} & b^{4}_{i+1} & b^{5}_{i+1} & b^{6}_{i+1} & b^{7}_{i+1} & b^{8}_{i+1} & & & & & & \\
 & & & & & & c^{1}_{i+1} & c^{2}_{i+1} & c^{3}_{i+1} & c^{4}_{i+1} & c^{5}_{i+1} & c^{6}_{i+1} & c^{7}_{i+1} & c^{8}_{i+1} & c^{9}_{i+1} & c^{10}_{i+1} & c^{11}_{i+1} & c^{12}_{i+1} & c^{13}_{i+1} & & & \\
 & & & & & & & & & & a^{1}_{i+2} & a^{2}_{i+2} & a^{3}_{i+2} & a^{4}_{i+2} & a^{5}_{i+2} & a^{6}_{i+2} & a^{7}_{i+2} & a^{8}_{i+2} & a^{9}_{i+2} & & & \\
 & & & & & & & & & & & b^{1}_{i+2} & b^{2}_{i+2} & b^{3}_{i+2} & b^{4}_{i+2} & b^{5}_{i+2} & b^{6}_{i+2} & b^{7}_{i+2} & b^{8}_{i+2} & & & \\
 & & & & & & & & & c^{1}_{i+2} & c^{2}_{i+2} & c^{3}_{i+2} & c^{4}_{i+2} & c^{5}_{i+2} & c^{6}_{i+2} & c^{7}_{i+2} & c^{8}_{i+2} & c^{9}_{i+2} & c^{10}_{i+2} & c^{11}_{i+2} & c^{12}_{i+2} & c^{13}_{i+2}
\end{bmatrix}
\begin{Bmatrix}
W_{i-3} \\ U^{s}_{i-2\frac{1}{2}} \\ U^{b}_{i-2\frac{1}{2}} \\ W_{i-2} \\ U^{s}_{i-1\frac{1}{2}} \\ U^{b}_{i-1\frac{1}{2}} \\ W_{i-1} \\ U^{s}_{i-\frac{1}{2}} \\ U^{b}_{i-\frac{1}{2}} \\ W_{i} \\ U^{s}_{i+\frac{1}{2}} \\ U^{b}_{i+\frac{1}{2}} \\ W_{i+1} \\ U^{s}_{i+1\frac{1}{2}} \\ U^{b}_{i+1\frac{1}{2}} \\ W_{i+2} \\ U^{s}_{i+2\frac{1}{2}} \\ U^{b}_{i+2\frac{1}{2}} \\ W_{i+3} \\ U^{s}_{i+3\frac{1}{2}} \\ U^{b}_{i+3\frac{1}{2}} \\ W_{i+4}
\end{Bmatrix}
=
\begin{Bmatrix}
a^{10}_{i-1} \\ b^{9}_{i-1} \\ c^{14}_{i-1} \\ a^{10}_{i} \\ b^{9}_{i} \\ c^{14}_{i} \\ a^{10}_{i+1} \\ b^{9}_{i+1} \\ c^{14}_{i+1} \\ a^{10}_{i+2} \\ b^{9}_{i+2} \\ c^{14}_{i+2}
\end{Bmatrix}$$

Fig 10. The system of equations written as a matrix equation.

in a structure are both equal to zero. This condition is automatically created at each end of the structure. When Eq 4.5 is written one station past the ends of the structure, some of the terms in the equation are equal to zero because the physical properties of the system are zero past the ends (see Fig 11). The remaining terms specify that the second derivative of vertical deflection with respect to distance (curvature) is equal to zero. A zero axial load is produced when the first derivative of horizontal displacement with respect to distance is set equal to zero (see Eq 3.2). This condition is also created automatically by the physical properties of the system.

A vertical deflection may be specified at any point in the structure by either of two methods. One method is to input a foundation spring of sufficient magnitude to insure a zero deflection. The other approach is to manipulate the matrix coefficients. A deflection can be specified at any Station i simply by the clearing of all of the coefficients in Eq 4.5 to zero except C_i^7 which is set equal to 1.0 and C_i^{14} which is set equal to the desired deflection.

The fixity (resistance to rotation) of a member may be controlled at any point by the specification of a rotational restraint. A rotational spring adds a bending moment to the system that is equal to the product of the slope at the point and the specified spring constant. A very large rotational restraint causes the slope at that point to be essentially zero. The zero curvature that is automatically created at the end of the member is over-ridden by the specification of a rotational restraint at the end.

Horizontal displacements can be controlled by the specification of horizontal springs. No provision is made in the present analysis to control the displacements by manipulation of the matrix coefficients.

To correctly model a cantilever such as the one shown in Fig 12a, the

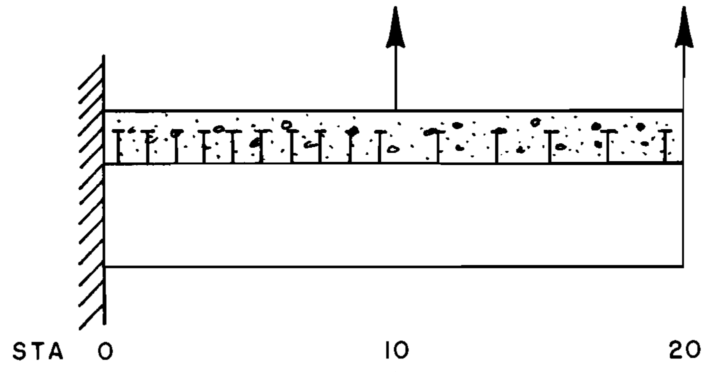
COEFFICIENT MATRIX

DEFLECTION MATRIX

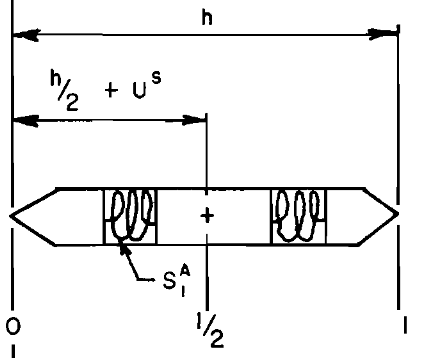
LOAD MATRIX

$$\left[\begin{array}{ccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & c^7_{-1} & c^8_{-1} & c^9_{-1} & c^{10}_{-1} & c^{11}_{-1} & c^{12}_{-1} & c^{13}_{-1} & & & & & & \\
 & & & & 0 & 0 & 0 & a^4_0 & 0 & 0 & a^7_0 & & & & & & & & \\
 & & & & & 0 & 0 & 0 & b^4_0 & 0 & 0 & b^7_0 & & & & & & & \\
 & & & 0 & 0 & 0 & c^4_0 & c^5_0 & c^6_0 & c^7_0 & c^8_0 & c^9_0 & c^{10}_0 & c^{11}_0 & c^{12}_0 & c^{13}_0 & & & \\
 & & & & & & & a^1_1 & a^2_1 & a^3_1 & a^4_1 & a^5_1 & a^6_1 & a^7_1 & a^8_1 & a^9_1 & & & \\
 & & & & & & & & b^1_1 & b^2_1 & b^3_1 & b^4_1 & b^5_1 & b^6_1 & b^7_1 & b^8_1 & & & \\
 & & & & & & c^1_1 & c^2_1 & c^3_1 & c^4_1 & c^5_1 & c^6_1 & c^7_1 & c^8_1 & c^9_1 & c^{10}_1 & c^{11}_1 & c^{12}_1 & c^{13}_1 \\
 & & & & & & & & & & & & \cdot & & & & & & \\
 & & & & & & & & & & & & \cdot & & & & & & \\
 & & & & & & & & & & & & \cdot & & & & & & \\
 & & & & & & & & & & & & \cdot & & & & & &
\end{array}\right]
\left\{\begin{array}{c}
W_{-3} \\ U^s_{-2\frac{1}{2}} \\ U^b_{-2\frac{1}{2}} \\ W_{-2} \\ U^s_{-1\frac{1}{2}} \\ U^b_{-1\frac{1}{2}} \\ W_{-1} \\ U^s_{-\frac{1}{2}} \\ U^b_{-\frac{1}{2}} \\ W_0 \\ U^s_{\frac{1}{2}} \\ U^b_{\frac{1}{2}} \\ W_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot
\end{array}\right\}
=
\left\{\begin{array}{c}
c^{14}_{-1} \\ a^{10}_0 \\ b^9_0 \\ c^{14}_0 \\ a^{10}_1 \\ b^9_1 \\ c^{14}_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot
\end{array}\right\}$$

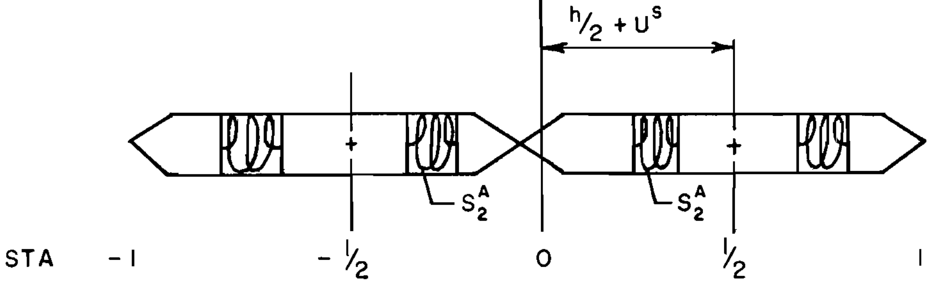
Fig 11. The equations at the end of the structure.



a. The physical problem.



b. A slab bar with zero displacement at Station 0.



c. A slab bar with zero displacement at Station -1/2.

Fig 12. A cantilever beam.

slope and horizontal displacements for both slab and beam should be set equal to zero at the member's end. A large rotational restraint can be used to enforce a slope that is essentially zero. It is not possible to set the displacements equal to zero at Station 0 because they are defined only at the half stations. It is possible, by adjustment of the axial spring stiffness, to set the displacement at Station -1/2 and still maintain the correct displacement at Station +1/2. If the displacement of Station 0 could be set equal to zero and an axial tension N^s were applied, then a displacement U^s would exist at Station 1/2 in Fig 12b. This relationship can be expressed as

$$U^s = \frac{N^s}{S_1^A} \tag{4.10}$$

where

$$S_1^A = \frac{2}{h} A_1 E_1 \tag{4.11}$$

In Fig 12c, the displacement is zero at Station -1/2, but the same displacement U^s is maintained at Station 1/2. The axial tension is still N^s , but the springs have changed to

$$S_2^A = \frac{2}{h} A_2 E_2 \tag{4.12}$$

The equivalent spring for the two springs in series is

$$S_E^A = \frac{\left(S_2^A\right)^2}{S_2^A + S_2^A} \tag{4.13}$$

$$S_E^A = \frac{1}{h} A_2 E_2 \tag{4.14}$$

Since U^s is the same for both cases

$$S_E^A = S_1^A \tag{4.15}$$

from which it is seen that

$$A_2E_2 = 2A_1E_1$$

Thus, to correctly model a cantilever, the products A^sE^s and A^bE^b should be twice the normal amount at the station at the point of fixity.

Accuracy of the Solution

Approximation errors are introduced when the finite-element model is substituted for the real structure. This type of error can be reduced to any desired level by dividing the model into more increments. An excessive number of increments should be avoided because computation time increases in simple proportion to the number of increments. Experience will enable the user to determine the optimum number of increments for his desired accuracy.

Because of the large number of arithmetic operations involved in the solution, round-off errors may occur. A CDC 1604 computer using approximately 11 decimal digits has been used to verify the method of solution, and no significant errors have been observed in the practical problems that have been solved. Errors can be caused by the specification of unreasonably large values of certain of the physical properties. A good rule-of-thumb is that the magnitude of a rotational restraint should never be greater than 10^3 times the magnitude of the sum of the bending stiffness of the members at that station. Similarly, the shear connector modulus should not exceed 10^2 times the sum of the bending stiffnesses.

Results

After the vertical deflection and horizontal displacements have been computed, bending moment, axial load, slip, force per shear connector, shear, and support reaction can easily be determined. Bending moment is computed for the slab and beam by Eqs 3.22 and 3.23. The formula used to compute the axial tension in the slab is given by Eq 3.2. The formula used to compute the beam axial tension is not shown because it is very similar to Eq 3.2. An expression for slip is given by Eq 3.10. The force per shear connector is simply the product of the slip and the shear connector modulus. An expression for the shear in the slab is obtained by a summation of moments about the center of the slab bar in Fig 9a. The formula is

$$V^s_{i-1/2} = \frac{1}{h}\Big[-M^s_{i-1} + M^s_i - K^c_{i-1/2}\gamma_{i-1/2}C^s_{i-1/2} + U^s_{i-1/2}K^s_{i-1/2}a^s_{i-1/2} - \frac{1}{2}\left(N^s_{i-1} + N^s_i\right)\left(-W_{i-1} + W_i\right)\Big] \qquad (4.16)$$

A similar formula can be derived for the beam shear. Two formulas are used to compute support reaction. At any station where a deflection is specified, the support reaction is

$$\begin{aligned} Q^R_i = {} & - V^s_{i-1/2} - V^b_{i-1/2} + V^s_{i+1/2} + V^b_{i+1/2} - Q_i \\ & + \frac{1}{2h}\left(T^s_{i-1} + T^b_{i-1} - T^s_{i+1} - T^b_{i+1}\right) - \frac{1}{4h^2}\Big[\left(R^s_{i-1} + R^b_{i-1}\right)W_{i-2} \\ & - \left(R^s_{i-1} + R^b_{i-1} + R^s_{i+1} + R^b_{i+1}\right)W_i + \left(R^s_{i+1} + R^b_{i+1}\right)W_{i+2}\Big] \qquad (4.17) \end{aligned}$$

Equation 4.17 can be derived by a summation of the vertical forces on a joint. At the other stations in the structure, the support reaction is simply the product of the vertical deflection and the foundation spring stiffness

$$Q^R_i = S_iW_i \qquad (4.18)$$

CHAPTER 5. THE COMPUTER PROGRAM

General

Program COMBM 1 (COMposite BeaM - 1^{st} version) is written in FORTRAN-63 language for the Control Data Corporation 1604 and 6600 computers. With minor changes, the program would be compatible with IBM computers. One subroutine, INTERP4, is included in the program. Compile times for the program are approximately two minutes for the 1604 computer and approximately 13 seconds for the 6600 computer. The program storage requirement is 21,071 words. A listing of the program and the definitions of the symbols used in the program are included in Appendix 2 and Appendix 3.

To describe the physical problem to the computer, it is first necessary to divide the member into a number of equal increments, which are designated by station numbers. Any number of increments 200 or less may be used. The left end of the structure should be located at Station 0. In Chapter 3 it was pointed out that some of the physical properties of the system are associated with the joints (full stations) while other properties are defined in the bars (half stations). To facilitate the description of problems, the half-station numbering system has been deleted. In this program each bar in the model has the same station number as the joint to the right of it.

All loads and restraints are defined at discrete points in the finite-element model. Distributed loads and restraints from one-half of the increment on each side of the joint are "lumped" at the joint. Therefore, end stations should receive half-values of the distributed effects. The input of distributed data is facilitated by SUBROUTINE INTERP4. Given a value at the initial and final stations in a distribution sequence, INTERP4 performs a linear interpolation between these extreme values and stores the appropriate value at each intermediate station. Concentrated loads that occur between stations should be split by the user to the two adjacent stations. The amount of load placed at each station should be inversely proportional to the distance between the station and the point of application of the load.

Any system of units may be used to describe the problem (for example, pounds and inches), but the system must be used consistently.

Procedure for Data Input

A Guide for Data Input is included in Appendix 1. The guide is designed so that additional copies may be furnished as separately bound extracts for routine use. A parallel study of the guide will help the reader understand the following discussion.

Any number of problems may be stacked and run together. The sequence of problems is preceded by two cards which describe the run. The first card of each problem contains the problem number and a brief description of the problem. The program continues working problems until a blank problem number is encountered; then, the run is terminated.

Tables of Data Input

Table 1 is the data-control table. It consists of a single card which must be input in each problem. The number of cards in the remaining tables and the data-hold options are specified in this table. The data-hold options allow the user to retain any of the data tables from the preceding problem. If Table 2 or 3 is held, it may not be modified, and the number of cards specified for it must be zero. Data in Tables 4, 5, 6, and 7 may be held and modified by the addition of new cards, but the total accumulated number of cards in each of these tables must be less than 100. The hold options for the various tables are independent of each other; however, care must be exercised in order to insure that data in the various tables are compatible.

In Table 2, the number of increments in the member and the increment length are specified. The number of increments must be 200 or less. For linear problems the remainder of the card is left blank. For nonlinear problems the maximum number of iterations must be specified in order to prevent excessive computation. The closure tolerance has the same units as the computed deflections. If the tolerance is unreasonably small, closure may be difficult to achieve. For most problems, a value in the range 1×10^{-6} to 1×10^{-8} inch is satisfactory. To encourage understanding of the solution process, the program requires that three monitor stations be specified.

Any desired vertical deflection may be specified for any station in the structure in Table 3. Each specification requires a separate card. A limit of 20 is placed on the number of specified deflections. The cards in this table may be stacked in any order.

Physical properties of the slab are described in Table 4. The properties include the modulus of elasticity, cross-section area, moment of inertia, distance from the neutral axis of the slab to the interface of the slab and beam, horizontal spring constant, and the distance from the neutral axis to the horizontal spring. The method used for description of distributed data is illustrated in Appendix 1. Half-values of the moment of inertia and cross-section area are automatically produced at the end of each distribution sequence. Half-values are not created for the modulus of elasticity because the bending stiffness (EI) and axial stiffness (EA) would then be only quarter-values. In addition, half-values are not created at the ends of distribution sequences for the distance from the neutral axis of the slab to the interface C^s since it would not be appropriate for this geometric property. The remaining values in the table are defined at the half-stations, and it is also not appropriate to have half-values at the ends of their distribution sequences. All of the values in Table 4 are accumulated algebraically in storage. There are no restrictions on the order of the cards, except that within a distribution sequence the stations must be in ascending order.

Physical properties of the beam are described in Table 5. The same comments as enumerated for the slab parameters also apply to the same beam parameters.

Transverse loads, foundation springs, and the modulus of the shear connectors are described in Table 6. The description of data in this table is very similar to Table 4. Half-values of transverse loads and foundation springs are created at the end of their distribution sequences.

Table 7 provides for the description of torques, rotational restraints, and longitudinal loads. The data-input rules of Table 4 apply to this table also. Torques and rotational restraints are always concentrated effects. Longitudinal loads can be either concentrated or distributed. Half-values are not automatically created for the longitudinal loads.

Error Messages

Checks for common types of data errors are included in the program. An error message which defines the message is printed if any of the following conditions occur:

(1) two deflections are specified at the same station,

(2) the allowable number of cards for an input table is exceeded, and

(3) the station numbers in a distribution sequence are out of order.

In addition to the specific error messages, a general purpose error message is provided for a number of unlikely errors. If the message "UNDESIGNATED ERROR STOP" is printed, the user must investigate the program to determine what caused the error. Any error detected by the program will cause the run to be abandoned. Specification of data past the ends of the structure will interfere with the automatically created boundary conditions and cause the solution to be in error. No check is provided for this type of error.

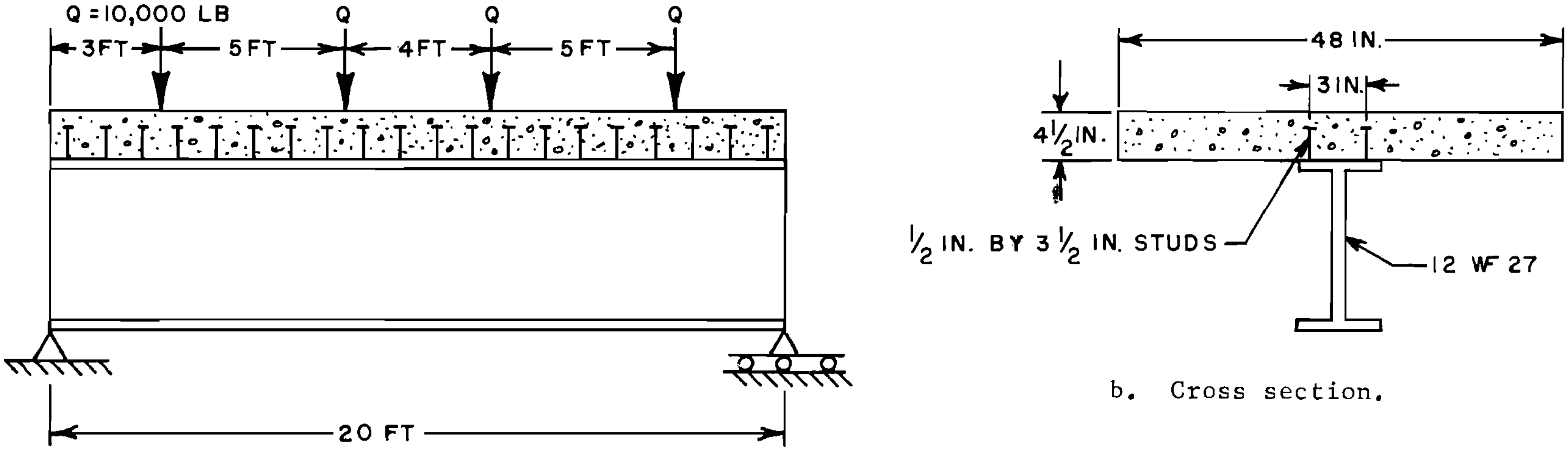
CHAPTER 6. EXAMPLE PROBLEMS

Purpose

A series of example problems are solved in this chapter in order to demonstrate the capabilities and prove the validity of the computer program. The first five problems illustrate the uses of the program. These problems are hypothetical, but they are typical of actual highway-bridge problems. In the sixth problem, the results computed by COMBM 1 are compared to the experimental results of Proctor (see Ref 13). In addition to the problems that are presented, each example structure has been analyzed for the limiting cases of complete shear interaction and no shear interaction. These limiting cases were analyzed with COMBM 1 and checked against a computer program developed by Matlock in Ref 10. Exact agreement was obtained. A listing of the input data is included in Appendix 5 and the computer output listing is included in Appendix 6.

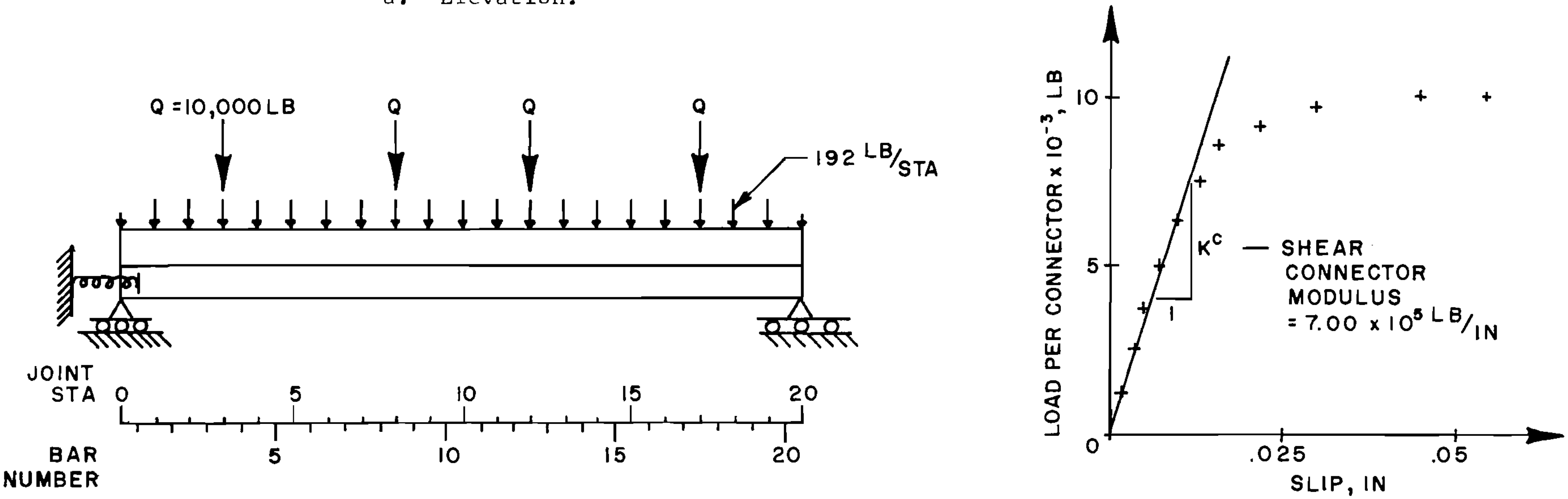
Example Problem 1. A Simply-Supported Composite Beam

This example problem demonstrates the method of analysis for a "shored" composite beam. A "shored" composite beam is one for which temporary supports are provided to carry the dead weight of the slab and beam during the setting period of the concrete. The structure analyzed in this problem is shown in Fig 13a. It is simply supported and has a span length of 20 ft. The member is composed of a 12 WF 27 beam and a 48-in by 4-1/2-in concrete slab. Light-weight concrete which weighs 110 lb/ft^3 and has a modulus of elasticity of 2.3×10^6 lb/in^2 is used in the slab. A modulus of elasticity of 2.9×10^7 lb/in^2 is assumed for the steel beam. Shear connection is provided by a double line of 1/2-in by 3-1/2-in welded stud shear connectors. The shear connectors are uniformly spaced at 1-ft intervals along the beam. A load-slip curve from Proctor (Ref 13) which was obtained from a push-out test on the shear connectors is



a. Elevation.

b. Cross section.



c. A model of the structure.

d. A load-slip curve.

Fig 13. A simply-supported composite beam.

shown in Fig 13d. The shear connector modulus is determined by the straight line through the linear region of the curve.

A model of the structure which has 20 increments is shown in Fig 13c. Simple supports at each end of the member are modeled by the specification of zero deflections at Stations 0 and 20. A horizontal spring is input at Station 0. This spring does not cause the problem to be nonlinear because the only effect of the spring is to fix the location of the structure in space; the axial load distribution is not affected. The maximum number of iterations, closure tolerance, and monitor stations are left blank because the problem is linear (the axial load is a function of vertical deflection only). Shear connectors are described from Station 1 to 20 because the connectors are properties related to the bars, which are designated by the same number as the joint to their right. The system of station numbers is shown in Fig 13c. The input value of shear connector modulus is twice the amount that is computed from Fig 13d because there are two connectors at each bar. Loads on the structure include the dead weight of the member itself plus the live loads shown in Fig 13c.

The deflections computed in Problem 1 are shown in Fig 14. Also shown are the deflected shapes of the structure for the cases of complete shear interaction and no shear interaction. Comparison of the curves shows that the shear connection used in Problem 1 is very close to the case of complete interaction. Problem 2, which is discussed in the following section, is closely related to Problem 1; therefore, the deflections computed in Problem 2 are also shown in Fig 14. The computed value "LOAD ON SHEAR CONNECTOR" which is printed in Table 9 is actually the load per bar and should be divided by the number of connectors per bar in order to obtain the load on each connector. This value should be compared to the load-slip curve to determine if the maximum allowable load or

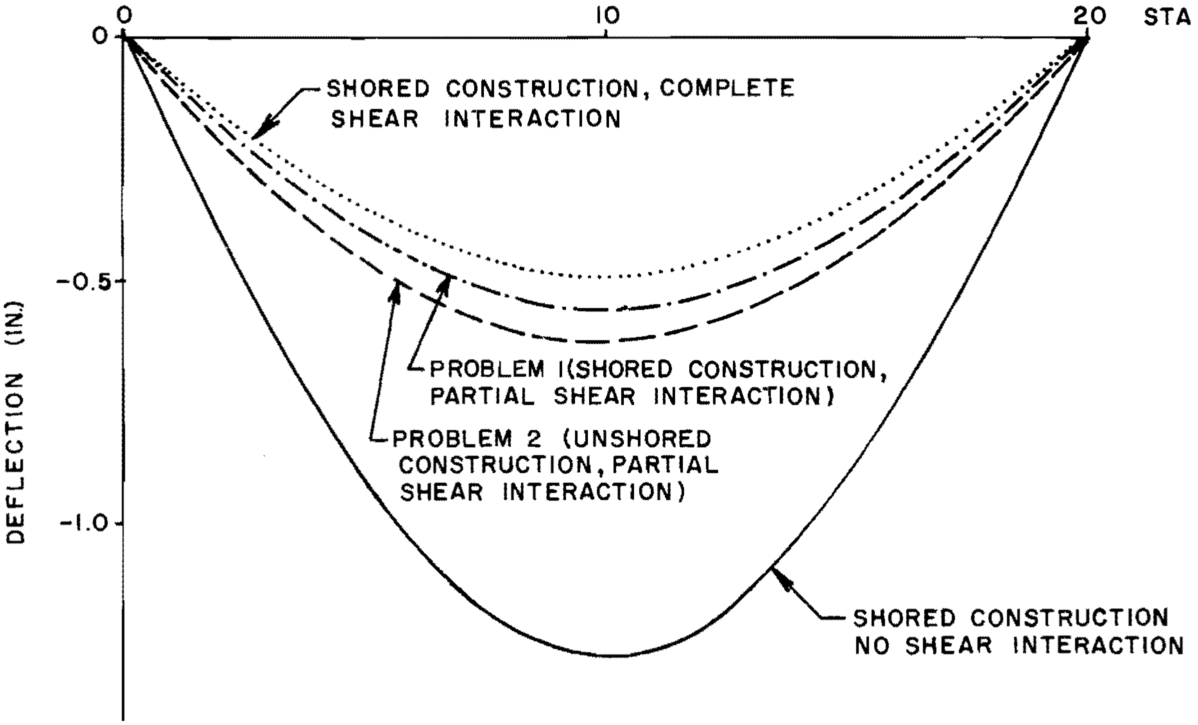


Fig 14. Deflected shapes for the structure of Problems 1 and 2.

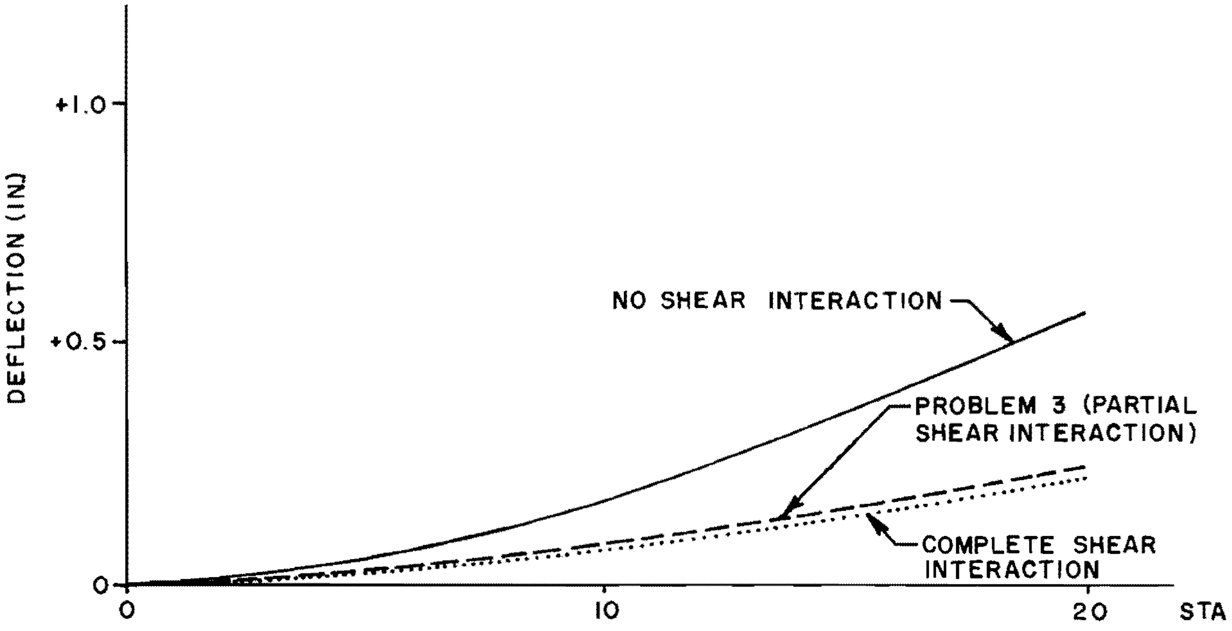


Fig 15. Deflected shapes for the structure of Problem 3.

proportional limit per connector has been exceeded.

Example Problem 2. An Unshored Construction Problem

The performance of a composite beam is affected by the support conditions while the concrete slab is hardening. When the beam supports its own weight plus the weight of the wet concrete when cast, it is called "unshored" construction and permanent stresses are locked into the beam. The total stress distribution under any given live load may be determined by the addition of the permanent stresses to the live-load stresses. This procedure is illustrated in this problem series. The structure to be analyzed is the same as the one analyzed in Problem 1.

A solution for the behavior of the beam under the dead load of the slab and beam is given in Problem 2A. The permanent stresses in the beam may be obtained from the values computed in this problem which considers the beam only.

In Problem 2B, the composite structure is subjected to the live loads shown in Fig 13C. It should be noted that the dead load is not present in this solution. When the values computed in 2A are added algebraically to the values in 2B, a final solution is obtained. For example, the bending moment in the beam at Station 10 is 1.152×10^5 in-lb plus 4.917×10^5 in-lb which is 6.069×10^5 in-lb. The description of the problem is facilitated by the data-hold options. All of the data from the previous problem except the loads are held. The only new data cards required are those that describe the slab properties, the loads, and the shear connectors. The final deflected shape of the structure is shown in Fig 14.

Example Problem 3. A Cantilever Beam

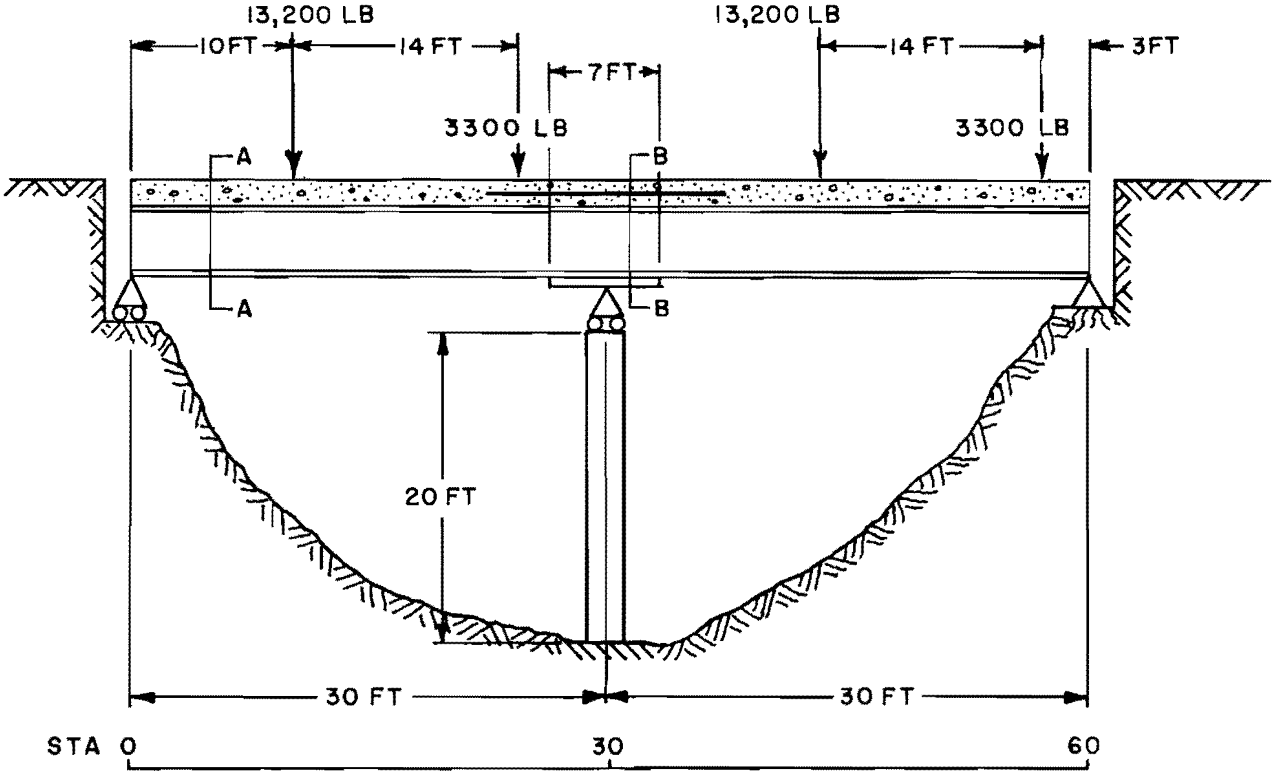
The hypothetical cantilever shown in Fig 12a is solved in this problem. It is assumed that the member has the same physical properties as the structure in Problem 1. Shear connectors are spaced according to the shear diagram. In the region from Station 0 to 10, a 6-in spacing is maintained between the pairs of shear connectors. From Station 10 to 20, the spacing is increased to 12 in.

In Chapter 4, it was shown that to correctly model a cantilever, the product of the cross-section area and the modulus of elasticity should be twice the normal value at the fixed end. Half-values of area are created at the end of each distribution sequence by INTERP4. Therefore, a concentrated value of area equal to one and a half times the normal value is added to both the slab and the beam at Station 0. A large horizontal spring is defined at Station 0 of both the slab and the beam. The description of the cantilever is completed by the specification of large rotational restraints at Station 0 for the slab and beam. The deflected shape is shown in Fig 15.

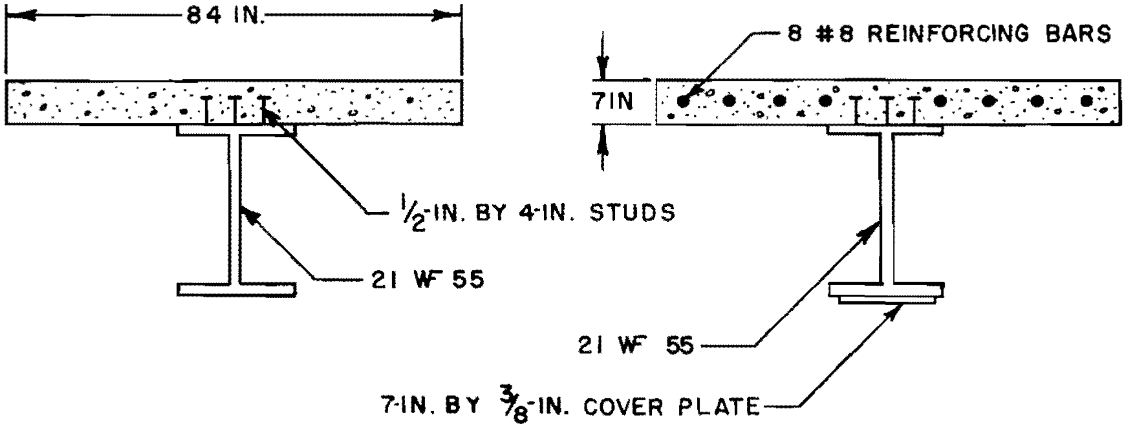
Example Problem 4. A Two-Span Composite Beam

A two-span, continuous composite beam is shown in Fig 16a. The negative moments that exist in the vicinity of the center support produce tensile stresses in the slab which make the analysis of this difficult. Consideration of the nonlinear properties of concrete is beyond the scope of this report; however, this example problem demonstrates a rational approximation of the behavior of the structure.

The analysis is simplified by the assumption that the slab has its full flexural stiffness except between the inflection points, where it is zero. For most problems, the location of the inflection points can be estimated. The accuracy of the solution can be determined by examination of the computed results. If large tensile stresses occur in the slab or if large compressive stresses are computed for the top edge of the beam between the inflection points, then a new set of assumptions should be made and the problem re-solved. Further refinements could be made in the analysis if a more accurate solution were desired.



a. The structure.



b. Section A-A.

c. Section B-B.

Fig 16. A two-span composite beam.

Inflection points are assumed to occur at Stations 22 and 38 of the structure in Fig 16a. A 7-in by 3/8-in cover plate is provided in this region. The moment of inertia of the slab is set equal to zero in this region, but the area and modulus of elasticity are not because eight reinforcement bars are present. Shear connection is provided by sets of shear connectors equally spaced at 1-ft intervals along the member. Three connectors are in each set and the individual connectors have the load-slip characteristics shown in Fig 13d. The beam is a 21 WF 55. Its modulus of elasticity is 3×10^7 lb/in^2. The 84-in by 7-in concrete slab weighs 150 lb/ft^3 and has a modulus of elasticity of 3×10^6 lb/in^2. The supports in the center and at the left end are assumed to be on rollers. A large horizontal spring is specified for the bottom of the beam at the right end which represents the fixed support.

Examination of the computed results shows that the assumptions made for this problem were reasonably accurate. Stresses in the slab can be determined from the bending moment and axial load. If stress diagrams are drawn for Stations 20 through 24 and 36 through 40, it can be seen that the stresses in the slab change from predominantly compression to predominantly tension at Stations 22 and 38, just as assumed. The deflected shape of the structure is shown in Fig 17.

Example Problem 5. A Nonlinear Problem

A nonlinear problem occurs when the rollers at the center support of the structure in Fig 16a become locked. The support column, which is fixed at its base, resists horizontal movements of the beam. The spring constant of the column is approximately 1×10^5 lb/in. It acts at the lower edge of the beam

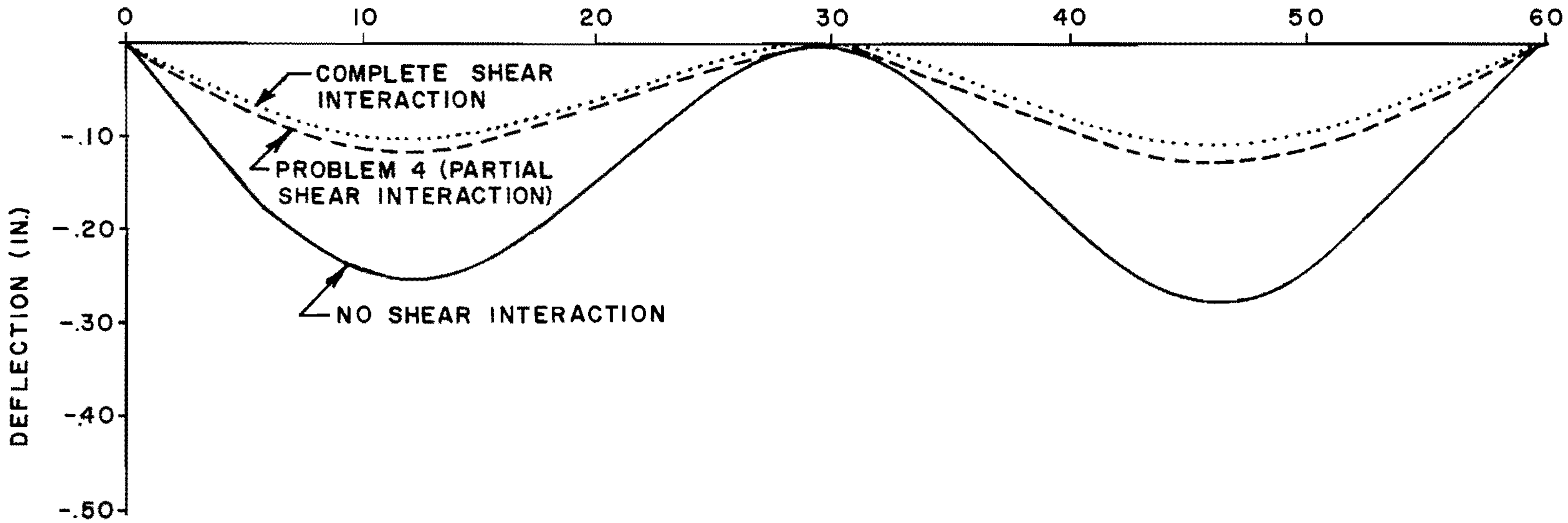


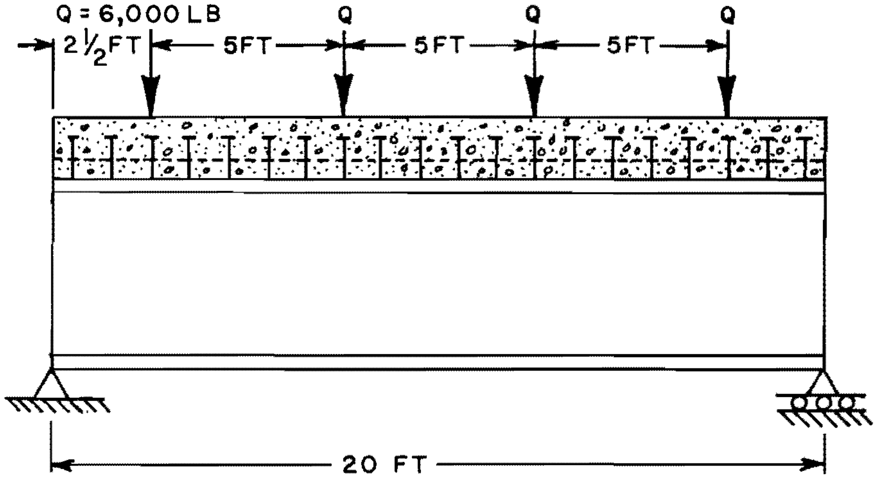
Fig 17. Deflected shapes for the structure of Problems 4 and 5.

which is 9.297 in. below the neutral axis of the beam. A much larger spring, 1×10^8 lb/in, is specified for the right end of the beam because it is assumed to be immobile. These two springs cause the axial loads to be dependent on both horizontal and vertical deflections. Longitudinal tractive loads of 50 percent of the concentrated vertical loads are specified at the surface of the slab at these four locations. These axial loads cause applied moments to also act on the slab at those points. A closure tolerance of 1×10^{-6} is specified and a limit of 30 is placed on the number of iterations.

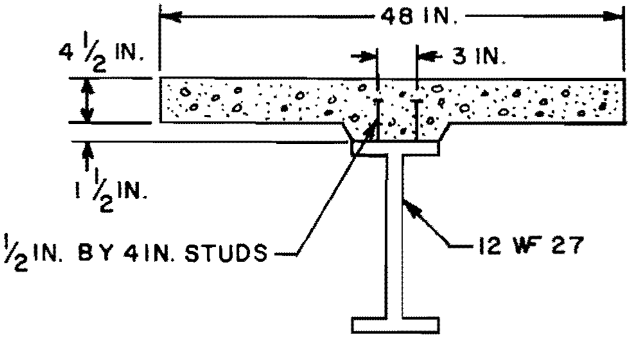
The iteration monitor data, which is printed in Table 8, shows that only three iterations were required to reach the specified closure tolerance. The longitudinal tractive loads reduce the effective stiffness of the beam which tends to increase the deflections. The horizontal spring at the center support tends to reduce the deflections in the second span because it increases the effective stiffness of the structure. The net result of these effects is to cause the deflections in the first span to be slightly more than the deflections in Problem 4 and the deflections in the second span to be less.

Example Problem 6. A Comparison of the Method with Experimental Results

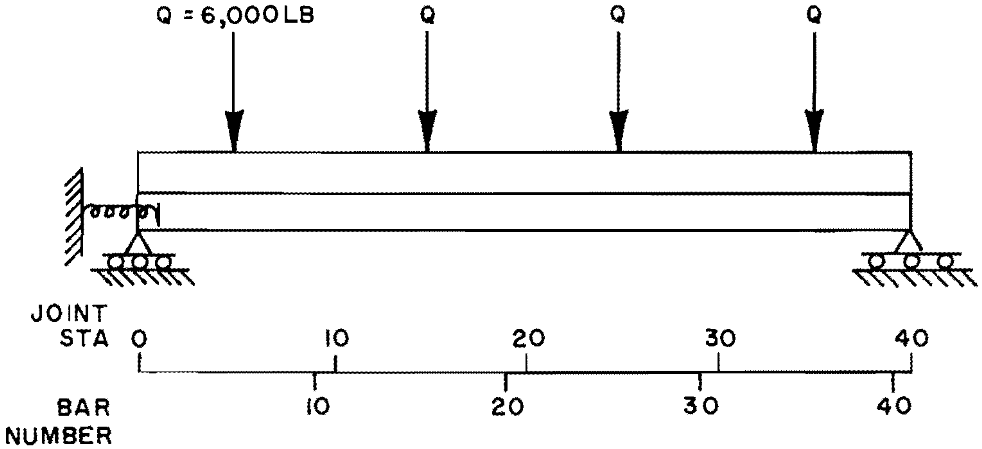
The purpose of this example problem is to verify the method of solution by comparison with the results of an experimental study performed by Proctor (Ref 13). The composite beam tested by Proctor is shown in Fig 18a. It is composed of a 12 WF 27 steel beam and 48-in by 4-1/2-in concrete slab with a 1-1/2-in haunch. Proctor reports moduli of elasticity of 2.3×10^6 lb/in^2 for the concrete and 2.9×10^7 lb/in^2 for the steel beam. Shear connection is provided by a double row of 1/2-in by 4-in welded studs. The studs are evenly spaced at 1-ft intervals along the length of the structure. In Proctor's test, the deflection gages were zeroed before the concentrated loads were applied;



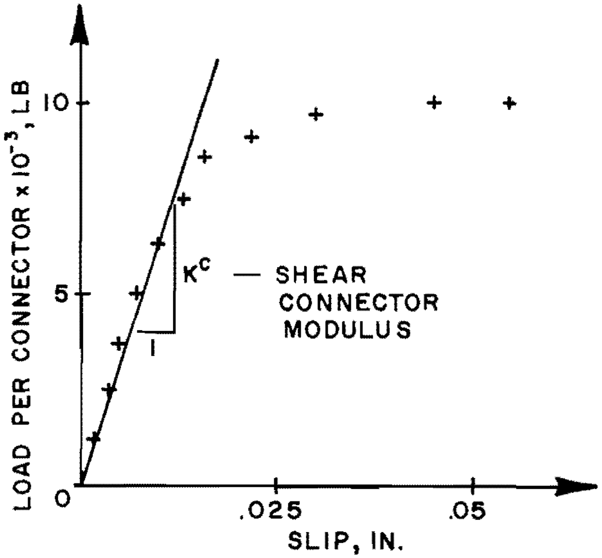
a. Elevation.



b. Cross section.



c. A model of the structure.



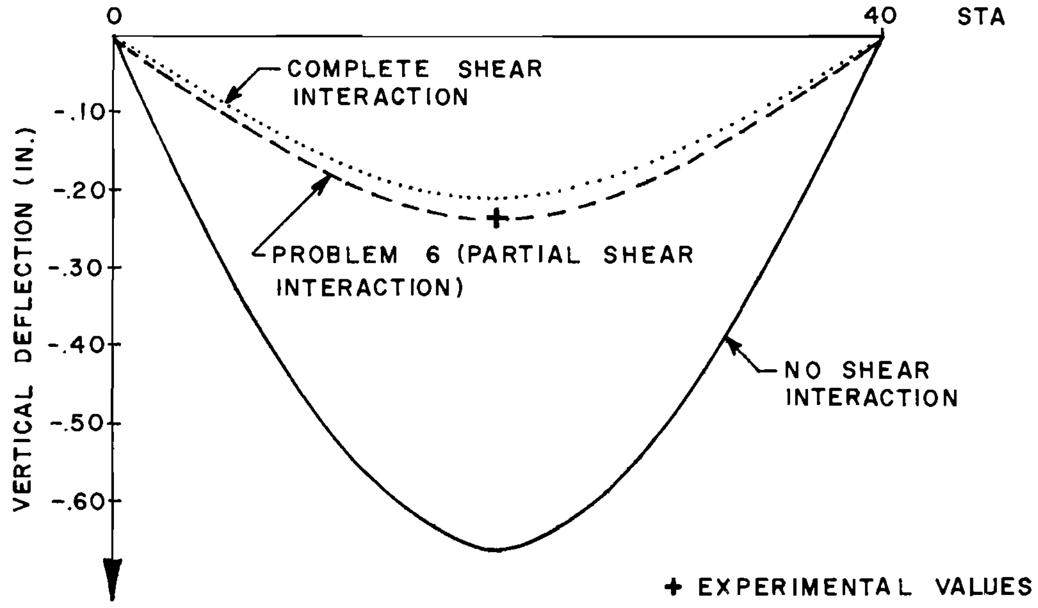
d. A load-slip curve.

Fig 18. An experimental composite beam.

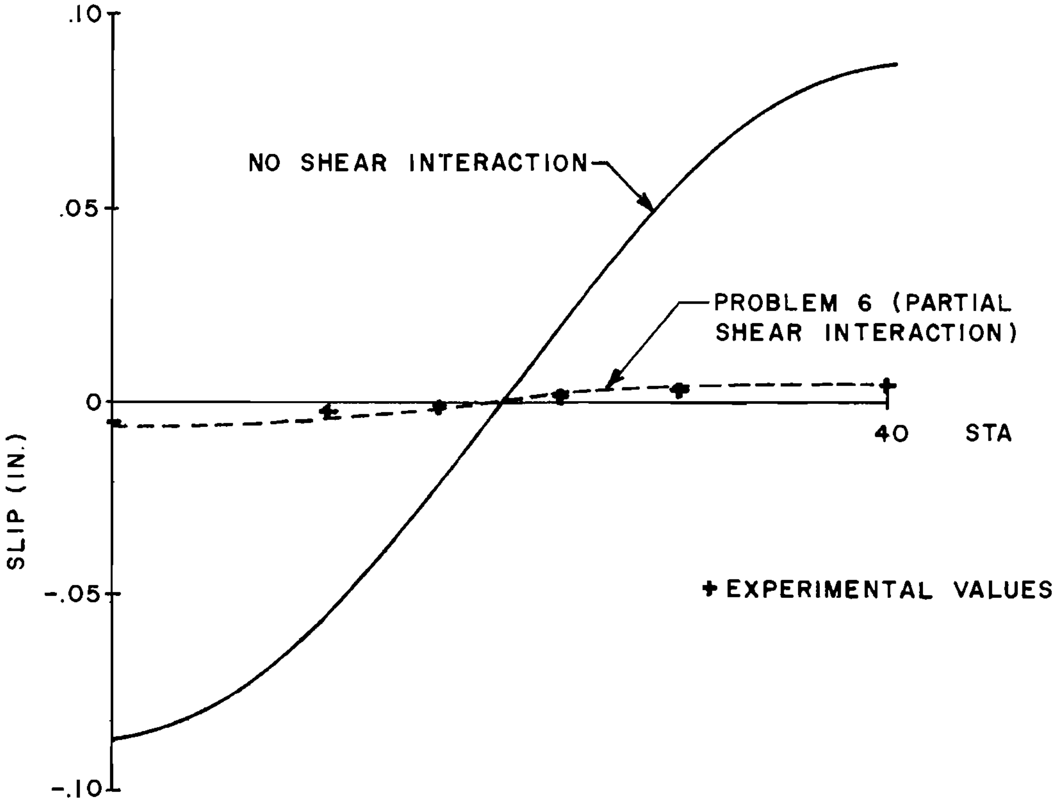
therefore, the measured deflections do not include the effect of the dead weight of the structure.

Each of the transverse loads in Fig 18a is located directly above a pair of shear connectors. In the bar-and-spring model, loads are defined at the joints while shear connectors are defined in the bars. Therefore, the real structure cannot be modeled exactly. A 40-increment model of the structure is shown in Fig 18c. In this model, the exact spacing between transverse loads can be maintained. The value of the shear connector modulus is determined by a straight line through the data points of Fig 18d. As with most experimental data, the choice of the best straight line is somewhat arbitrary. Any value of shear connector modulus between 6×10^5 lb/in and 9×10^5 lb/in is a reasonable approximation. The value of 8×10^5 lb/in is used in this problem because there are bond and friction forces in the real structure that are eliminated in a push-out test. Proctor's test results show that the haunch is in the region of tensile stress; therefore, the haunch has no effect except to increase the distance from the interface to the neutral axis of the slab.

A comparison of the analytical and experimental results is given in Fig 19. The curves are the results computed by COMBM 1 and the "+" symbols are the experimental results reported by Proctor. Fig 19a is a comparison of vertical deflections. Proctor's value of 0.230 in. for the center-line deflection, which is the only value reported, compares exactly with the computed value of 0.230 in. Six experimental values of slip are shown in Fig 19b. The measured slips are located at the ends of the slab, 4-1/2 ft from the center line, and 1-1/2 ft from the center line. A value of end slip of 0.0046 in. was reported by Proctor. This value is in reasonable agreement with the computed value of 0.0057 in. The values of slip do not compare as well as the deflections because the



a. Vertical deflection.



b. Horizontal slip.

Fig 19. A comparison of analytical and experimental results.

computed values of slip are much more sensitive to the choice of shear connector modulus. A series of supplementary problems was run to determine the relative effect of shear connector modulus on computed values of slip and deflection. For moduli of 7×10^5 lb/in and 11×10^5 lb/in, the end slip was 0.0064 in. and 0.0042 in.; the center-line deflections were 0.233 in. and 0.223 in.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

Summary

A method has been presented for the analysis of composite beams that is valid for any degree of interaction between the elements. The method is directly applicable to, but not limited to, the highway bridge problem of a concrete slab over a steel beam with shear connectors at their interface. A computer program, COMBM 1, has been written which utilizes the method of analysis. Correct usage of the program has been demonstrated by a series of example problems.

The principal features of the method are

(1) use of a finite-element model to simulate the real structural system,

(2) describing the load-deflection behavior with three equations which are written about each station in the structure,

(3) use of a special version of Gaussian elimination for most efficient solution of the system of equations.

Recommendations for Further Research

Extension of the method of solution to include shear connectors with nonlinear load-slip curves would be an important development. Ingram (Ref 9) has developed a technique for solving beams on nonlinear foundation springs that could be modified to fit the case of nonlinear load-slip curves. A nonlinear curve could be represented in the computer by a series of points. For any specific slip γ the load-slip relationship could be represented by a tangent to the curve. The tangent has a slope K^c and an intercept P . With these values of shear connector modulus and longitudinal load, the problem could be solved by the method presented in this text. New values of slip could be computed and the entire process repeated until the values of slip from two successive iterations agreed to a preset tolerance.

A more accurate analysis of a composite structural system would consider the nonlinear material properties of the concrete slab. Haliburton (Ref 6) has presented a technique for the solution of nonlinear bending problems that could be incorporated into the method of analysis that has been presented.

The analysis of a bridge-floor system has been investigated by Ingram (Ref 8). Ingram solved the problem of a plate supported by beams, but his analysis neglected the transfer of horizontal shear between the plate and beam. A natural evolution of the method presented in this text would be a combination of it with the work of Ingram.

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APPENDIX 1

GUIDE FOR DATA INPUT FOR COMBM 1

GUIDE FOR DATA INPUT FOR COMBM 1

With Supplementary Notes

extract from

A FINITE-ELEMENT METHOD OF ANALYSIS FOR COMPOSITE BEAMS

by

Thomas P. Taylor and Hudson Matlock

January 1968

COMBM 1 GUIDE FOR DATA INPUT --- Card forms

IDENTIFICATION OF PROGRAM AND RUN (2 alphanumeric cards per run)

1	80
1	80

IDENTIFICATION OF PROBLEM (one card each problem; program stops if PROB NUM is left blank)

PROB NUM	DESCRIPTION OF PROBLEM (alphanumeric)
1 5	11 80

TABLE 1. PROGRAM CONTROL DATA (one card each problem)

ENTER "1" TO HOLD PRIOR TABLE						NUM CARDS ADDED FOR TABLE					
2	3	4	5	6	7	2	3	4	5	6	7
15	20	25	30	35	40	45	50	55	60	65	70

TABLE 2. CONSTANTS (one card, or none if Table 2 of preceding problem is held)

NUM INCRS	INCR LENGTH	MAX ITERS	CLOSURE TOLERANCE	MONITOR STATIONS		
10	21 30	41 45	55	60	65	70

TABLE 3. SPECIFIED DEFLECTIONS (number of cards according to Table 1; none if preceding Table 3 is held)

STATION	DEFLECTION
10	21 30

TABLE 4. SLAB PROPERTIES

STA	TO STA	ENTER 1 IF CONT'D ON NEXT CARD	E^s MODULUS OF ELASTICITY	I^s MOMENT OF INERTIA	A^s CROSS-SECTION AREA	C^s DISTANCE FROM N.A. TO INTERFACE	K^s HORIZONTAL SPRING	a^s DISTANCE FROM N.A. TO HORIZONTAL SPRING
6 10	15	20	30	40	50	60	70	80

TABLE 5. BEAM PROPERTIES

STA	TO STA	ENTER 1 IF CONT'D ON NEXT CARD	E^b MODULUS OF ELASTICITY	I^b MOMENT OF INERTIA	A^b CROSS-SECTION AREA	C^b DISTANCE FROM N.A. TO INTERFACE	K^b HORIZONTAL SPRING	a^b DISTANCE FROM N.A. TO HORIZONTAL SPRING
6 10	15	20	30	40	50	60	70	80

TABLE 6. SLAB AND BEAM DATA

STA	TO STA	ENTER 1 IF CONT'D ON NEXT CARD	K^c SHEAR CONNECTOR MODULUS	Q TRANSVERSE FORCE	S SPRING SUPPORT
6 10	15	20	30	40	50

TABLE 7. SLAB AND BEAM DATA

STA	TO STA	ENTER 1 IF CONT'D ON NEXT CARD	T^s SLAB TRANSVERSE COUPLE	T^b BEAM TRANSVERSE COUPLE	R^s SLAB ROTATIONAL RESTRAINT	R^b BEAM ROTATIONAL RESTRAINT	P^s SLAB LONGITUDINAL LOAD	P^b BEAM LONGITUDINAL LOAD
6 10	15	20	30	40	50	60	70	80

STOP CARD (ONE BLANK CARD AT END OF RUN)
1 80

GENERAL PROGRAM NOTES

The data cards must be stacked in proper order for the program to run.

A consistent system of units must be used for all input data, for example, pounds and inches.

All 5-space words are understood to be right-justified integers or whole decimal numbers . . . . . -43

All 10-space words are right-justified floating-point decimal numbers . . . . -4.321E+03

TABLE 1. PROGRAM-CONTROL DATA

For Tables 2 and 3, the user must choose between holding all of the data from the preceding problem or entering entirely new data. If the hold option for either of these tables is set equal to 1, the number of cards input for that table must be zero.

In Tables 4, 5, 6, and 7, the data is accumulated by adding to previously stored data. The number of cards input is independent of the hold option, except the cumulative total of cards in each of the tables can not exceed 100.

Card counts in Table 1 should be rechecked after the coding of each problem is completed.

TABLE 2. CONSTANTS

Typical units for the increment length are inches.

The maximum number of increments into which the beam may be divided is 200.

The remainder of the card is blank for linear problems.

For nonlinear problems, the maximum number of iterations must be specified to prevent excessive computation. Most practical problems will reach the final solution in less than 30 iterations.

Specification of an unreasonably small closure tolerance makes closure difficult to achieve. A tolerance of 1.0×10^{-6} is sufficient for most problems.

Three monitor stations must be specified. The horizontal displacements of the monitor stations are printed after each iteration to aid understanding of the closure process.

TABLE 3. SPECIFIED DEFLECTIONS

The maximum number of stations for which deflections may be specified is 20.

TABLE 4. SLAB PROPERTIES

Typical units:

variables:	E^s	I^s	A^s	C^s	K^s	a^s
values per station:	lb/in^2	in^4	in^2	in	lb/in	in

Data should not be entered (nor held from the preceding problem) which would express effects beyond the ends of the composite beam.

The left end of the composite beam must be located at Station 0.

The variations in the interpolation and distribution process are explained and illustrated on page 68.

There are no restrictions on the order of cards in Table 4, except that within a distribution sequence the stations must be in ascending order.

At end stations of each distribution sequence, half-values are automatically created for the moment of inertia and the cross section area. Care must be taken that double amounts of the other parameters are not input at points where they change value.

TABLE 5. BEAM PROPERTIES

Typical units:

variables:	E^b	I^b	A^b	C^b	K^b	a^b
values per station:	lb/in^2	in^4	in^2	in	lb/in	in

Data in Table 5 is governed by the same rules as Table 4.

TABLE 6. SLAB AND BEAM DATA

Typical units:

variables:	K^c	Q	S
values per station:	lb/in	lb	lb/in

Data in Table 6 is governed by the same rules as Table 4.

At end stations of each distribution sequence, half-values are automatically created for the transverse force and the spring support.

TABLE 7. SLAB AND BEAM DATA

Typical units:

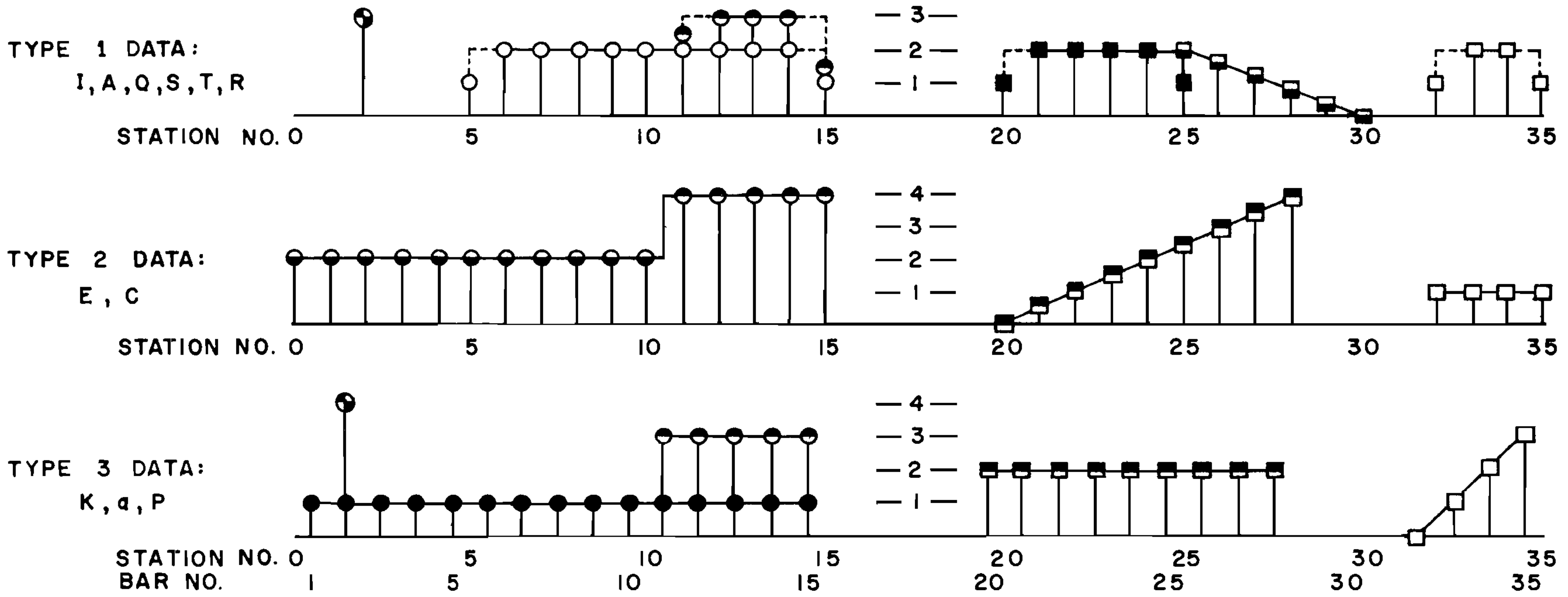
variables:	T^s	T^b	R^s	R^b	P^s	P^b
values per station:	in-lb	in-lb	$\frac{\text{in-lb}}{\text{rad}}$	$\frac{\text{in-lb}}{\text{rad}}$	lb	lb

Data in Table 7 is governed by the same rules as Table 4.

At end stations of each distribution sequence, half-values are automatically created for the slab and beam transverse couples, and slab and beam rotational restraints.

	FROM STA	TO STA	CONT'D TO NEXT CARD?	TYPE 1 DATA	TYPE 2 DATA	TYPE 3 DATA	
Individual Card Input							
Data concentrated at one station	2	→ 2	0 = NO	3.0		3.0	◕
Data uniformly distributed	0	→ 10	0 = NO		2.0		◒
	11	→ 15	0 = NO	1.0	4.0	2.0	◓
	5	→ 15	0 = NO	2.0			○
	1	→ 15	0 = NO			1.0	●
Multiple Card Sequence							
First of sequence	20		1 = YES	2.0			■
Interior of sequence		→ 25	1 = YES	2.0			⬓
End of sequence		→ 30	0 = NO	0.0			
	20		1 = YES		0.0	2.0	⬒
		→ 28	0 = NO		4.0	2.0	
	32		1 = YES	2.0	1.0	0.0	□
		→ 35	0 = NO	2.0	1.0	3.0	

Resulting Distribution of Data



APPENDIX 2

LISTING OF PROGRAM DECK OF COMBM 1

```
      COMBM1.

      PROGRAM COMBM 1 (INPUT,OUTPUT)                                    13SE66
    1 FORMAT (   52H     PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -
     1                                28H  REVISION DATE = 18 JAN 68 )
      DIMENSION  AN1(32), AN2(14),                                      28MR6
     1           Q(207), S(207), RS(207), RB(207), TS(207), TB(207),    28MR6
     2           PS(207), PB(207), ES(207), EB(207), SI(207), BI(207),  28MR6
     3           AS(207), AB(207), CS(207), CB(207), SCM(207), FS(207), 12AP6
     4           FB(207), W(207), US(207), UB(207), SH(207), SHD(207),  08JE6
     5           BH(207), BHD(207), DW(207), BMS(207), BMB(207),        08JE6
     6           VS(207), VB(207), REACT(207), KEY(207), A(10,207),     08JE6
     7           B(9,207), C(14,207), IN14(100), IN24(100), KR24(100),  08JE6
     8           ESN2(100), SIN2(100), ASN2(100), CSN2(100), SHN2(100), 09JE6
     9           SHDN(100), IN15(100), IN25(100), KR25(100), EBN2(100)  22SE66
      DIMENSION  BIN2(100), ABN2(100), CBN2(100), BHN2(100), BHDN(100), 08JE6
     1           IN16(100), IN26(100), KR26(100), SCMN(100), QN2(100),  08JE6
     2           SN2(100), IN17(100), IN27(100), KR27(100), TSN2(100),  09JE6
     3           TBN2(100), RSN2(100), RBN2(100), PSN2(100), PBN2(100), 08JE6
     4           KSW4(100), KSW5(100), KSW6(100), KSW7(100), IN13(20),  08JE6
     5           WS(20), TC(14), UST(207), UBT(207), SAL(207), BAL(207),25JL6
     6           GAMA(207), FPC(207), UM(6)                             25JL6
   10 FORMAT (    5H      , 80X, 10HI-----TRIM )                        27FE4 ID
   11 FORMAT (    5H1     , 80X, 10HI-----TRIM )                        27FE4 ID
   12 FORMAT (  16A5   )                                                04MY3 ID
   13 FORMAT (         5X, 16A5 )                                       27FE4 ID
   14 FORMAT ( A5, 5X, 14A5 )                                           18FE5 ID
   15 FORMAT (///10H     PROB , /5X, A5, 5X, 14A5 )                     18FE5 ID
   16 FORMAT (///17H     PROB (CONTD), /5X, A5, 5X, 14A5 )              18FE5 ID
   19 FORMAT (///48H     RETURN THIS PAGE TO TIME RECORD FILE -- HM )   12MR5 ID
   20 FORMAT ( 10X, 14I5 )                                              08JE6
   21 FORMAT ( 5X, I5, 10X, E10.3, 10X, I5, E10.3,3I5 )                 29SE66
   31 FORMAT ( 5X, I5, 10X, E10.3 )                                     26JL6
   41 FORMAT ( 5X, 3I5, 6E10.3 )                                        01AP6
  100 FORMAT (///35H     TABLE 1 - PROGRAM-CONTROL DATA                 08JE6
     1   /  43X, 35H                    TABLE NUMBER                    08JE6
     2   /  43X, 40H              2    3    4    5    6    7            08JE6
     3 //        46H          HOLD FROM PRECEDING PROBLEM (1=HOLD),     28MR6
     4                7X, 6I5,                                          09JE6
     5   /       38H          NUM CARDS INPUT THIS PROBLEM, 15X, 6I5 )  08JE6
  200 FORMAT (///24H     TABLE 2 - CONSTANTS    / )                     28MR6
  201 FORMAT (   30H          NUMBER OF INCREMENTS, 48X, I5,            25JL6
     1       /   28H          INCREMENT LENGTH  ,45X, E10.3,            25JL6
     2       /   28H          NONLINEAR PROBLEM , 50X, A5,              25JL6
     3       /   28H          MAX NUM ITERATIONS, 50X, I5,              25JL6
     4       /   28H          CLOSURE TOLERANCE , 45X, E10.3,           25JL6
     5       /   34H          LIST OF MONITOR STATIONS, 34X, 3I5 )      29JL6
  300 FORMAT (///40H     TABLE 3  -  SPECIFIED DEFLECTIONS              26JL6
     1         // 30H          STA     DEFLECTION    /    )             25JL6
  310 FORMAT ( 10X, I3, 5X, E10.3 )                                     25JL6
  400 FORMAT (///35H     TABLE 4  -  SLAB PROPERTIES       / )          26JL6
  401 FORMAT (   50H     FROM TO CONTD  MODULUS    MOMENT     CROSS-    26JL6
     1           35H  DISTANCE, HORIZONTAL  DISTANCE,                   26JL6
     2       /   50H      STA STA         OF         OF       SECTION   26JL6
     3           35H   N.A. TO     SPRING     N.A. TO                   26JL6
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     4       /   50H                   ELASTICITY   INERTIA     AREA     26JL6
     5           35H  INTERFACE           HORZ SPRING     / )            26JL6
  411 FORMAT (      5X, 2I4, I3, 1X, 6E11.3 )                            28MR6
  412 FORMAT (      5X, I4, 4X, I3, 1X, 6E11.3 )                         28MR6
  413 FORMAT (      9X, I4, I3, 1X, 6E11.3 )                             28MR6
  500 FORMAT (///40H     TABLE 5  -  BEAM PROPERTIES           / )       26JL6
  600 FORMAT (///50H     TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM    26JL6
     1        // 50H     FROM TO CONTD    SHEAR   TRANSVERSE   SPRING    26JL6
     2         / 50H      STA STA       CONNECTOR    LOAD      SUPPORT   26JL6
     3         / 30H                     MODULUS       /  )              26JL6
  700 FORMAT (///50H     TABLE 7  -  DATA FOR THE SLAB AND BEAM          26JL6
     1        // 50H     FROM TO CONTD    SLAB       BEAM       SLAB     26JL6
     2           30H    BEAM       SLAB       BEAM                       26JL6
     3         / 50H      STA STA      TRANSVERSE TRANSVERSE ROTATIONAL  26JL6
     4           35H ROTATIONAL  LONGITUD.  LONGITUD.                    29JL6
     5         / 50H                     COUPLE     COUPLE    RESTRAINT  26JL6
     6           35H  RESTRAINT    LOAD       LOAD       / )             26JL6
  800 FORMAT (///40H     TABLE 8 - ITERATION MONITOR DATA     )          26JL6
  805 FORMAT ( / 50H             STA     DISPLACEMENTS AT STATIONS       25JL6
     1         / 15H      ITER  NOT, 11X, I3, 20X, I3, 19X, I3,          29DE6
     2         / 51H       NUM CLSD    U-SLAB     U-BEAM      U-SLAB     29DE6
     3           35H  U-BEAM      U-SLAB     U-BEAM     /  )             29DE6
  810 FORMAT (5X, 2I5,  E12.3, E11.3, E12.3, E11.3, E12.3, E11.3 )       29DE6
  830 FORMAT ( //50H     SOLUTION NOT CLOSED TO SPECIFIED TOLERANCE    ) 27JL6
  850 FORMAT (///35H     TABLE 9  -  COMPUTED RESULTS                    26JL6
     1        // 50H      STA     VERTICAL      SLAB         SLAB        26JL6
     2           35H  BEAM        BEAM       LOAD ON                     26JL6
     3         / 50H             DEFLECTION    BENDING       AXIAL       26JL6
     4           35H BENDING      AXIAL       SHEAR                      26JL6
     5         / 50H                           MOMENT        LOAD        26JL6
     6           35H MOMENT       LOAD      CONNECTOR    / )             26JL6
  875 FORMAT (///35H     TABLE 10  -  COMPUTED RESULTS                   26JL6
     1        // 50H      STA       SLAB        SLAB         BEAM        26JL6
     2           30H  BEAM       SUPPORT      SLIP                       26JL6
     3        /  50H             HORIZONTAL    SHEAR     HORIZONTAL      26JL6
     4           25H SHEAR      REACTION                                 29JL6
     5        /  47H               DISPLAC                  DISPLAC  / ) 26JL6
  860 FORMAT ( 5X, I4, 2X, 5E12.3 )                                      26JL6
  870 FORMAT ( 71X, E12.3 )                                              26JL6
  880 FORMAT ( 5X, I4, 50X, E12.3 )                                      29JL6
  890 FORMAT ( 11X, 4E12.3, 12X, E12.3 )                                 26JL6
  903 FORMAT ( / 25H                     NONE   )                        28MR6
  904 FORMAT ( //40H     TOO MUCH DATA FOR AVAILABLE STORAGE    // )     28MR6
  905 FORMAT (   46H          USING DATA FROM THE PREVIOUS PROBLEM   )   28MR6
  907 FORMAT ( / 48H     ERROR STOP -- TWO DEFLECTIONS SPECIFIED FOR     25JL6
     1           20H THE SAME STATION    )                               27JL6
  910 FORMAT (   43H          ADDITIONAL DATA FOR THIS PROBLEM   )       28MR6
  980 FORMAT (///40H     UNDESIGNATED ERROR STOP                      )  28MR6
C-----START EXECUTION OF PROGRAM                                         28MR6
               NCT3 = 0                                                  28MR6
               NCT4 = 0                                                  28MR6
               NCT5 = 0                                                  28MR6
               NCT6 = 0                                                  28MR6
               NCT7 = 0                                                  28MR6
          ITEST = 5H                                                     18FE5 ID
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 1000 PRINT 10                                                          12JL3 ID
      CALL TIC TOC (1)                                                  26SE66
      READ  12, ( AN1(N), N = 1, 32 )                                   18FE5 ID
 1010 READ  14,  NPROB, ( AN2(N), N = 1, 14 )                           28AG3 ID
         IF ( NPROB - ITEST ) 1020, 9990, 1020                          26FE5 ID
 1020 PRINT 11                                                          26AG3 ID
      PRINT 1                                                           18FE5 ID
      PRINT 13, ( AN1(N), N = 1, 32 )                                   18FE5 ID
      PRINT 15, NPROB, ( AN2(N), N = 1, 14 )                            26AG3 ID
C-----INPUT TABLE 1                                                     28MR6
 1100 READ 20, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7, NCD2, NCD3,    08JE6
     1          NCD4, NCD5, NCD6, NCD7                                  08JE6
      PRINT 100, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7, NCD2, NCD3,  08JE6
     1            NCD4, NCD5, NCD6, NCD7                                08JE6
C-----INPUT TABLE 2                                                     28MR6
 1200 PRINT 200                                                         28MR6
         IF ( KEEP2 ) 9980, 1210, 1255                                  28MR6
 1210 READ 21, M, H, ITMAX, CLTOL, IM1, IM2, IM3                        29JL6
C-----COMPUTE CONSTANTS AND INDICES                                     28MR6
                HT2 = H + H                                             28MR6
                HE2 = H * H                                             28MR6
                HE3 = H * HE2                                           28MR6
                MP2 = M + 2                                             12AP6
                MP3 = M + 3                                             28MR6
                MP4 = M + 4                                             28MR6
                MP5 = M + 5                                             28MR6
                MP6 = M + 6                                             28MR6
                MP7 = M + 7                                             28MR6
         GO TO 1260                                                     28MR6
 1255 PRINT 905                                                         28MR6
 1260    IF ( ITMAX ) 9980, 1262, 1263                                  29JL6
 1262           LABEL = 5H   NO                                         25JL6
         GO TO 1265                                                     25JL6
 1263           LABEL = 5H  YES                                         25JL6
 1265 PRINT 201, M, H, LABEL, ITMAX, CLTOL, IM1, IM2, IM3               26JL6
C-----CLEAR STORAGE                                                     28MR6
         DO 1290  J = 1, MP7                                            08JE6
                W(J)  = 0.0                                             28MR6
                US(J) = 0.0                                             08JE6
                UB(J) = 0.0                                             08JE6
                FS(J) = 0.0                                             28MR6
                FB(J) = 0.0                                             28MR6
                BMS(J) = 0.0                                            29JL6
                BMB(J) = 0.0                                            29JL6
                SAL(J) = 0.0                                            29JL6
                BAL(J) = 0.0                                            29JL6
                GAMA(J) = 0.0                                           29JL6
                FPC(J) = 0.0                                            29JL6
                VS(J) = 0.0                                             29JL6
                VB(J) = 0.0                                             29JL6
                REACT(J) = 0.0                                          29JL6
         DO 1270  N = 1, 10                                             08JE6
                A(N,J) = 0.0                                            08JE6
 1270    CONTINUE                                                       08JE6
         DO 1275  N = 1, 9                                              08JE6
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               B(N,J) = 0.0                                             08JE6
 1275     CONTINUE                                                      08JE6
          DO 1280  N = 1, 14                                            08JE6
               C(N,J) = 0.0                                             08JE6
 1280     CONTINUE                                                      08JE6
 1290     CONTINUE                                                      08JE6
C-----INPUT TABLE 3                                                     01JE5
      PRINT 300                                                         11JA5
          DO 1303  J = 1, MP7                                           23FE5
               KEY(J) = 1                                               03JE3
 1303     CONTINUE                                                      23FE5
          IF ( KEEP3 ) 9980, 1310, 1305                                 26MY5
 1305 PRINT 905                                                         26MY5
          GO TO 1326                                                    26MY5
 1310     IF ( NCD3 - 20 ) 1312, 1312, 1311                             25MY5
 1311 PRINT 904                                                         25MY5
          GO TO 9990                                                    25MY5
 1312          NCT3 = NCD3                                              25MY5
          IF( 1      .GT.NCT3    ) GO TO 1326                           01SE66
          DO 1325  N = 1, NCT3                                          25MY5
      READ 31, IN13(N), WS(N)                                           25JL6
 1325     CONTINUE                                                      02FE5
 1326     IF ( NCT3 ) 9980, 1327, 1328                                  25MY5
 1327 PRINT 903                                                         25MY5
          GO TO 1400                                                    25MY5
          IF( 2      .GT.NCT3    ) GO TO 1351                           01SE66
 1328     DO 1350  JA = 2, NCT3                                         25MY5
               JM1 = JA - 1                                             31DE4
          DO 1345  N = JA, NCT3                                         02FE5
          IF ( IN13(JM1) - IN13(N) ) 1345, 1330, 1340                   02FE5
 1330 PRINT 907                                                         25MY5
          GO TO 9990                                                    25MY5
C-----ARRANGE THE CARDS IN ASCENDING ORDER OF STA NUMBER                01JE5
 1340          INSAV = IN13(JM1)                                        02FE5
               WSAV = WS(JM1)                                           31DE4
               IN13(JM1) = IN13(N)                                      31DE4
               WS(JM1) = WS(N)                                          31DE4
               IN13(N) = INSAV                                          31DE4
               WS(N) = WSAV                                             31DE4
 1345     CONTINUE                                                      02FE5
 1350     CONTINUE                                                      02FE5
 1351     CONTINUE                                                      13SE66
          IF( 1      .GT.NCT3    ) GO TO 1400                           01SE66
          DO 1380  N = 1, NCT3                                          27MY5
               JS = IN13(N) + 4                                         31DE4
               KEY(JS) = 2                                              25JL6
      PRINT 310, IN13(N), WS(N)                                         25JL6
 1380     CONTINUE                                                      02FE5
C-----INPUT TABLE 4                                                     30MR6
 1400 PRINT 400                                                         28MR6
      PRINT 401                                                         26JL6
          IF ( KEEP4 ) 9980, 1401, 1410                                 29MR6
 1401          NC14 = 1                                                 28MR6
               NCT4 = NCD4                                              28MR6
          GO TO 1430                                                    28MR6
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 1410 PRINT 905                                                         28MR6
          IF( 1     .GT.NCT4    ) GO TO 1427                            01SE66
          DO 1425  N = 1, NCT4                                          28MR6
               KSW4N = KSW4(N)                                          13SE66
          GO TO ( 1413, 1417, 1421, 1421  ), KSW4 N                     13SE66
 1413 PRINT 411, IN14(N), IN24(N), KR24(N), ESN2(N), SIN2(N), ASN2(N),  28MR6
     1           CSN2(N), SHN2(N), SHDN(N)                              09JE6
          GO TO 1425                                                    28MR6
 1417 PRINT 412,IN14(N), KR24(N), ESN2(N), SIN2(N), ASN2(N), CSN2(N),   09JE6
     1           SHN2(N), SHDN(N)                                       09JE6
          GO TO 1425                                                    28MR6
 1421 PRINT 413, IN24(N), KR24(N), ESN2(N), SIN2(N), ASN2(N), CSN2(N),  09JE6
     1           SHN2(N), SHDN(N)                                       09JE6
 1425     CONTINUE                                                      28MR6
 1427     CONTINUE                                                      21SE66
      PRINT 910                                                         28MR6
               NC14 = NCT4 + 1                                          28MR6
               NCT4 = NCT4 + NCD4                                       28MR6
 1430     IF ( NCT4 - 100 ) 1435, 1435, 1433                            28MR6
 1433 PRINT 904                                                         28MR6
          GO TO 9990                                                    28MR6
 1435     IF ( NCD4 ) 9980, 1437, 1440                                  28MR6
 1437 PRINT 903                                                         28MR6
          GO TO 1500                                                    28MR6
 1440          KR1 = 0                                                  28MR6
          DO 1470  N = NC14, NCT4                                       28MR6
      READ 41, IN14(N), IN24(N), KR24(N), ESN2(N), SIN2(N), ASN2(N),    28MR6
     1         CSN2(N), SHN2(N), SHDN(N)                                09JE6
               KSW4(N) = 1 + KR24(N) + 2 * KR1                          30MR6
               KR1 = KR24(N)                                            28MR6
               KSW4N = KSW4(N)                                          13SE66
          GO TO ( 1450, 1455, 1460, 1460 ) , KSW4 N                     13SE66
 1450 PRINT 411, IN14(N), IN24(N), KR24(N), ESN2(N), SIN2(N), ASN2(N),  28MR6
     1           CSN2(N), SHN2(N), SHDN(N)                              09JE6
          GO TO 1470                                                    28MR6
 1455 PRINT 412,IN14(N), KR24(N), ESN2(N), SIN2(N), ASN2(N), CSN2(N),   09JE6
     1           SHN2(N), SHDN(N)                                       09JE6
          GO TO 1470                                                    28MR6
 1460 PRINT 413, IN24(N), KR24(N), ESN2(N), SIN2(N), ASN2(N), CSN2(N),  09JE6
     1           SHN2(N), SHDN(N)                                       09JE6
 1470     CONTINUE                                                      28MR6
C-----INPUT TABLE 5                                                     28MR6
 1500 PRINT 500                                                         28MR6
      PRINT 401                                                         26JL6
          IF ( KEFP5 ) 9980, 1501, 1510                                 28MR6
 1501          NC15 = 1                                                 28MR6
               NCT5 = NCD5                                              28MR6
          GO TO 1530                                                    28MR6
 1510 PRINT 905                                                         28MR6
          IF( 1     .GT.NCT5    ) GO TO 1526                            01SE66
          DO 1525  N = 1, NCT5                                          28MR6
               KSW5N = KSW5(N)                                          13SE66
          GO TO ( 1513, 1517, 1521, 1521 ), KSW5 N                      13SE66
 1513 PRINT 411, IN15(N), IN25(N), KR25(N), EBN2(N), BIN2(N), ABN2(N),  28MR6
     1           CBN2(N), BHN2(N), BHDN(N)                              09JE6
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          GO TO 1525                                                    28MR6
 1517 PRINT 412, IN15(N), KR25(N), EBN2(N), BIN2(N), ABN2(N), CBN2(N),  09JE6
     1           BHN2(N), BHDN(N)                                       09JE6
          GO TO 1525                                                    29MR6
 1521 PRINT 413, IN25(N), KR25(N), EBN2(N), BIN2(N), ABN2(N), CBN2(N),  09JE6
     1           BHN2(N), BHDN(N)                                       09JE6
 1525     CONTINUE                                                      29MR6
 1526     CONTINUE                                                      13SE66
      PRINT 910                                                         29MR6
               NC15 = NCT5 + 1                                          29MR6
               NCT5 = NCT5 + NCD5                                       29MR6
 1530     IF ( NCT5 - 100 ) 1535, 1535, 1533                            29MR6
 1533 PRINT 904                                                         29MR6
          GO TO 9990                                                    30MR6
 1535     IF ( NCD5 ) 9980, 1537, 1540                                  29MR6
 1537 PRINT 903                                                         29MR6
          GO TO 1600                                                    29MR6
 1540          KR1 = 0                                                  29MR6
          DO 1570  N = NC15, NCT5                                       29MR6
      READ 41, IN15(N), IN25(N), KR25(N), EBN2(N), BIN2(N), ABN2(N),    29MR6
     1         CBN2(N), BHN2(N), BHDN(N)                                09JE6
               KSW5(N) = 1 + KR25(N) + 2 * KR1                          30MR6
               KR1 = KR25(N)                                            29MR6
               KSW5N = KSW5(N)                                          13SE66
          GO TO ( 1550, 1555, 1560, 1560 ), KSW5 N                      13SE66
 1550 PRINT 411, IN15(N), IN25(N), KR25(N), EBN2(N), BIN2(N), ABN2(N),  28MR6
     1           CBN2(N), BHN2(N), BHDN(N)                              09JE6
          GO TO 1570                                                    29MR6
 1555 PRINT 412, IN15(N), KR25(N), EBN2(N), BIN2(N), ABN2(N), CBN2(N),  09JE6
     1           BHN2(N), BHDN(N)                                       09JE6
          GO TO 1570                                                    29MR6
 1560 PRINT 413, IN25(N), KR25(N), EBN2(N), BIN2(N), ABN2(N), CBN2(N),  09JE6
     1           BHN2(N), BHDN(N)                                       09JE6
 1570     CONTINUE                                                      29MR6
C-----INPUT TABLE 6                                                     29MR6
 1600 PRINT 600                                                         29MR6
          IF ( KEEP6 ) 9980, 1601, 1610                                 29MR6
 1601          NC16 = 1                                                 29MR6
               NCT6 = NCD6                                              29MR6
          GO TO 1630                                                    29MR6
 1610 PRINT 905                                                         29MR6
          IF( 1     .GT.NCT6    ) GO TO 1626                            01SE66
          DO 1625  N = 1, NCT6                                          29MR6
               KSW6N = KSW6(N)                                          13SE66
          GO TO ( 1613, 1617, 1621, 1621 ), KSW6 N                      13SE66
 1613 PRINT 411, IN16(N), IN26(N), KR26(N), SCMN(N), QN2(N), SN2(N)     09JE6
          GO TO 1625                                                    29MR6
 1617 PRINT 412, IN16(N), KR26(N), SCMN(N), QN2(N), SN2(N)              09JE6
          GO TO 1625                                                    29MR6
 1621 PRINT 413, IN26(N), KR26(N), SCMN(N), QN2(N), SN2(N)              09JE6
 1625     CONTINUE                                                      29MR6
 1626     CONTINUE                                                      13SE66
      PRINT 910                                                         29MR6
               NC16 = NCT6 + 1                                          29MR6
               NCT6 = NCT6 + NCD6                                       29MR6
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 1630     IF ( NCT6 - 100 ) 1635, 1635, 1633                            29MR6
 1633 PRINT 904                                                         29MR6
          GO TO 9990                                                    29MR6
 1635     IF ( NCD6 ) 9980, 1637, 1640                                  29MR6
 1637 PRINT 903                                                         29MR6
          GO TO 1700                                                    29MR6
 1640          KR1 = 0                                                  29MR6
          DO 1670  N = NC16, NCT6                                       29MR6
      READ 41, IN16(N), IN26(N), KR26(N), SCMN(N), QN2(N), SN2(N)       09JE6
               KSW6(N) = 1 + KR26(N) + 2 * KR1                          29MR6
               KSW6N = KSW6(N)                                          13SE66
          GO TO ( 1650, 1655, 1660, 1660 ), KSW6 N                      13SE66
 1650 PRINT 411, IN16(N), IN26(N), KR26(N), SCMN(N), QN2(N), SN2(N)     09JE6
          GO TO 1670                                                    29MR6
 1655 PRINT 412, IN16(N), KR26(N), SCMN(N), QN2(N), SN2(N)              09JE6
          GO TO 1670                                                    29MR6
 1660 PRINT 413, IN26(N), KR26(N), SCMN(N), QN2(N), SN2(N)              09JE6
 1670     CONTINUE                                                      29MR6
C-----INPUT TABLE 7                                                     08JE6
 1700 PRINT 700                                                         08JE6
          IF ( KEEP7 ) 9980, 1701, 1710                                 08JE6
 1701          NC17 = 1                                                 08JE6
               NCT7 = NCD7                                              08JE6
          GO TO 1730                                                    08JE6
 1710 PRINT 905                                                         08JE6
          IF( 1      .GT.NCT7    ) GO TO 1726                           01SE66
          DO 1725  N = 1, NCT7                                          08JE6
               KSW7N = KSW7(N)                                          13SE66
          GO TO ( 1713, 1717, 1721, 1721 ), KSW7 N                      13SE66
 1713 PRINT 411, IN17(N), IN27(N), KR27(N), TSN2(N), TBN2(N), RSN2(N),  08JE6
     1           RBN2(N), PSN2(N), PBN2(N)                              08JE6
          GO TO 1725                                                    08JE6
 1717 PRINT 412, IN17(N), KR27(N), TSN2(N), TBN2(N), RSN2(N), RBN2(N),  08JE6
     1           PSN2(N), PBN2(N)                                       08JE6
          GO TO 1725                                                    08JE6
 1721 PRINT 413, IN27(N), KR27(N), TSN2(N), TBN2(N), RSN2(N), RBN2(N),  08JE6
     1           PSN2(N), PBN2(N)                                       08JE6
 1725     CONTINUE                                                      08JE6
 1726     CONTINUE                                                      13SE66
      PRINT 910                                                         08JE6
               NC17 = NCT7 + 1                                          08JE6
               NCT7 = NCT7 + NCD7                                       08JE6
 1730     IF ( NCT7 - 100 ) 1735, 1735, 1733                            08JE6
 1733 PRINT 904                                                         08JE6
          GO TO 9990                                                    08JE6
 1735     IF ( NCD7 ) 9980, 1737, 1740                                  08JE6
 1737 PRINT 903                                                         08JE6
          GO TO 1800                                                    08JE6
 1740          KR1 = 0                                                  08JE6
          DO 1770  N = NC17, NCT7                                       08JE6
      READ 41, IN17(N), IN27(N), KR27(N), TSN2(N), TBN2(N), RSN2(N),    08JE6
     1         RBN2(N), PSN2(N), PBN2(N)                                08JE6
               KSW7(N) = 1 + KR27(N) + 2 * KR1                          08JE6
               KR1 = KR27(N)                                            08JE6
               KSW7N = KSW7(N)                                          13SE66
```

```
          GO TO ( 1750, 1755, 1760, 1760 ), KSW7 N                      13SE66
 1750 PRINT 411, IN17(N), IN27(N), KR27(N), TSN2(N), TBN2(N), RSN2(N),  08JE6
     1           RBN2(N), PSN2(N), PBN2(N)                              08JE6
          GO TO 1770                                                    08JE6
 1755 PRINT 412, IN17(N), KR27(N), TSN2(N), TBN2(N), RSN2(N), RBN2(N),  08JE6
     1         PSN2(N), PBN2(N)                                         08JE6
          GO TO 1770                                                    08JE6
 1760 PRINT 413, IN27(N), KR27(N), TSN2(N), TBN2(N), RSN2(N), RBN2(N),  08JE6
     1           PSN2(N), PBN2(N)                                       08JE6
 1770     CONTINUE                                                      08JE6
 1800          LSM = 1                                                  02JL6
C-----INTERPOLATE AND DISTRIBUTE VALUES FROM TABLE 4                    29MR6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, ESN2, ES, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, CSN2, CS, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, SHN2, SH, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, SHDN, SHD, LSM )      15JL6
               LSM = 0                                                  02JL6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, ASN2, AS, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT4, IN14, IN24, KR24, SIN2, SI, LSM )       15JL6
C-----INTERPOLATE AND DISTRIBUTE VALUES FROM TABLE 5                    29MR6
               LSM = 1                                                  29MR6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, EBN2, EB, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, CBN2, CB, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, BHN2, BH, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, BHDN, BHD, LSM )      15JL6
               LSM = 0                                                  29MR6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, ABN2, AB, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT5, IN15, IN25, KR25, BIN2, BI, LSM )       15JL6
C-----INTERPOLATE AND DISTRIBUTE VALUES FROM TABLE 6                    29MR6
               LSM = 1                                                  29MR6
      CALL INTERP4 ( MP7, NCT6, IN16, IN26, KR26, SCMN, SCM, LSM )      15JL6
               LSM = 0                                                  05AP6
      CALL INTERP4 ( MP7, NCT6, IN16, IN26, KR26, QN2, Q, LSM )         15JL6
      CALL INTERP4 ( MP7, NCT6, IN16, IN26, KR26, SN2, S, LSM )         15JL6
C-----INTERPOLATE AND DISTRIBUTE VALUES FROM TABLE 7                    08JE6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, TSN2, TS, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, TBN2, TB, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, RSN2, RS, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, RBN2, RB, LSM )       15JL6
               LSM = 1                                                  08JE6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, PSN2, PS, LSM )       15JL6
      CALL INTERP4 ( MP7, NCT7, IN17, IN27, KR27, PBN2, PB, LSM )       15JL6
               CS(3) = CS(4)                                            29JL6
               CB(3) = CB(4)                                            29JL6
               CS(MP5) = CS(MP4)                                        29JL6
               CB(MP5) = CB(MP4)                                        29JL6
          DO 1850  J = 1, MP7                                           29MR6
               FS(J) = ES(J) * SI(J)                                    29MR6
               FB(J) = EB(J) * BI(J)                                    29MR6
 1850     CONTINUE                                                      29MR6
               KERR = 0                                                 26JL6
               ITER = 0                                                 25JL6
C-----STORE VALUES OF DISPLACEMENT FROM THE PREVIOUS ITERATION          25JL6
 3000     DO 3100  J = 1, MP7                                           25JL6
               UST(J) = US(J)                                           25JL6
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               UBT(J) = UB(J)                                           26JL6
 3100     CONTINUE                                                      25JL6
               ITER = ITER + 1                                          25JL6
               SMD = 0.0                                                25JL6
               NSTA = 0                                                 25JL6
               NS = 1                                                   09JE6
               SMP = 0.0                                                10JE6
               SMP1 = 0.0                                               10JE6
C-----COMPUTE MATRIX COEFFICIENTS                                       08JE6
          DO 3500  J = 3, MP5                                           15JE6
               SMD = SMD + SH(J-1) * US(J-1) + BH(J-1) * UB(J-1)        25JL6
               SMD1 = SMD + 0.5 * ( SH(J) * US(J) + BH(J) * UB(J) )     25JL6
               SMD2 = 2.0 * SMD + 1.5 * ( SH(J) * US(J) + BH(J) * UB(J))25JL6
     1                +0.5 * ( SH(J+1) * US(J+1) + BH(J+1) * UB(J+1) )  27JL6
               SMD3 = SMD + SH(J) * US(J) + BH(J) * UB(J)               25JL6
     1                + 0.5 * ( SH(J+1) * US(J+1) + BH(J+1) * UB(J+1) ) 27JL6
               SMP      = SMP + PS(J-1) + PB(J-1)                       10JE6
               SMP1     = SMP + PS(J) + PB(J)                           10JE6
               A(1,J)   = AS(J-1) * ES(J-1) / H                         25JL6
               A(2,J)   = 0.0                                           25JL6
               A(3,J)   = 0.5 * ( CS(J-1) + CS(J) + CB(J-1)  + CB(J) )  25JL6
     1                    * SCM(J) / H                                  25JL6
               A(4,J)   = - ( AS(J-1) * ES(J-1) + AS(J) * ES(J) ) / H   26JL6
     1                    - SH(J) - SCM(J)                              25JL6
               A(5,J)   = SCM(J)                                        27JL6
               A(6,J)   = - 0.5 * ( CS(J-1) + CS(J) + CB(J-1) + CB(J) ) 27JL6
     1                    * SCM(J) / H                                  25JL6
               A(7,J)   = AS(J) * ES(J) / H                             25JL6
               A(8,J)   = 0.0                                           25JL6
               A(9,J)   = 0.0                                           25JL6
               A(10,J)  = - PS(J)                                       26JL6
               B(1,J)   = AB(J-1) * EB(J-1) / H                         25JL6
               B(2,J)   = - 0.5 * ( CS(J-1) + CS(J) + CB(J-1) + CB(J) ) 25JL6
     1                    * SCM(J) / H                                  25JL6
               B(3,J)   = SCM(J)                                        25JL6
               B(4,J)   = - ( AB(J-1) * EB(J-1) + AB(J) * EB(J) ) / H   25JL6
     1                    - BH(J) - SCM(J)                              25JL6
               B(5,J)   = 0.5 * ( CS(J-1) + CS(J) + CB(J-1) + CB(J) )   25JL6
     1                    * SCM(J) / H                                  25JL6
               B(6,J)   = 0.0                                           25JL6
               B(7,J)   = AB(J) * EB(J) / H                             25JL6
               B(8,J)   = 0.0                                           25JL6
               B(9,J)   = - PB(J)                                       25JL6
               C(1,J)   = FS(J-1) + FB(J-1) - 0.25 * H                  29JE6
     1                    * ( RS(J-1) + RB(J-1) )                       29JE6
               C(2,J)   = CS(J-1) * AS(J-1) * ES(J-1) * H               07JE6
               C(3,J)   = - CB(J-1) * AB(J-1) * EB(J-1) * H             09JE6
               C(4,J)   = - 2.0 * ( FS(J-1) + FB(J-1) + FS(J) + FB(J) ) 07JE6
     1                    + HE2 * ( SMP + 0.5 * ( PS(J) + PB(J) ) )     09JE6
     2                    - SMD1 * HE2                                  25JL6
               C(5,J)   = - ( CS(J-1) * AS(J-1) * ES(J-1) + 2.0 * CS(J) 07JE6
     1                    * AS(J) * ES(J) + H * ( 0.5 * ( CS(J-1)       07JE6
     2                    + CS(J) ) + SHD(J) ) * SH(J) ) * H            07JE6
               C(6,J)   = ( CB(J-1) * AB(J-1) * EB(J-1) + 2.0 * CB(J)   07JE6
     1                    * AB(J) * EB(J) + H * ( 0.5 * ( CB(J-1)       07JE6
```

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     2                  + CB(J) ) + BHD(J) ) * BH(J) ) * H                 07JE6
            C(7,J)    = FS(J-1) + FB(J-1) + 4.0 * ( FS(J) + FB(J) )        07JE6
     1                  + FS(J+1) + FB(J+1) - ( 2.0 * SMP + 1.5 *          07JE6
     2                  ( PS(J) + PB(J) ) + 0.5 * ( PS(J+1)                07JE6
     3                  + PB(J+1) ) ) * HE2 + S(J) * HE3 + 0.25 * H        29JE6
     4                  * ( RS(J-1) + RB(J-1) + RS(J+1) + RB(J+1) )        29JE6
     5                  + SMD2 * HE2                                       25JL6
            C(8,J)    = ( 2.0 * CS(J) * AS(J) * ES(J) + CS(J+1)            07JE6
     1                  * AS(J+1) * ES(J+1) + ( 0.5 * ( CS(J)              07JE6
     2                  + CS(J+1) ) + SHD(J+1) ) * SH(J+1) * H ) * H       09JE6
            C(9,J)    = - ( 2.0 * CB(J) * AB(J) * EB(J) + CB(J+1)          07JE6
     1                  * AB(J+1) * EB(J+1) + ( 0.5 * ( CB(J)              07JE6
     2                  + CB(J+1) ) + BHD(J+1) ) * BH(J+1) * H ) * H       09JE6
            C(10,J)   = - 2.0 * ( FS(J) + FB(J) + FS(J+1) + FB(J+1) )      09JE6
     1                  + ( SMP1 + 0.5 * ( PS(J+1) + PB(J+1) ) ) * HE2     09JE6
     2                  - SMD3 * HE2                                       25JL6
            C(11,J)   = - CS(J+1) * AS(J+1) * ES(J+1) * H                  09JE6
            C(12,J)   = CB(J+1) * AB(J+1) * EB(J+1) * H                    09JE6
            C(13,J)   = FS(J+1) + FB(J+1) - 0.25 * H * ( RS(J+1)           29JE6
     1                  + RB(J+1) )                                        29JE6
            C(14,J)   = Q(J) * HE3 + 0.5 * ( - PS(J) * ( CS(J-1)           09JE6
     1                  + CS(J) ) + PS(J+1) * ( CS(J) + CS(J+1) )          07JE6
     2                  + PB(J) * ( CB(J-1) + CB(J) ) - PB(J+1)            07JE6
     3                  * ( CB(J) + CB(J+1) ) ) * HE2 - 0.5 * HE2          29JE6
     4                  * ( TS(J-1) + TB(J-1) - TS(J+1) - TB(J+1) )        29JE6
 3500     CONTINUE                                                         16JE6
C-----BEGIN GAUSSIAN ELIMINATION                                           09JE6
 4000     DO 6000  J = 4, MP5                                              15JE6
          IF ( KEY(J) - 1 ) 9980, 4200, 4050                               30JE6
C-----SET SPECIFIED DEFLECTION                                             15JE6
 4050     DO 4085  N = 1, 14                                               25JL6
               C(N,J) = 0.0                                                30JE6
 4085     CONTINUE                                                         30JE6
               C(7,J) = 1.0                                                30JE6
               C(14,J) = WS(NS)                                            30JE6
               NS = NS + 1                                                 30JE6
 4200     IF( C(7,J-1) ) 4201,4401,4201                                    04OC66
 4201          CM = - A(3,J) / C(7,J-1)                                    04OC66
          DO 4250  N = 3, 10                                               06JE6
               TC(N) = CM * C(N+4,J-1)                                     08JE6
               A(N,J) = A(N,J) + TC(N)                                     06JE6
 4250     CONTINUE                                                         06JE6
               CM = -B(2,J) / C(7,J-1)                                     06JE6
          DO 4300  N = 2, 9                                                06JE6
               TC(N) = CM * C(N+5,J-1)                                     08JE6
               B(N,J) = B(N,J) + TC(N)                                     06JE6
 4300     CONTINUE                                                         06JE6
               CM = - C(4,J) / C(7,J-1)                                    06JE6
          DO 4350  N = 4, 10                                               06JE6
               TC(N) = CM * C(N+3,J-1)                                     06JE6
               C(N,J) = C(N,J) + TC(N)                                     06JE6
 4350     CONTINUE                                                         06JE6
               C(14,J) = C(14,J) + CM * C(14,J-1)                          06JE6
               CM = - C(1,J+1) / C(7,J-1)                                  06JE6
          DO 4400  N = 1, 7                                                06JE6
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                TC(N) = CM * C(N+6,J-1)                               06JE6
                C(N,J+1) = C(N,J+1) + TC(N)                           06JE6
 4400      CONTINUE                                                   06JE6
                C(14,J+1) = C(14,J+1) + CM * C(14,J-1)                06JE6
 4401      IF( A(4,J) ) 4402,4651,4402                                040C66
 4402           CM = - B(3,J) / A(4,J)                                06JE6
           DO 4500  N = 3, 9                                          06JE6
                TC(N) = CM * A(N+1,J)                                 06JE6
                B(N,J) = B(N,J) + TC(N)                               06JE6
 4500      CONTINUE                                                   06JE6
                CM = - C(5,J) / A(4,J)                                06JE6
           DO 4550  N = 5, 10                                         06JE6
                TC(N) = CM * A(N-1,J)                                 06JE6
                C(N,J) = C(N,J) + TC(N)                               06JE6
 4550      CONTINUE                                                   06JE6
                C(14,J) = C(14,J) + CM * A(10,J)                      06JE6
                CM = - A(1,J+1) / A(4,J)                              06JE6
           DO 4600  N = 1, 6                                          06JE6
                TC(N) = CM * A(N+3,J)                                 06JE6
                A(N,J+1) = A(N,J+1) + TC(N)                           08JE6
 4600      CONTINUE                                                   06JE6
                A(10,J+1) = A(10,J+1) + CM * A(10,J)                  06JE6
                CM = - C(2,J+1) / A(4,J)                              06JE6
           DO 4650  N = 2, 7                                          06JE6
                TC(N) = CM * A(N+2,J)                                 06JE6
                C(N,J+1) = C(N,J+1) + TC(N)                           06JE6
 4650      CONTINUE                                                   06JE6
                C(14,J+1) = C(14,J+1) + CM * A(10,J)                  06JE6
 4651      IF( B(4,J) ) 4652,6000,4652                                040C66
 4652           CM = - C(6,J) / B(4,J)                                06JE6
           DO 4700  N = 6, 10                                         06JE6
                TC(N) = CM * B(N-2,J)                                 06JE6
                C(N,J) = C(N,J) + TC(N)                               08JE6
 4700      CONTINUE                                                   06JE6
                C(14,J) = C(14,J) + CM * B(9,J)                       06JE6
                CM = - A(2,J+1) / B(4,J)                              06JE6
           DO 4750  N = 2, 6                                          06JE6
                TC(N) = CM * B(N+2,J)                                 08JE6
                A(N,J+1) = A(N,J+1) + TC(N)                           06JE6
 4750      CONTINUE                                                   06JE6
                A(10,J+1) = A(10,J+1) + CM * B(9,J)                   06JE6
                CM = - B(1,J+1) / B(4,J)                              06JE6
           DO 4800  N = 1, 5                                          06JE6
                TC(N) = CM * B(N+3,J)                                 06JE6
                B(N,J+1) = B(N,J+1) + TC(N)                           06JE6
 4800      CONTINUE                                                   06JE6
                B(9,J+1) = B(9,J+1) + CM * B(9,J)                     06JE6
                CM = - C(3,J+1) / B(4,J)                              06JE6
           DO 4850  N = 3, 7                                          06JE6
                TC(N) = CM * B(N+1,J)                                 06JE6
                C(N,J+1) = C(N,J+1) + TC(N)                           06JE6
 4850      CONTINUE                                                   06JE6
                C(14,J+1) = C(14,J+1) + CM * B(9,J)                   06JE6
 6000      CONTINUE                                                   06JE6
C-----BEGIN BACK-SUBSTITION                                           07JE6
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          DO 6100  L = 3, MP5                                             07JE6
               J = MP5 + 3 - L                                            09JE6
          IF( C(7,J) ) 6005,6010,6005                                     050C66
 6005          W(J) = - 1.0 / C(7,J) * ( C(8,J) * US(J+1) + C(9,J)        07JE6
    1                     * UB(J+1) + C(10,J) * W(J+1) + C(11,J) * US(J+2)  07JE6
    2                     + C(12,J) * UB(J+2) + C(13,J) * W(J+2) - C(14,J) )07JE6
 6010     IF( B(4,J) ) 6015,6020,6015                                     050C66
 6015          UB(J) = -1.0 / B(4,J) * ( B(5,J) * W(J) + B(6,J)           07JE6
    1                   * US(J+1) + B(7,J) * UB(J+1) + B(8,J) * W(J+1)    07JE6
    2                   - B(9,J) )                                        10JE6
 6020     IF( A(4,J) ) 6025,6100,6025                                     050C66
 6025          US(J) = - 1.0 / A(4,J) * ( A(5,J) * UB(J) + A(6,J)         07JE6
    1                   * W(J) + A(7,J) * US(J+1) + A(8,J) * UB(J+1)      07JE6
    2                   + A(9,J) * W(J+1) - A(10,J) )                     07JE6
 6100     CONTINUE                                                        07JE6
          IF ( ITER - 1 ) 9980, 6110, 6120                                02AG6
 6110 PRINT 800                                                           02AG6
      PRINT 805, IM1, IM2, IM3                                            25JL6
C---- DETERMINE IF PROBLEM IS NONLINEAR                                   25JL6
 6120     IF ( ITMAX ) 9980, 6150, 6200                                   02AG6
 6150 PRINT 903                                                           25JL6
          GO TO 8000                                                      25JL6
C-----CHECK THE NUMBER OF ITERATIONS AGAINST THE SPECIFIED LIMIT          25JL6
 6200     IF ( ITER - ITMAX ) 6300, 6300, 6250                            26JL6
 6250          KERR = 1                                                   26JL6
          GO TO 8000                                                      26JL6
 6300     DO 6400  J = 4, MP5                                             27JL6
C-----COMPARE DISPLACEMENTS TO THE PREVIOUS ITERATION                     25JL6
          IF ( ABSF( US(J) - UST(J) ) - CLTOL ) 6350, 6350, 6375          26JL6
 6350     IF ( ABSF( UB(J) - UBT(J) ) - CLTOL ) 6400, 6400, 6375          25JL6
 6375          NSTA = NSTA + 1                                            25JL6
 6400     CONTINUE                                                        25JL6
               JM1 = IM1 + 4                                              27JL6
               JM2 = IM2 + 4                                              27JL6
               JM3 = IM3 + 4                                              27JL6
               UM(1) = US(JM1)                                            25JL6
               UM(2) = UB(JM1)                                            25JL6
               UM(3) = US(JM2)                                            25JL6
               UM(4) = UB(JM2)                                            25JL6
               UM(5) = US(JM3)                                            25JL6
               UM(6) = UB(JM3)                                            25JL6
      PRINT 810, ITER, NSTA, ( UM(N), N = 1, 6 )                          25JL6
          IF ( NSTA ) 9980, 8000, 3000                                    26JL6
C-----COMPUTE RESULTS                                                     26JL6
 8000          W(2) = 2.0 * W(3) - W(4)                                   26JL6
               W(MP6) = 2.0 * W(MP5) - W(MP4)                             26JL6
          DO 8050  J = 3, MP5                                             26JL6
               DW2 = ( W(J-1) - 2.0 * W(J) + W(J+1) ) / HE2               26JL6
               BMS(J) = FS(J) * DW2                                       26JL6
               BMB(J) = FB(J) * DW2                                       26JL6
               SAL(J) = ( - US(J) + US(J+1) ) * AS(J) * ES(J) / H         26JL6
               BAL(J) = - ( - UB(J) + UB(J+1) ) * AB(J) * EB(J) / H       29JL6
 8050     CONTINUE                                                        26JL6
          DO 8100  J = 4, MP5                                             26JL6
               GAMA(J) = US(J) - UB(J) + 0.5 / H * ( CS(J-1) + CS(J)      26JL6
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```
     1                  + CB(J-1) + CB(J) ) * ( - W(J-1) + W(J) )       26JL6
              FPC(J) = SCM(J) * GAMA(J)                                  26JL6
              VS(J) = ( - BMS(J-1) + BMS(J) - FPC(J) * 0.5               26JL6
     1                * ( CS(J-1) + CS(J) ) + US(J) * SH(J) * SHD(J)    26JL6
     2                - ( SAL(J-1) + SAL(J) ) * 0.5 * ( - W(J-1)        26JL6
     3                + W(J) ) ) / H                                     26JL6
              VB(J) = ( - BMB(J-1) + BMB(J) - FPC(J) * 0.5               26JL6
     1                * ( CB(J-1) + CB(J) ) - UB(J) * BH(J) * BHD(J)    26JL6
     2                + ( BAL(J-1) + BAL(J) ) * 0.5 * ( - W(J-1)        26JL6
     3                + W(J) ) ) / H                                     26JL6
 8100         CONTINUE                                                   26JL6
          DO 8150  J = 3, MP5                                            26JL6
          IF ( KEY(J) - 1 ) 9980, 8130, 8120                             02AG6
 8120         REACT(J) = - VS(J) - VB(J) + VS(J+1) + VB(J+1)            02AG6
     1                  - Q(J) + ( TS(J-1) + TB(J-1) - TS(J+1)          26JL6
     2                  - TB(J+1) ) / HT2 - ( ( RS(J-1) + RB(J-1) )     26JL6
     3                  * W(J-2) - ( RS(J-1) + RB(J-1) ) * W(J)         26JL6
     4                  - ( RS(J+1) + RB(J+1) ) * W(J) + ( RS(J+1)      26JL6
     5                  + RB(J+1) ) * W(J+2) ) / ( 4.0 * HE2 )          02AG6
          GO TO 8150                                                     02AG6
 8130         REACT(J) = S(J) * W(J)                                     02AG6
 8150     CONTINUE                                                       26JL6
C-----PRINT RESULTS                                                      26JL6
      PRINT 11                                                           26JL6
      PRINT 1                                                            26JL6
      PRINT 13, ( AN1(N), N = 1, 32 )                                    26JL6
      PRINT 16, NPROB, ( AN2(N), N = 1, 14 )                             26JL6
          IF ( KERR ) 9980, 8175, 8160                                   26JL6
 8160 PRINT 830                                                          26JL6
 8175 PRINT 850                                                          26JL6
              ISTA = - 1                                                 26JL6
      PRINT 860, ISTA, W(3), BMS(3), SAL(3), BMB(3), BAL(3)              26JL6
          DO 8200  J = 4, MP5                                            26JL6
              ISTA = J - 4                                               26JL6
      PRINT 870, FPC(J)                                                  26JL6
      PRINT 860, ISTA, W(J), BMS(J), SAL(J), BMB(J), BAL(J)              26JL6
 8200     CONTINUE                                                       26JL6
      PRINT 11                                                           26JL6
      PRINT 1                                                            26JL6
      PRINT 13, ( AN1(N), N = 1, 32 )                                    26JL6
      PRINT 16, NPROB, ( AN2(N), N = 1, 14 )                             26JL6
          IF ( KERR ) 9980, 8195, 8180                                   26JL6
 8180 PRINT 830                                                          26JL6
 8195 PRINT 875                                                          26JL6
              ISTA = - 1                                                 26JL6
      PRINT 880, ISTA, REACT(3)                                          26JL6
          DO 8300  J = 4, MP5                                            26JL6
              ISTA = J - 4                                               26JL6
      PRINT 890, US(J), VS(J), UB(J), VB(J), GAMA(J)                     26JL6
      PRINT 880, ISTA, REACT(J)                                          26JL6
 8300     CONTINUE                                                       26JL6
      CALL TIC TOC (4)                                                   25SE66
          GO TO 1010                                                     26AG3 ID
 9980 PRINT 980                                                          28MR6
 9990 CONTINUE                                                           12MR5 ID
```

```
9999 CONTINUE                                                          04MY3 ID
     PRINT 11                                                          08MY3 ID
     PRINT 1                                                           18FE5 ID
     PRINT 13, ( AN1(N), N = 1, 32 )                                   18FE5 ID
     PRINT 19                                                          26AG3 ID
     END                                                               04MY3 ID
     SUBROUTINE INTERP4 ( MP7, NCT, JN1, JN2, KR2, ZN, Z, LSM )        15JL6
     DIMENSION JN1(100), JN2(100), KR2(100), ZN(100), Z(207)           28JE6
 905 FORMAT ( //40H     ERROR STOP -- STATIONS NOT IN ORDER )          14MY5
 908 FORMAT ( //43H     UNDESIGNATED ERROR STOP IN SUBROUTINE  )       14MY5
         DO 1603  J = 1, MP7                                           26MR5
              Z(J) = 0.0                                               26MR5
1603     CONTINUE                                                      26MR5
              M = MP7 - 7                                              10FE6
              KR1 = 0                                                  12JA5
         IF( 1     .GT.NCT     ) GO TO 1676                            01SE66
         DO 1675  NC = 1, NCT                                          26MR5
         IF ( KR1 ) 1698, 1605, 1610                                   02JL6
1605          NC1 = NC                                                 12JA5
              JV = JN1(NC1)                                            28JE6
              KSM = 0                                                  28JE6
         IF ( KR2(NC) ) 1698, 1610, 1670                               02JL6
1610          J1 = JV + 4                                              28JE6
              J2 = JN2(NC) + 4                                         28JE6
              JS = J1 + KSM                                            02JL6
              DENOM = J2 - J1                                          28JE6
              JINCR = 1                                                28JE6
              ESM = 1.0                                                28JE6
              ISW = 1 - LSM                                            28JE6
         IF ( DENOM ) 1695, 1620, 1630                                 12JA5
1620          DENOM = 1.0                                              12JA5
              ISW = 0                                                  12JA5
1630     DO 1650  J = JS, J2, JINCR                                    28JE6
              DIFF = J - J1                                            28JE6
              PART = DIFF / DENOM                                      02JL6
              Z(J) = Z(J) + ( ZN(NC1) + PART * ( ZN(NC) - ZN(NC1) ) )  28JE6
    1                WM * ESM                                          28JE6
1650     CONTINUE                                                      12JA5
              KSM = LSM                                                28JE6
         IF ( ISW ) 1698, 1660, 1655                                   28JE6
1655          JINCR = J2 - J1                                          12JA5
              ESM = -0.5                                               12JA5
              ISW = 0                                                  12JA5
         GO TO 1630                                                    12JA5
1660     IF ( KR2(NC) ) 1698, 1670, 1665                               12JA5
1665          JV = JN2(NC)                                             28JE6
1670          KR1 = KR2(NC)                                            12JA5
              NC1 = NC                                                 12JA5
1675     CONTINUE                                                      12JA5
1676 RETURN                                                            14MY5
1695 PRINT 905                                                         14MY5
         GO TO 1799                                                    18JA8
1698 PRINT 908                                                         14MY5
         GO TO 1799                                                    18JA8
1799     CONTINUE                                                      18JA8
```

```
      END                                                                 04MA3 ID
      SUBROUTINE TIC TOC (J)                                              240C66
   10 FORMAT(///30X19HELAPSED CPU TIME = I5,8H MINUTESF9.3,8H SECONDS )  25SE66
   11 FORMAT(///30X15HCOMPILE TIME = ,I5,8H MINUTES,F9.3,8H SECONDS    )  25SE66
   12 FORMAT(///30X24HTIME FOR THIS PROBLEM = ,I5,8H MINUTES,F9.3,        25SE66
     1       8H SECONDS  )                                                25SE66
               I = J - 2                                                  240C66
          IF( I-1 ) 40,30,30                                              25SE66
   30          FI4 = F                                                    25SE66
   40 CALL SECOND (F)                                                     25SE66
               II1 = F                                                    25SE66
               I1 = II1 / 60                                              25SE66
               FI2 =  F - I1*60                                           25SE66
          IF( I ) 50,70,60                                                25SE66
   50 PRINT 11, I1,FI2                                                    25SE66
          GO TO 990                                                       25SE66
   60          FI3 = F - FI4                                              25SE66
               I2 = FI3 / 60                                              25SE66
               FI3 = FI3 - I2*60                                          25SE66
      PRINT 12, I2, FI3                                                   25SE66
          IF( I-1 ) 990,990,70                                            25SE66
   70 PRINT 10, I1,FI2                                                    25SE66
  990 CONTINUE                                                            25SE66
      RETURN                                                              25SE66
      END                                                                 25SE66
```

APPENDIX 3

GLOSSARY OF NOTATION FOR COMBM 1

```
C-----NOTATION FOR COMBM 1                                              06AG6
C
C
C         A( , )              MATRIX COEFFICIENTS                       06AG6
C         AB( )               CROSS SECTIONAL AREA OF BEAM              06AG6
C         ABN2( )             BEAM CROSS SECTIONAL AREA ( INPUT )       06AG6
C         AN1( ), AN2( )      IDENTIFICATION AND REMARKS (ALPHA-NUM)    06AG6
C         AS( )               CROSS SECTIONAL AREA OF SLAB              06AG6
C         ASN2( )             SLAB CROSS SECTIONAL AREA ( INPUT )       06AG6
C         B( , )              MATRIX COEFFICIENTS                       06AG6
C         BAL( )              BEAM AXIAL LOAD                           06AG6
C         BH( )               BEAM HORIZONTAL SPRING CONSTANT           06AG6
C         BHD( )              DIST OF BEAM N.A. TO HORIZ SPRING         06AG6
C         BHDN( )             DIST OF BEAM N.A. TO HORIZ SPRING (INPUT) 06AG6
C         BI( )               BEAM MOMENT OF INERTIA                    06AG6
C         BIN2( )             BEAM MOMENT OF INERTIA ( INPUT )          06AG6
C         BMB( )              BENDING MOMENT IN BEAM                    06AG6
C         BMS( )              BENDING MOMENT IN SLAB                    06AG6
C         C( , )              MATRIX COEFFICIENTS                       06AG6
C         CB( )               DISTANCE FROM BEAM N.A. TO INTERFACE      06AG6
C         CBN2( )             DIST FROM BEAM N.A. TO INTERFACE ( INPUT )06AG6
C         CLTOL               CLOSURE TOLERANCE FOR NON-LINEAR SOLUTION 06AG6
C         CM                  COEFFICIENT MULTIPLIER FOR ELIMINATING    06AG6
C                                  TERMS BELOW THE MAIN DIAGONAL        06AG6
C         CS( )               DISTANCE FROM SLAB N.A. TO INTERFACE      06AG6
C         CSN2( )             DIST FROM SLAB N.A. TO INTERFACE ( INPUT )06AG6
C         DENOM               DENOMINATOR                               06AG6
C         DIFF                DIFFERENCE                                06AG6
C         DW( )               FIRST DERIVATIVE OF DEFLECTION ( SLOPE )  06AG6
C         DW2                 SECOND DERIVATIVE OF DEFLECTION           06AG6
C         EB( )               MODULUS OF ELASTICITY OF BEAM             06AG6
C         EBN2( )             BEAM MODULUS OF ELASTICITY ( INPUT )      06AG6
C         ES( )               MODULUS OF ELASTICITY OF SLAB             06AG6
C         ESM                 MULTIPLIER FOR END STATIONS               06AG6
C         ESN2( )             SLAB MODULUS OF ELASTICITY ( INPUT )      06AG6
C         FB( )               BEAM FLEXURAL STIFFNESS  (TOTAL PER STA)  06AG6
C         FPC( )              FORCE IN SHEAR CONNECTORS (TOTAL PER STA) 06AG6
C         FS( )               SLAB FLEXURAL STIFFNESS  (TOTAL PER STA)  06AG6
C         GAMA( )             TOTAL  SLIP AT INTERFACE                  06AG6
C         H                   INCREMENT LENGTH                          06AG6
C         HE2                 H SQUARED                                 06AG6
C         HE3                 H CUBED                                   06AG6
C         HT2                 H TIMES 2                                 06AG6
C         IM1, IM2, IM3       MONITOR STATIONS                          06AG6
C         IN13( )             EXTERNAL STA NUMBER FOR SPECIFIED DEFLECT 06AG6
C         IN14( ), IN15( ),   INITIAL EXTERNAL STA USED IN TABLES       06AG6
C           IN16( ), IN17( )       4, 5, 6, AND 7                       06AG6
C         IN24( ), IN25( ),   FINAL EXTERNAL STA USED IN TABLES         06AG6
C           IN26( ), IN27( )       4, 5, 6, AND 7                       06AG6
C         INSAV               TEMPORARY VALUE OF IN13( )                06AG6
C         ISTA                OUTPUT VALUE OF STA NUMBER                06AG6
C         ISW                 ROUTING SWITCH                            06AG6
C         ITER                ITERATION NUMBER                          06AG6
C         ITEST               = 5 ALPHANUMERIC BLANKS USED TO TERMINATE 06AG6
C                                  THE PROGRAM                          06AG6
```

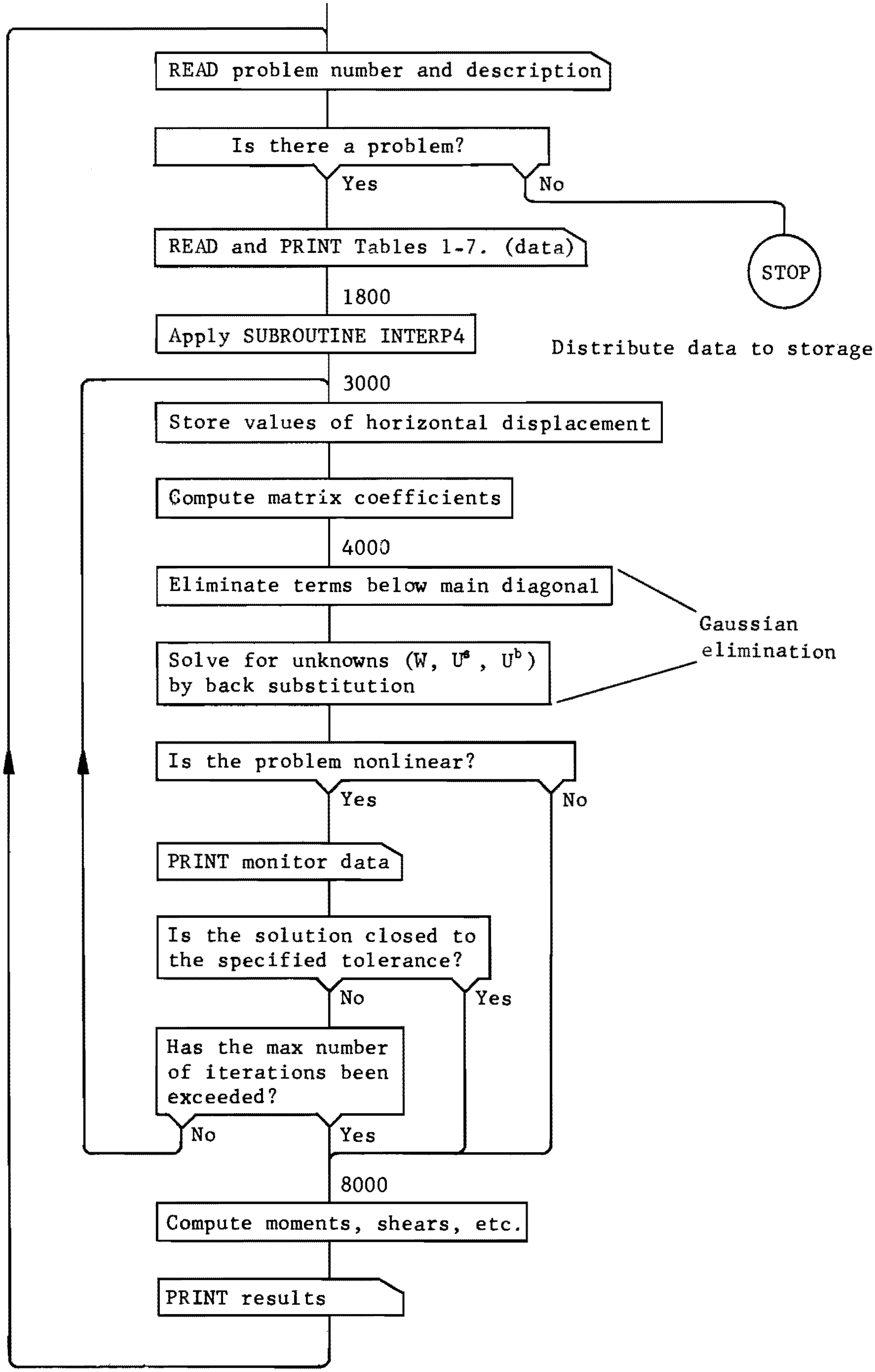
```
C         ITMAX               MAXIMUM NUMBER OF ITERATIONS ALLOWED FOR  06AG6
C                                  NON-LINEAR SOLUTION                  06AG6
C         J                   DO LOOP INDEX, = STA NUMBER               06AG6
C         J1                  INITIAL STA IN THE DISTRIBUTION SEQUENCE  06AG6
C         J2                  FINAL STATION IN THE DISTRIBUTION SEQUENCE06AG6
C         JA                  INDEX IN TABLE 3 SORTING PROCEDURE        06AG6
C         JINCR               INCREMENTATION INDEX                      06AG6
C         JM1                 JA - 1                                    06AG6
C         JM2, JM3            INTERNAL MONITOR STATION NUMBER           06AG6
C         JN1( ), JN2( )      INITIAL AND FINAL EXTERNAL STATION NUMBER 06AG6
C                                  OF THE DISTRIBUTION SEQUENCE         06AG6
C         JS                  STA OF SPECIFIED DEFLECTION               06AG6
C         JV                  INITIAL STA NUMBER ON PREVIOUS CARD       06AG6
C         KEEP2 THRU KEEP7    IF = 1, KEEP PRIOR DATA, TABLES 2-7       06AG6
C         KERR                SWITCH TO INDICATE IF SOLUTION IS CLOSED  06AG6
C         KEY( )              ROUTING SWITCH FOR SPECIFIED DEFLECTIONS  06AG6
C         KR1                 PRIOR VALUE OF KR2( )                     06AG6
C         KR2( )              CONTINUE SWITCH                           06AG6
C         KR24( ), KR25( ),   CONTINUE SWITCHES IN TABLES               06AG6
C           KR26( ), KR27( )         4, 5, 6, AND 7                     06AG6
C         KSM                 SWITCH USED FOR DISTRIBUTING VALUES TO    06AG6
C                                  HALF-STATIONS                        06AG6
C         KSW4( ), KSW5( ),   ROUTING SWITCH IN TABLES                  06AG6
C           KSW6( ), KSW7( )         4, 5, 6, AND 7                     06AG6
C         L                   DO LOOP INDEX                             06AG6
C         LABEL               DUMMY VARIABLE USED TO LABEL PROBLEMS     06AG6
C         LSM                 SWITCH FOR DISTRIBUTING VALUES TO         06AG6
C                                  HALF-STATIONS                        06AG6
C         M                   TOTAL NUMBER OF INCREMENTS                06AG6
C         MP2 THRU MP7        M + 2  THRU  M + 7                        06AG6
C         N                   MATRIX COEFFICIENT SUPERSCRIPT            06AG6
C         NC14 THRU NC17      INITIAL INDEX VALUE FOR THE INPUT TO THE  06AG6
C                                  PARTICULAR TABLE                     06AG6
C         NCD2 THRU NCD7      NUM CARDS IN TABLES 2 THRU 7, THIS PROB   06AG6
C         NCT3 THRU NCT7      TOTAL NUMBER OF CARDS IN THE PARTICULAR   06AG6
C                                  TABLE                                06AG6
C         NPROB               PROBLEM NUMBER (PROGRAM STOPS IF BLANK)   06AG6
C         NS                  INDEX NUMBER FOR SPECIFIED DEFLECTION     06AG6
C         NSTA                NUMBER OF STATIONS NOT CLOSED             06AG6
C         PART                INTERPOLATION FRACTION                    06AG6
C         PB( )               LONGITUDINAL BEAM LOAD                    06AG6
C         PBN2( )             LONGITUDINAL BEAM LOAD ( INPUT )          06AG6
C         PS( )               LONGITUDINAL SLAB LOAD                    06AG6
C         PSN2( )             LONGITUDINAL SLAB LOAD ( INPUT )          06AG6
C         Q( )                TRANSVERSE FORCE (TOTAL PER STA)          06AG6
C         QN2( )              TRANSVERSE FORCE ( INPUT )                06AG6
C         RB( )               ROTATIONAL BEAM RESTRAINT (TOTAL PER STA) 06AG6
C         RBN2( )             ROTATIONAL BEAM RESTRAINT ( INPUT )       06AG6
C         REACT( )            SUPPORT REACTION AT EACH STA              06AG6
C         RS( )               ROTATIONAL SLAB RESTRAINT (TOTAL PER STA) 06AG6
C         RSN2( )             ROTATIONAL SLAB RESTRAINT ( INPUT )       06AG6
C         S( )                SPRING SUPPORT STIFFNESS (TOTAL PER STA)  06AG6
C         SAL( )              SLAB AXIAL LOAD                           06AG6
C         SCM( )              SHEAR CONNECTOR MODULUS (TOTAL PER STA)   06AG6
C         SCMN( )             SHEAR CONNECTOR MODULUS ( INPUT )         06AG6
```

```
C           SH( )                 SLAB HORIZONTAL SPRING CONSTANT            06AG6
C           SHD( )                DIST OF SLAB N.A. TO HORIZ SPRING          06AG6
C           SHDN( )               DIST OF SLAB N.A. TO HORIZ SPRING (INPUT)  06AG6
C           SI( )                 SLAB MOMENT OF INERTIA                     06AG6
C           SIN2( )               SLAB MOMENT OF INERTIA ( INPUT )           06AG6
C           SMD                   SUMMATION OF PRODUCT OF HORIZ SPRING AND   06AG6
C                                      HORIZ DISPLACEMENT                    06AG6
C           SMD1 THRU SMD3        NONLINEAR TERMS OF THE EQUATION            06AG6
C           SMP                   SUMMATION OF LONGITUDINAL LOADS            06AG6
C           SMP1                  SMP + ADDITIONAL LONGITUDINAL LOADS        06AG6
C           SN2( )                SPRING SUPPORT STIFFNESS ( INPUT )         06AG6
C           TB( )                 TRANSVERSE BEAM TORQUE  (TOTAL PER STA)    06AG6
C           TBN2( )               TRANSVERSE BEAM TORQUE ( INPUT )           06AG6
C           TC( )                 TEMPORARY COEFFICIENTS USED TO ELIMINATE   06AG6
C                                      TERMS BELOW THE MAIN DIAGONAL         06AG6
C           TS( )                 TRANSVERSE SLAB TORQUE  (TOTAL PER STA)    06AG6
C           TSN2( )               TRANSVERSE SLAB TORQUE ( INPUT )           06AG6
C           UB( )                 LONGITUDINAL DISPLACEMENT OF BEAM          06AG6
C           UBT( )                LONGITUDINAL DISPLACEMENT OF BEAM          06AG6
C                                      FROM PREVIOUS ITERATION               06AG6
C           UM( )                 DISPLACEMENTS AT THE MONITOR STATIONS      06AG6
C           US( )                 LONGITUDINAL DISPLACEMENT OF SLAB          06AG6
C           UST( )                LONGITUDINAL DISPLACEMENT OF SLAB          06AG6
C                                      FROM PREVIOUS ITERATION               06AG6
C           VB( )                 SHEAR IN BEAM                              06AG6
C           VS( )                 SHEAR IN SLAB                              06AG6
C           W( )                  LATERAL DEFLECTION                         06AG6
C           WS(   )               SPECIFIED VALUE OF DEFL AT STA JS          06AG6
C           WSAV                  TEMPORARY VALUE OF WS( )                   06AG6
C           Z( )                  INTERPOLATED VALUE                         06AG6
C           ZN( )                 INPUT VALUE FOR INTERPOLATION              06AG6
```

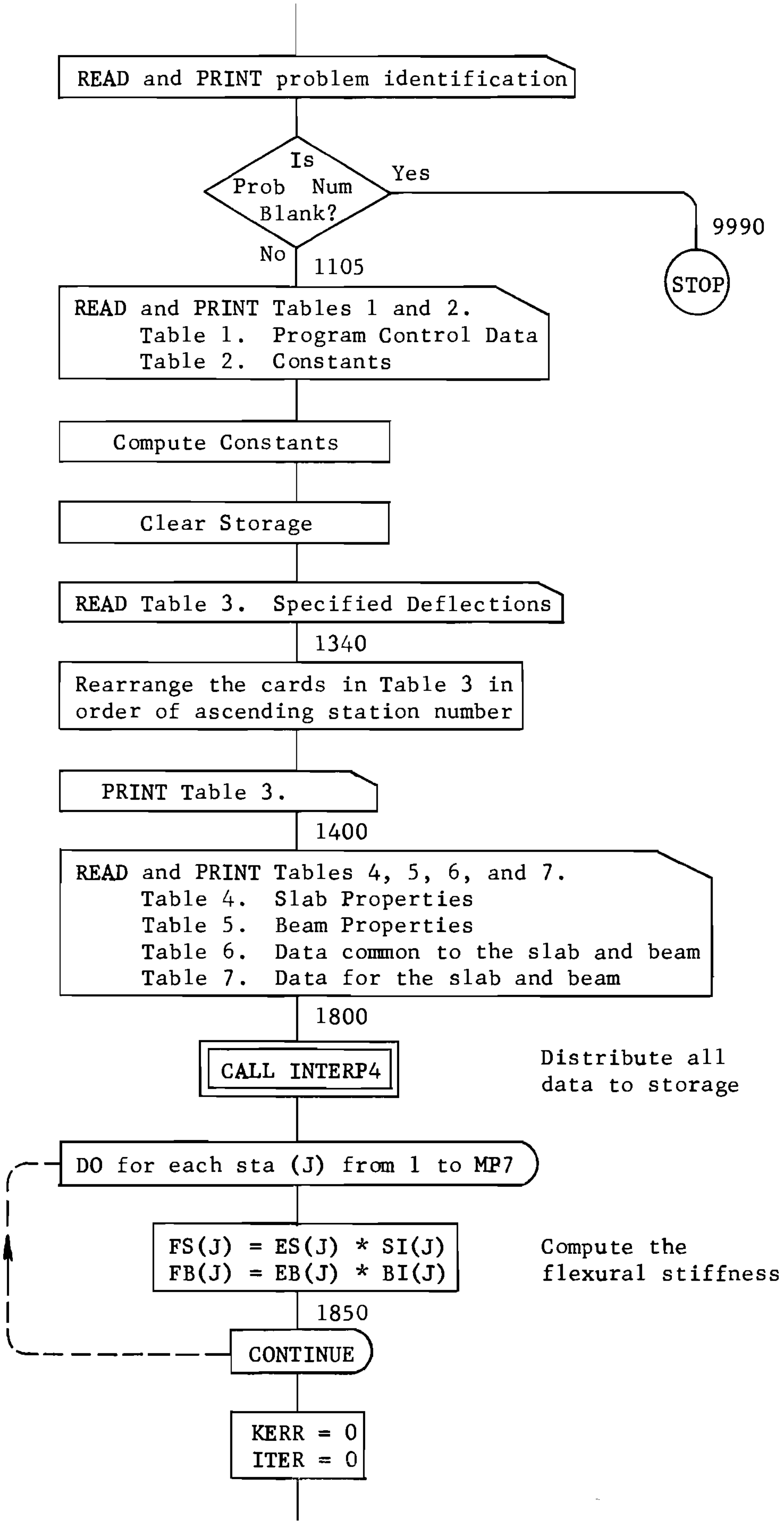
APPENDIX 4

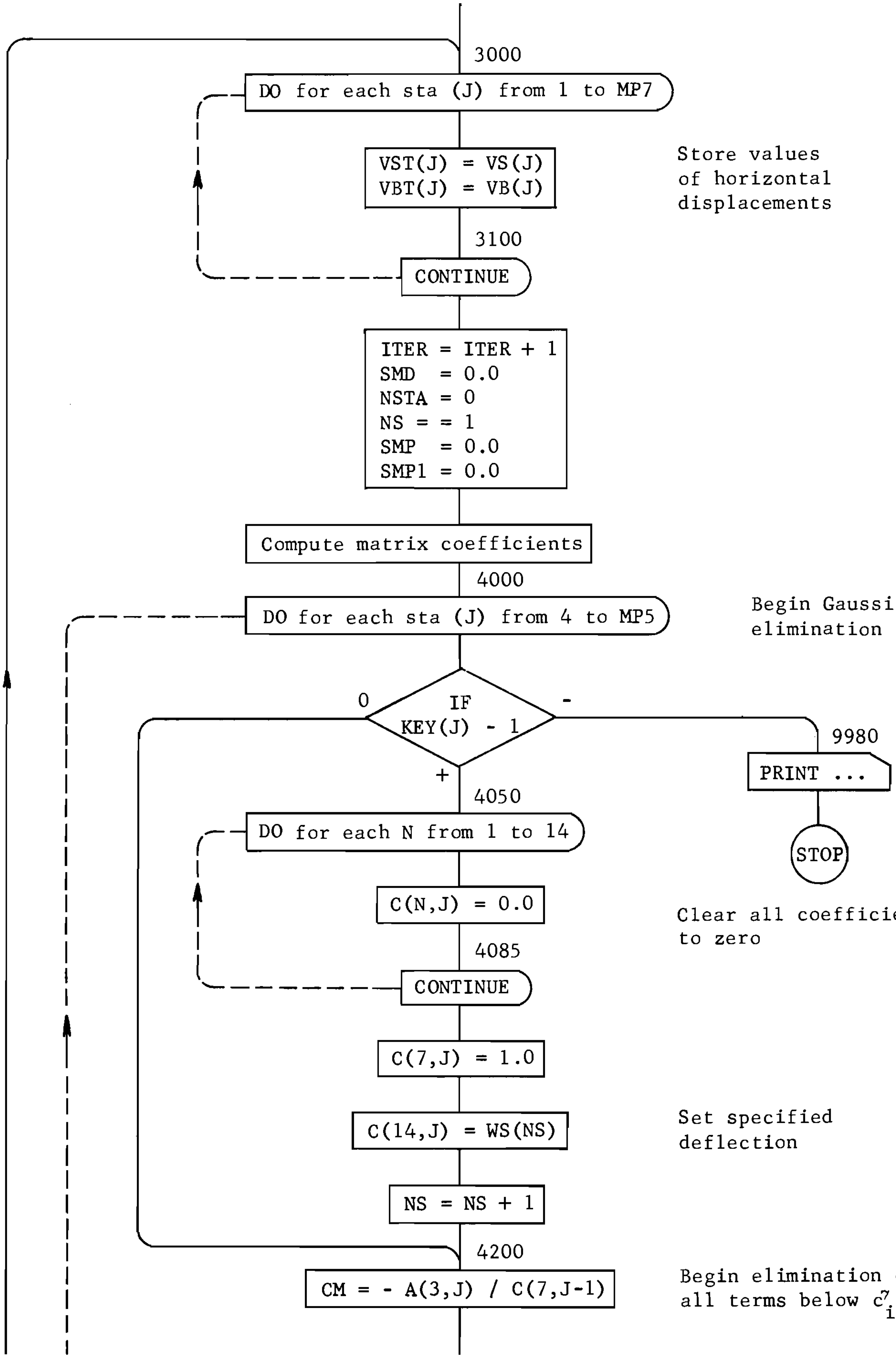
FLOW DIAGRAMS FOR COMBM 1

SUMMARY FLOW DIAGRAM FOR PROGRAM COMBM 1



GENERAL FLOW DIAGRAM FOR PROGRAM COMBM 1





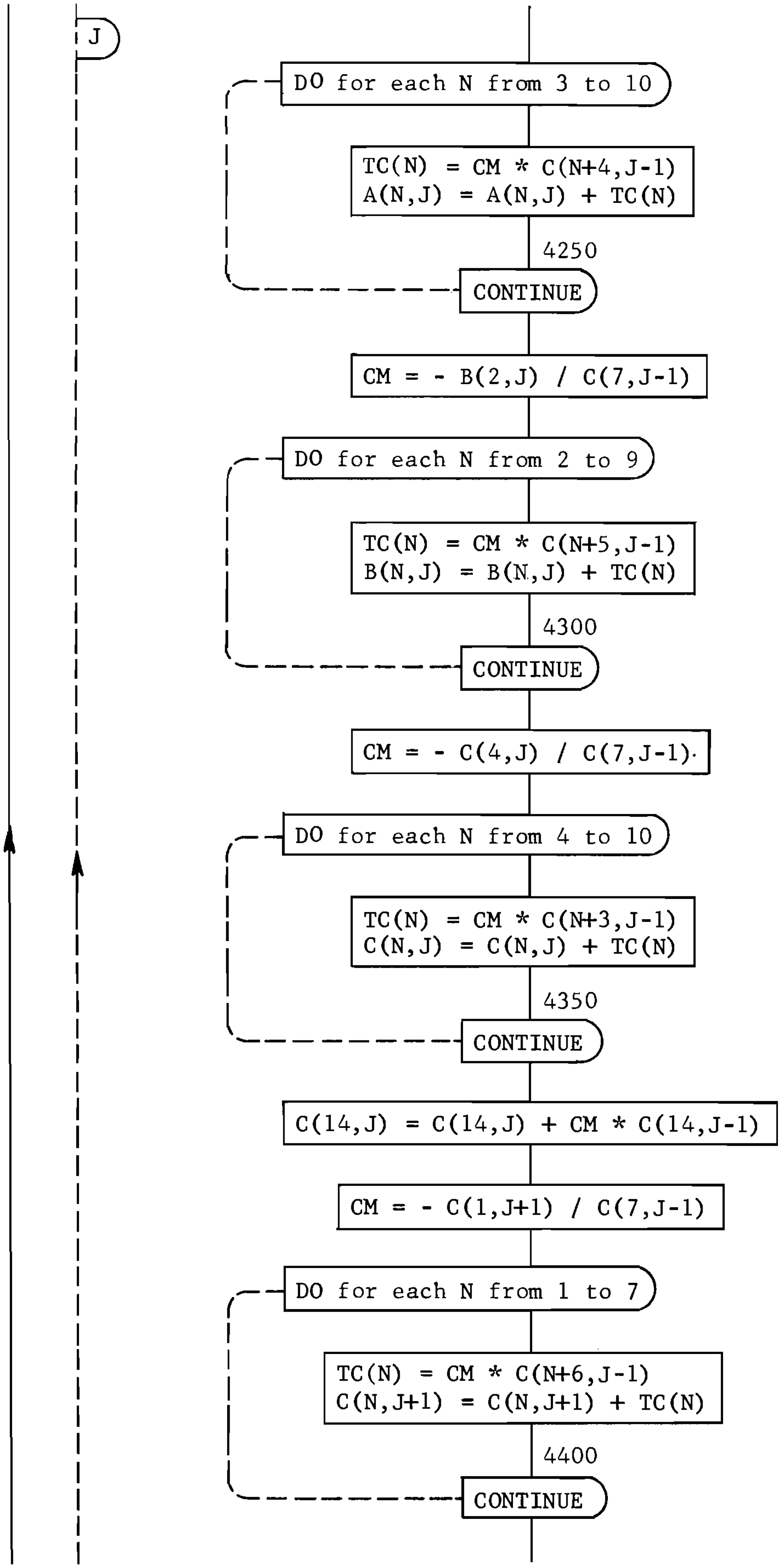
Store values of horizontal displacements

Begin Gaussian elimination

Clear all coefficients to zero

Set specified deflection

Begin elimination of all terms below c^7_{i-1}

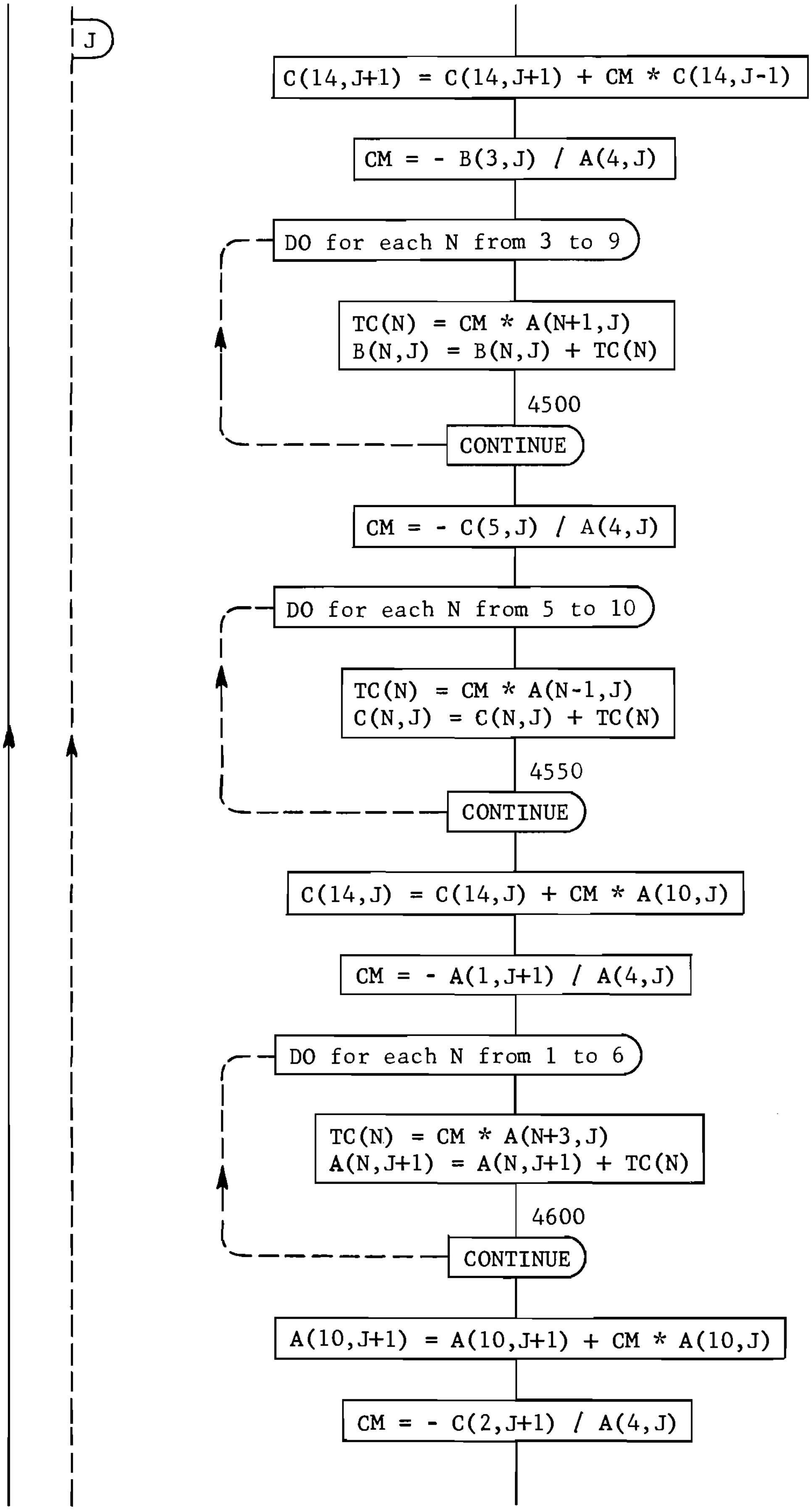


Eliminate a_i^3

Eliminate b_i^2

Eliminate c_i^4

Eliminate c_{i+1}^1

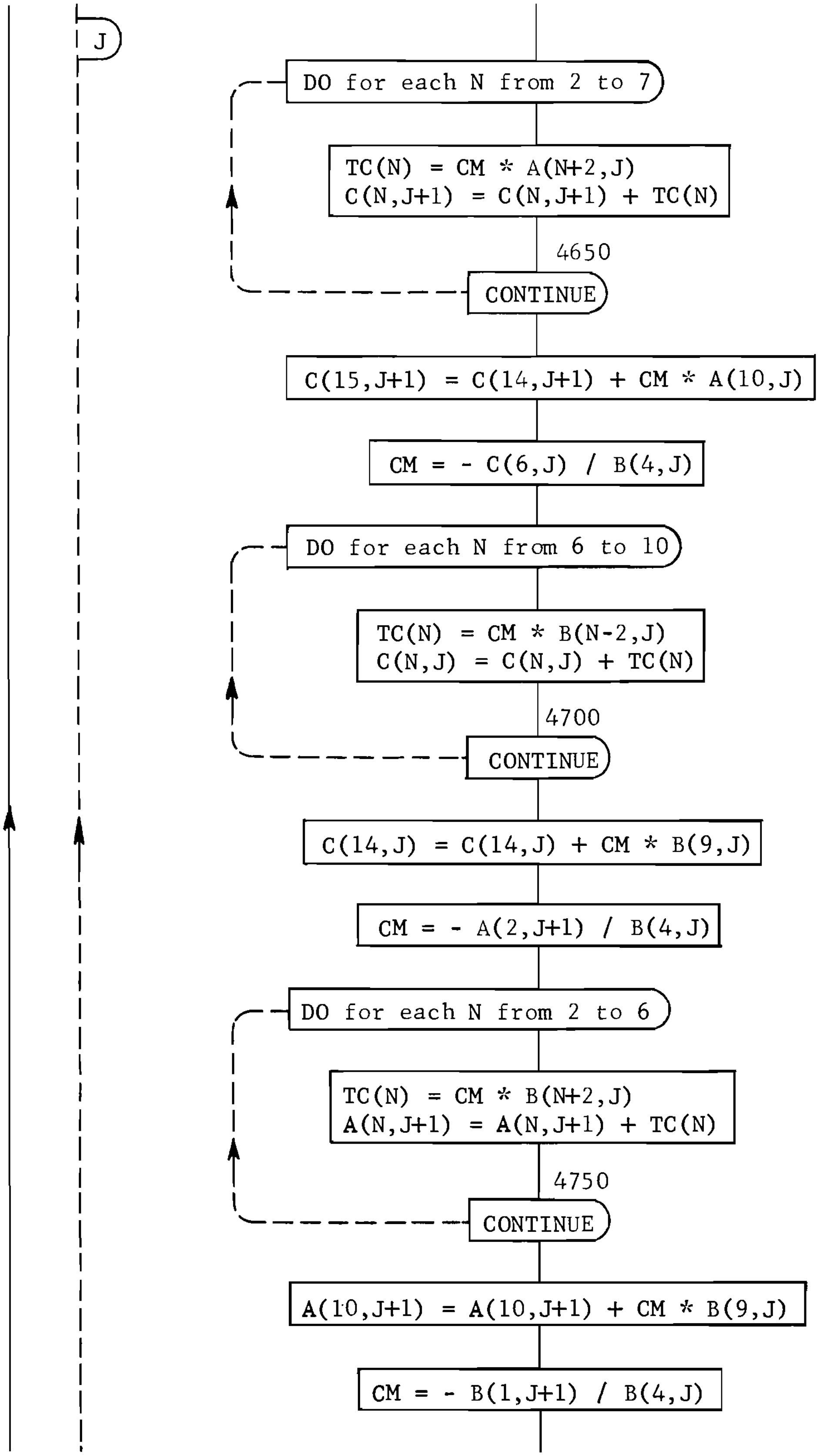


Begin elimination of all terms below a_i^4

Eliminate b_i^3

Eliminate c_i^5

Eliminate a_{i+1}^1

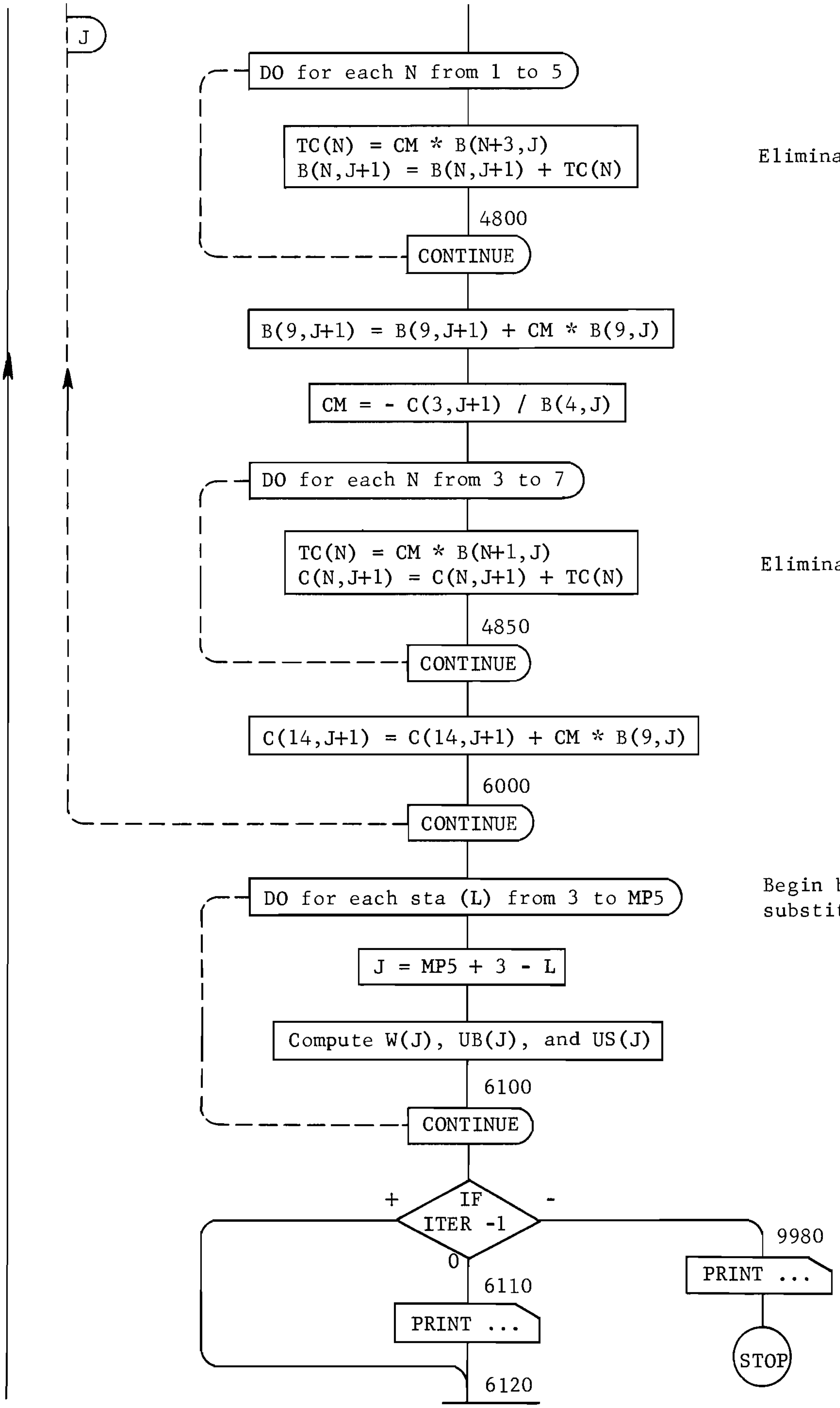


Eliminate c^{2}_{i+1}

Begin elimination of all terms below b^{4}_{i}

Eliminate c^{6}_{i}

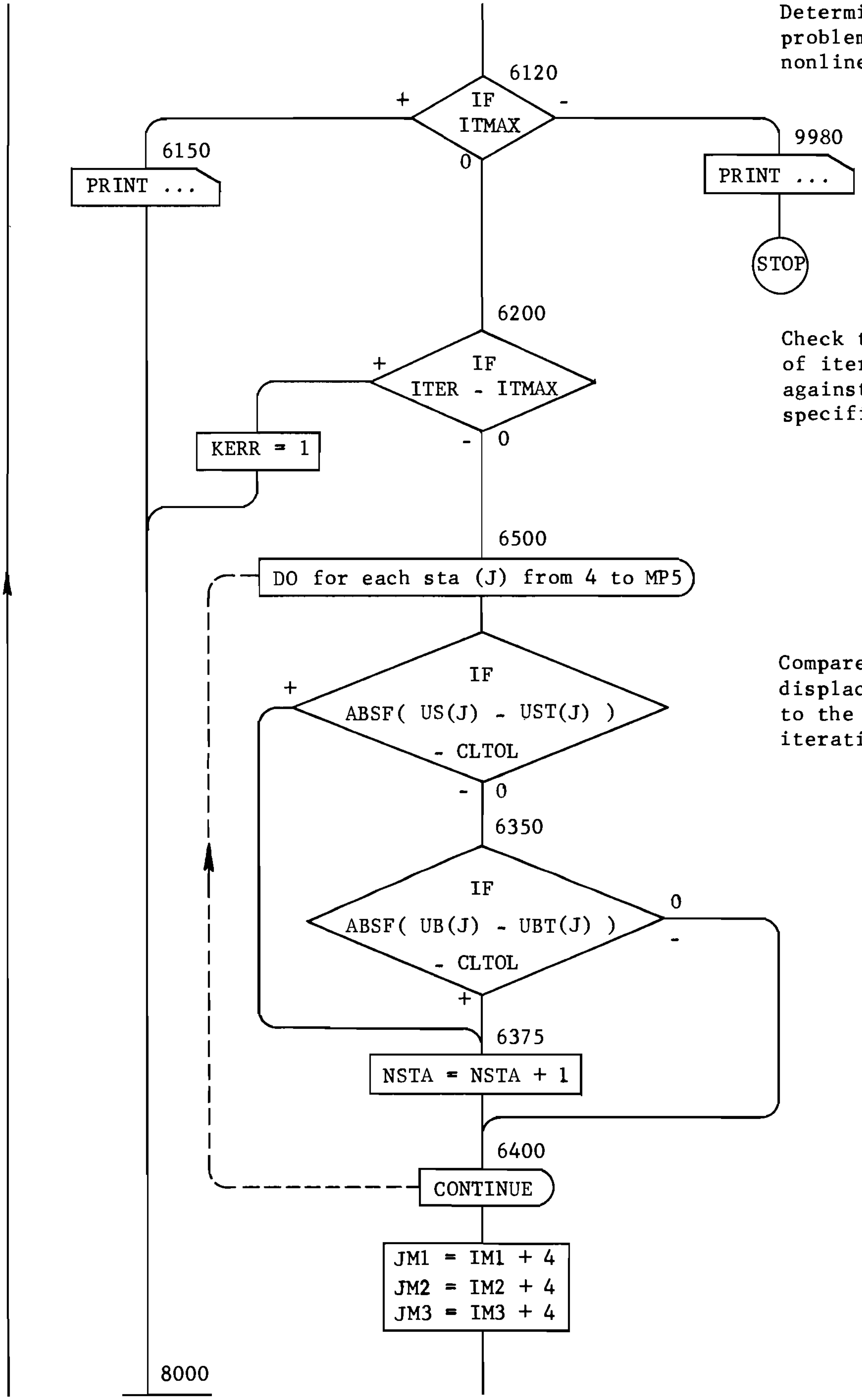
Eliminate a^{2}_{i+1}



Eliminate b^{1}_{i+1}

Eliminate c^{3}_{i+1}

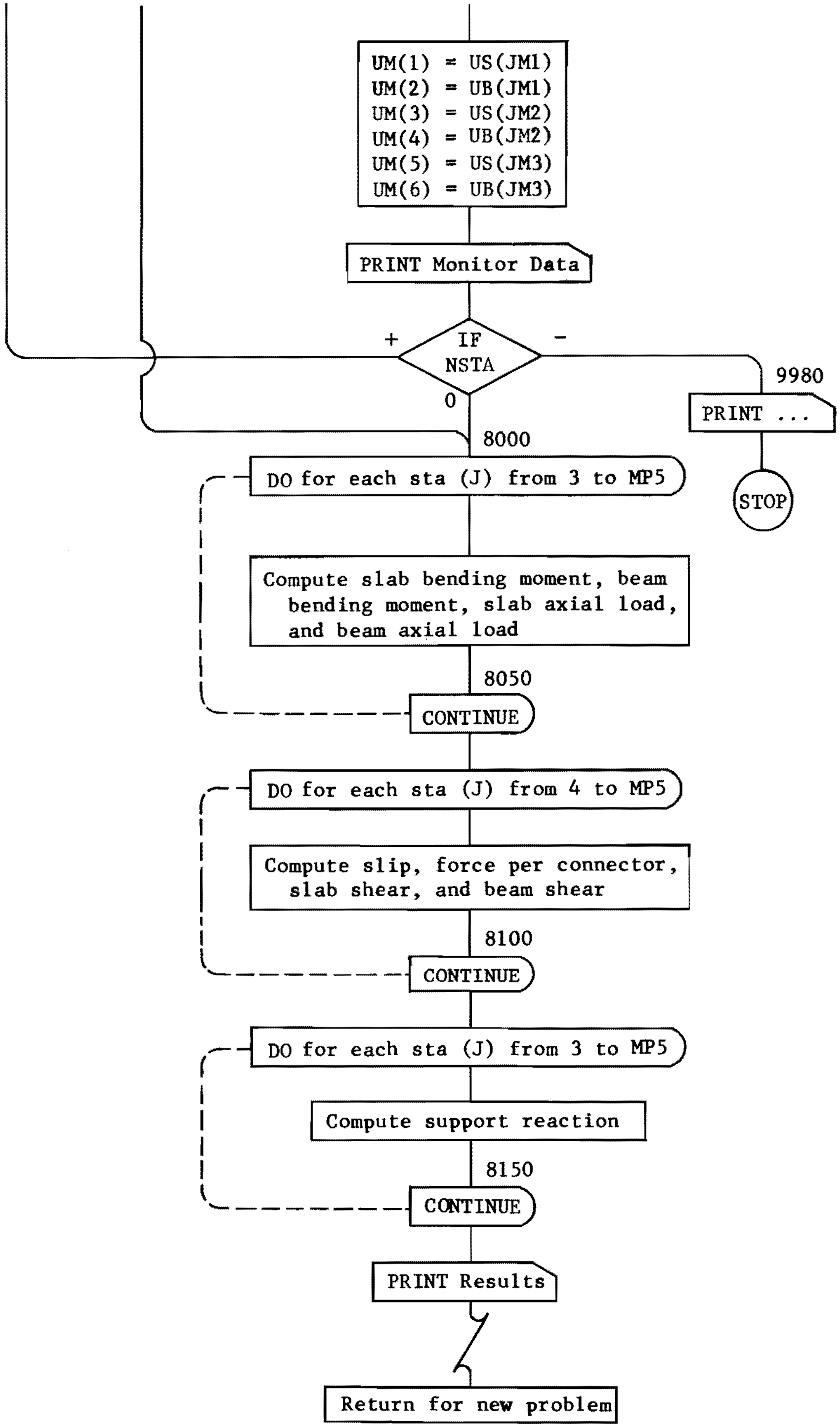
Begin back
substitution



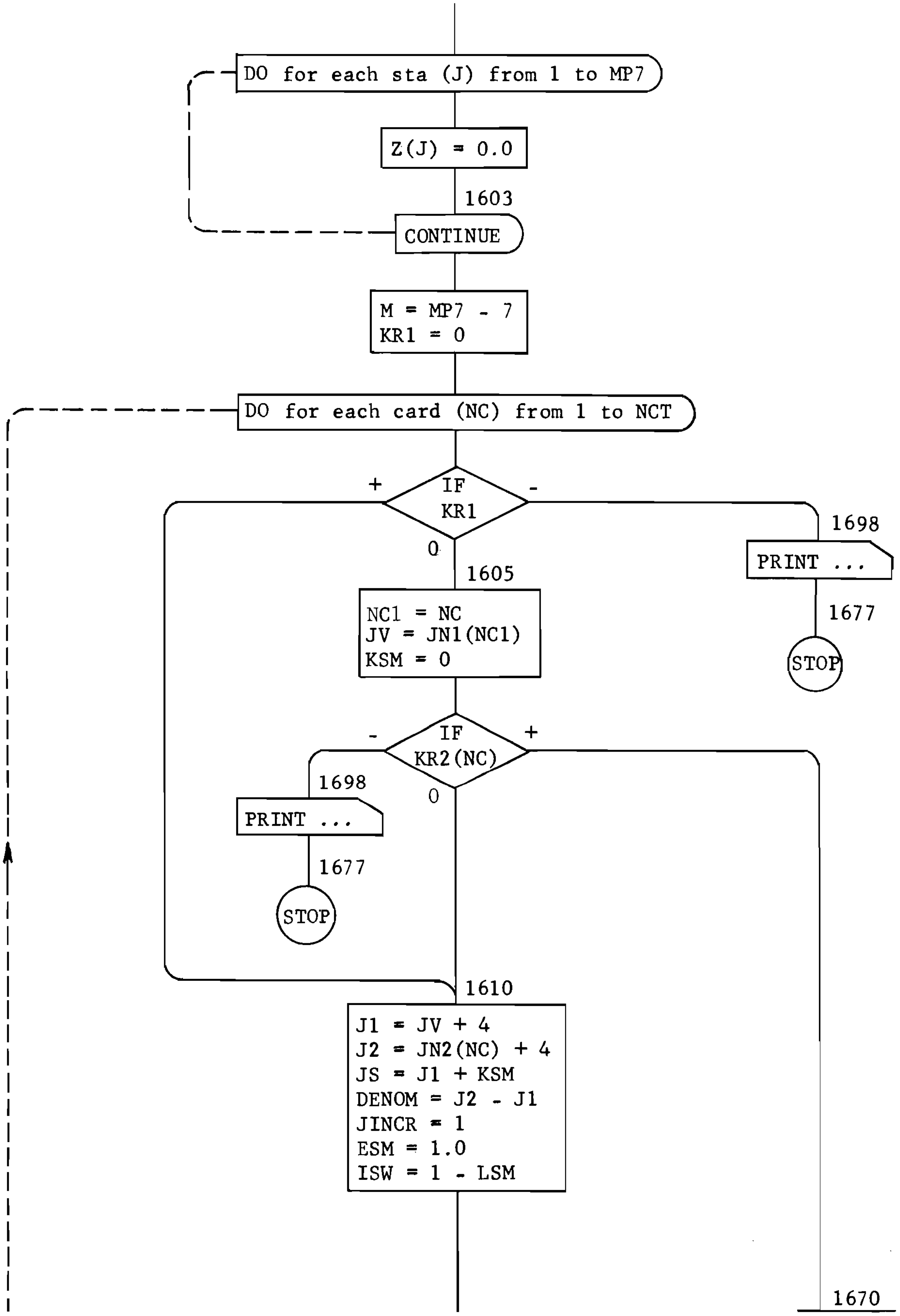
Determine if problem is nonlinear

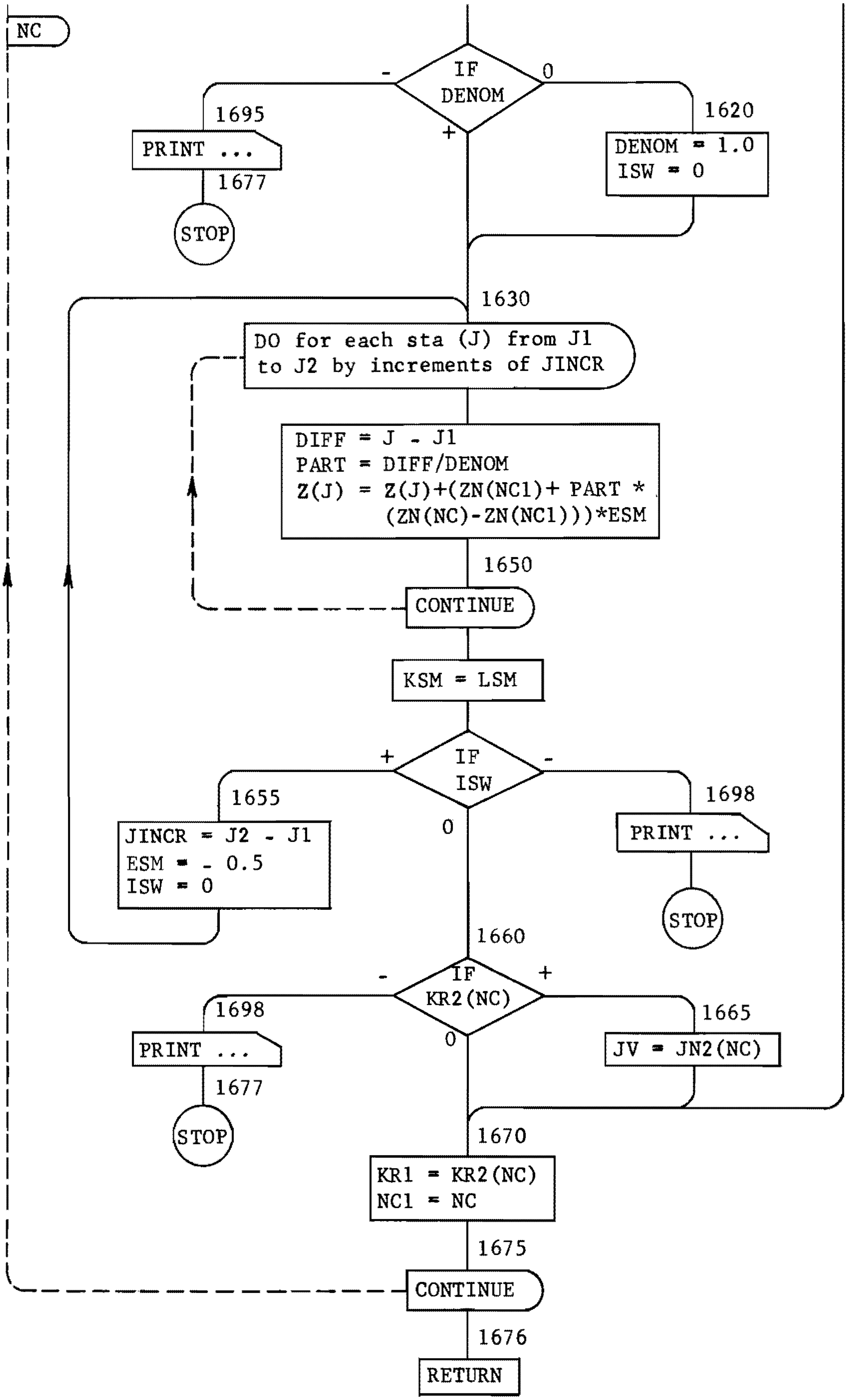
Check the number of iterations against the specified limit

Compare displacements to the previous iteration


UM(1) = US(JM1)
UM(2) = UB(JM1)
UM(3) = US(JM2)
UM(4) = UB(JM2)
UM(5) = US(JM3)
UM(6) = UB(JM3)
PRINT Monitor Data
+
IF NSTA
−
0
9980
PRINT ...
STOP
8000
DO for each sta (J) from 3 to MP5
Compute slab bending moment, beam bending moment, slab axial load, and beam axial load
8050
CONTINUE
DO for each sta (J) from 4 to MP5
Compute slip, force per connector, slab shear, and beam shear
8100
CONTINUE
DO for each sta (J) from 3 to MP5
Compute support reaction
8150
CONTINUE
PRINT Results
Return for new problem

SUBROUTINE INTERP4




NC
IF DENOM
-
0
+
1695
PRINT ...
1677
STOP
1620
DENOM = 1.0
ISW = 0
1630
DO for each sta (J) from J1 to J2 by increments of JINCR
DIFF = J - J1
PART = DIFF/DENOM
Z(J) = Z(J)+(ZN(NC1)+ PART * (ZN(NC)-ZN(NC1)))*ESM
1650
CONTINUE
KSM = LSM
IF ISW
+
-
0
1655
JINCR = J2 - J1
ESM = - 0.5
ISW = 0
1698
PRINT ...
STOP
1660
IF KR2(NC)
-
+
0
1698
PRINT ...
1677
STOP
1665
JV = JN2(NC)
1670
KR1 = KR2(NC)
NC1 = NC
1675
CONTINUE
1676
RETURN

APPENDIX 5

LISTING OF INPUT DATA FOR EXAMPLE PROBLEMS

```
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM
    1     SIMPLE BEAM, UNIFORM SHEAR CONNECTOR SPACING
              0                             1    2    1    2    6    0
        20           1.200E+01
         0           0.000E+00
        20           0.000E+00
         0   20    0 2.300E+06 3.647E+02 2.160E+02 2.250E+00
         0   20    0 2.900E+07 2.041E+02 7.970E+00 6.000E+00
         0    0    0                                         1.000E+06 0.000E+00
         1   20    0 1.400E+06
         0   20    0          -1.920E+02
         3    3    0          -1.000E+04
         8    8    0          -1.000E+04
        12   12    0          -1.000E+04
        17   17    0          -1.000E+04
   2A     SIMPLE BEAM, BEAM PROPERTIES ONLY
              0                             1    2    0    2    1    0
        20           1.200E+01
         0           0.000E+00
        20           0.000E+00
         0   20    0 2.900E+07 2.041E+02 7.970E+00 6.000E+00
         0    0    0                                         1.000E+06 0.000E+00
         0   20    0          -1.920E+02
   2B     SIMPLE COMPOSITE BEAM, LIVE LOAD ONLY
              1    1    0    1    0    0    0    0    1    0    5    0
         0   20    0 2.300E+06 3.647E+02 2.160E+02 2.250E+00
         1   20    0 1.400E+06
         3    3    0          -1.000E+04
         8    8    0          -1.000E+04
        12   12    0          -1.000E+04
        17   17    0          -1.000E+04
    3     A CANTILEVER BEAM, SHEAR CONNECTORS SPACED ACCORDING TO SHEAR DIAGRAM
              0                             1    1    2    2    8    1
        20           6.000E+00
         0           0.000E+00
         0   20    0 2.300E+06 3.647E+02 2.160E+02 2.250E+00
         0    0    0                     3.240E+02           1.000E+12
         0   20    0 2.900E+07 2.041E+02 7.970E+00 6.000E+00
         0    0    0                     1.196E+01           1.000E+12
         1   10    0 1.400E+06
        12   12    0 1.400E+06
        14   14    0 1.400E+06
        16   16    0 1.400E+06
        18   18    0 1.400E+06
        20   20    0 1.400E+06
        10   10    0           5.000E+03
        20   20    0           5.000E+03
         0    0    0                     1.000E+13 1.000E+13
    4     A TWO-SPAN BEAM
              0                             1    3    5    8    6    0
        60           1.200E+01
         0           0.000E+00
        30           0.000E+00
        60           0.000E+00
```

```
    0   22    0 3.000E+06 2.401E+03 5.880E+02
    0   60    0                               3.500E+00
   23   37    0           0.000E+00 6.320E+00
   23   37    0 3.000E+07
   38   60    0 3.000E+06 2.401E+03 5.880E+02
    0   60    0 3.000E+07
    0   26    0           1.141E+03 1.618E+01
    0   26                                    1.040E+01
   26   34    0           1.394E+03 1.881E+01
   27   33    0                               1.188E+01
   34   60    0           1.141E+03 1.618E+01
   34   60    0                               1.040E+01
   60   60    0                                         1.000E+08 1.040E+01
    1   60    0 2.100E+06
    0   60    0          -6.750E+02
   10   10    0          -1.320E+04
   24   24    0          -3.300E+03
   43   43    0          -1.320E+04
   57   57    0          -3.300E+03
5    A TWO-SPAN BEAM WITH TRACTIVE FORCES
         0    1    1    1    1    0    1    0    0    1    0    4
   60           1.200E+01             30 1.000E-06   15   30   45
   30   30    0                                         1.000E+05 9.297E+00
   10   10    0+2.310E+04                              +6.600E+03
   24   24    0+5.775E+03                              +1.650E+03
   43   43    0+2.310E+04                              +6.600E+03
   57   57    0+5.775E+03                              +1.650E+03
6    AN EXPERIMENTAL COMPOSITE BEAM
         0                             1    2    1    2    5    0
   40           6.000E+00
    0           0.000E+00
   40           0.000E+00
    0   40    0 2.300E+06 3.647E+02 2.160E+02 3.750E+00
    0   40    0 2.900E+07 2.041E+02 7.970E+00 6.000E+00
    0    0    0                                         1.000E+06
    1   40    0 8.000E+05
    5    5    0          -6.000E+03
   15   15    0          -6.000E+03
   25   25    0          -6.000E+03
   35   35    0          -6.000E+03
```

APPENDIX 6

COMPUTED RESULTS FOR EXAMPLE PROBLEMS

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR   -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT      RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
    1      SIMPLE BEAM, UNIFORM SHEAR CONNECTOR SPACING


TABLE 1 - PROGRAM-CONTROL DATA
                                                               TABLE NUMBER
                                                       2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)              0    0    0    0    0    0
     NUM CARDS INPUT THIS PROBLEM                      1    2    1    2    6    0


TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                      20
     INCREMENT LENGTH                                                   1.200E+01
     NONLINEAR PROBLEM                                                         NO
     MAX NUM ITERATIONS                                                        -0
     CLOSURE TOLERANCE                                               -0.
     LIST OF MONITOR STATIONS                                      -0   -0     -0


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA      DEFLECTION

       0       0.
      20       0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS     MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF          OF      SECTION    N.A. TO    SPRING      N.A. TO
              FLASTICITY   INERTIA     AREA     INTERFACE             HORZ SPRING

   0  20  0   2.300F+06  3.647F+02  2.160E+02  2.250E+00 -0.          -0.


TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS     MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF          OF      SECTION    N.A. TO    SPRING      N.A. TO
              ELASTICITY   INERTIA     AREA     INTERFACE             HORZ SPRING

   0  20  0   2.900E+07  2.041E+02  7.970E+00  6.000E+00 -0.          -0.
   0   0  0  -0.        -0.        -0.        -0.        1.000E+06  0.
```

```
TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD   SHEAR   TRANSVERSE   SPRING
 STA STA      CONNECTOR    LOAD      SUPPORT
               MODULUS

   1  20  0   1.400E+06 -0.          -0.
   0  20  0  -0.        -1.920E+02 -0.
   3   3  0  -0.        -1.000E+04 -0.
   8   8  0  -0.        -1.000E+04 -0.
  12  12  0  -0.        -1.000E+04 -0.
  17  17  0  -0.        -1.000E+04 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD   SLAB        BEAM        SLAB       BEAM        SLAB       BEAM
 STA STA     TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL  LONGITUD.  LONGITUD.
               COUPLE      COUPLE    RESTRAINT  RESTRAINT     LOAD       LOAD

               NONE


TABLE 8 - ITERATION MONITOR DATA

      STA     DISPLACEMENTS AT STATIONS
 ITER  NOT              -0                     -0                     -0
  NUM CLSD    U-SLAB      U-BEAM      U-SLAB      U-BEAM      U-SLAB      U-BEAM

               NONE
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT      RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   1     SIMPLE BEAM, UNIFORM SHEAR CONNECTOR SPACING


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL     SLAB        SLAB        BEAM        BEAM       LOAD ON
        DEFLECTION   BENDING      AXIAL      BENDING      AXIAL       SHEAR
                     MOMENT       LOAD       MOMENT       LOAD      CONNECTOR

  -1    8.987E-02   0.          0.          0.          -0.
                                                                   0.
   0    0.          1.293E-09   9.193E-09   9.127E-09   3.006E-08
                                                                 -1.719E+04
   1   -8.987E-02   1.490E+04  -1.719E+04   1.052E+05  -1.719E+04
                                                                 -1.656E+04
   2   -1.772E-01   3.017E+04  -3.375E+04   2.129E+05  -3.375E+04
                                                                 -1.517E+04
   3   -2.593E-01   4.657E+04  -4.892E+04   3.286E+05  -4.892E+04
                                                                 -1.268E+04
   4   -3.334E-01   5.033E+04  -6.160E+04   3.552E+05  -6.160E+04
                                                                 -1.093E+04
   5   -3.989E-01   5.561E+04  -7.253E+04   3.924E+05  -7.253E+04
                                                                 -9.464E+03
   6   -4.549E-01   6.210E+04  -8.200E+04   4.382E+05  -8.200E+04
                                                                 -7.936E+03
   7   -5.002E-01   6.987E+04  -8.993E+04   4.930E+05  -8.993E+04
                                                                 -5.969E+03
   8   -5.335E-01   7.937E+04  -9.590E+04   5.600E+05  -9.590E+04
                                                                 -3.069E+03
   9   -5.531E-01   7.665E+04  -9.897E+04   5.409E+05  -9.897E+04
                                                                 -9.441E+02
  10   -5.596E-01   7.583E+04  -9.992E+04   5.351E+05  -9.992E+04
                                                                  9.441E+02
  11   -5.531E-01   7.665E+04  -9.897E+04   5.409E+05  -9.897E+04
                                                                  3.069E+03
  12   -5.335E-01   7.937E+04  -9.590E+04   5.600E+05  -9.590E+04
                                                                  5.969E+03
  13   -5.002E-01   6.987E+04  -8.993E+04   4.930E+05  -8.993E+04
                                                                  7.936E+03
  14   -4.549E-01   6.210E+04  -8.200E+04   4.382E+05  -8.200E+04
                                                                  9.464E+03
  15   -3.989E-01   5.561E+04  -7.253E+04   3.924E+05  -7.253E+04
                                                                  1.093E+04
  16   -3.334E-01   5.033E+04  -6.160E+04   3.552E+05  -6.160E+04
                                                                  1.268E+04
  17   -2.593E-01   4.657E+04  -4.892E+04   3.286E+05  -4.892E+04
                                                                  1.517E+04
  18   -1.772E-01   3.017E+04  -3.375E+04   2.129E+05  -3.375E+04
                                                                  1.656E+04
  19   -8.987E-02   1.490E+04  -1.719E+04   1.052E+05  -1.719E+04
                                                                  1.719E+04
  20    0.         -2.587E-09   9.193E-09  -1.825E-08  -8.554E-09
                                                                  0.
  21    8.987E-02   0.          0.          0.          -0.
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118         CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   1     SIMPLE BEAM, UNIFORM SHEAR CONNECTOR SPACING


TABLE 10  -  COMPUTED RESULTS

  STA      SLAB         SLAB        BEAM        BEAM      SUPPORT       SLIP
        HORIZONTAL      SHEAR    HORIZONTAL     SHEAR     REACTION
          DISPLAC                  DISPLAC

   -1                                                    0.
         4.951E-02   1.422E-10  -3.006E-14   6.480E-10                -1.228E-02
    0                                                    2.192E+04
         4.951E-02   4.401E+03  -3.319E-14   1.742E+04                -1.228E-02
    1                                                    0.
         4.909E-02   4.192E+03   8.925E-04   1.744E+04                -1.183E-02
    2                                                    0.
         4.827E-02   3.928E+03   2.645E-03   1.751E+04                -1.083E-02
    3                                                    0.
         4.709E-02   2.351E+03   5.185E-03   8.897E+03                -9.060E-03
    4                                                    0.
         4.560E-02   2.123E+03   8.383E-03   8.933E+03                -7.806E-03
    5                                                    0.
         4.385E-02   1.955E+03   1.215E-02   8.909E+03                -6.760E-03
    6                                                    0.
         4.187E-02   1.811E+03   1.641E-02   8.861E+03                -5.669E-03
    7                                                    0.
         3.970E-02   1.653E+03   2.108E-02   8.827E+03                -4.264E-03
    8                                                    0.
         3.738E-02   1.896E+02   2.605E-02   9.840E+01                -2.192E-03
    9                                                    0.
         3.499E-02   5.444E+01   3.119E-02   4.156E+01                -6.744E-04
   10                                                    0.
         3.258E-02  -5.444E+01   3.638E-02  -4.156E+01                 6.744E-04
   11                                                    0.
         3.019E-02  -1.896E+02   4.152E-02  -9.840E+01                 2.192E-03
   12                                                    0.
         2.787E-02  -1.653E+03   4.650E-02  -8.827E+03                 4.264E-03
   13                                                    0.
         2.570E-02  -1.811E+03   5.117E-02  -8.861E+03                 5.669E-03
   14                                                    0.
         2.372E-02  -1.955E+03   5.542E-02  -8.909E+03                 6.760E-03
   15                                                    0.
         2.197E-02  -2.123E+03   5.919E-02  -8.933E+03                 7.806E-03
   16                                                    0.
         2.048E-02  -2.351E+03   6.239E-02  -8.897E+03                 9.060E-03
   17                                                    0.
         1.930E-02  -3.928E+03   6.493E-02  -1.751E+04                 1.083E-02
   18                                                    0.
         1.848E-02  -4.192E+03   6.668E-02  -1.744E+04                 1.183E-02
   19                                                    0.
         1.807E-02  -4.401E+03   6.757E-02  -1.742E+04                 1.228E-02
   20                                                    2.192E+04
         1.807E-02   1.811E-10   6.757E-02   1.489E-09                 1.228E-02
   21                                                    0.


                        TIME FOR THIS PROBLEM =      0 MINUTES     1.055 SECONDS

                        ELAPSED CPU TIME =      0 MINUTES    11.414 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT      RE-PCH BY JJP           RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM



PROB
   2A      SIMPLE BEAM, BEAM PROPERTIES ONLY



TABLE 1 - PROGRAM-CONTROL DATA
                                                              TABLE NUMBER
                                                      2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)             0    0    0    0    0    0
     NUM CARDS INPUT THIS PROBLEM                     1    2    0    2    1    0



TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                      20
     INCREMENT LENGTH                                                   1.200E+01
     NONLINEAR PROBLEM                                                         NO
     MAX NUM ITERATIONS                                                        -0
     CLOSURE TOLERANCE                                                  -0.
     LIST OF MONITOR STATIONS                                         -0   -0   -0



TABLE 3  -  SPECIFIED DEFLECTIONS

     STA      DEFLECTION

       0        0.
      20        0.



TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS     MOMENT     CROSS-     DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF         OF       SECTION     N.A. TO    SPRING      N.A. TO
              ELASTICITY   INERTIA     AREA      INTERFACE             HORZ SPRING


                 NONE



TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS     MOMENT     CROSS-     DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF         OF       SECTION     N.A. TO    SPRING      N.A. TO
              ELASTICITY   INERTIA     AREA      INTERFACE             HORZ SPRING

   0  20  0    2.900E+07  2.041E+02  7.970E+00  6.000E+00 -0.         -0.
   0   0  0   -0.        -0.        -0.        -0.         1.000E+06  0.
```

```
TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD   SHEAR    TRANSVERSE   SPRING
 STA STA       CONNECTOR    LOAD      SUPPORT
                MODULUS

   0  20   0  -0.          -1.920E+02 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD   SLAB        BEAM        SLAB        BEAM        SLAB        BEAM
 STA STA     TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL  LONGITUD.  LONGITUD.
               COUPLE      COUPLE    RESTRAINT  RESTRAINT     LOAD        LOAD

               NONE


TABLE 8 - ITERATION MONITOR DATA

        STA      DISPLACEMENTS AT STATIONS
 ITER   NOT             -0                    -0                    -0
  NUM CLSD     U-SLAB      U-BEAM      U-SLAB      U-BEAM      U-SLAB      U-BEAM

               NONE
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   2A     SIMPLE BEAM, BEAM PROPERTIES ONLY


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL      SLAB        SLAB         BEAM        BEAM      LOAD ON
        DEFLECTION    BENDING      AXIAL       BENDING      AXIAL      SHEAR
                      MOMENT       LOAD        MOMENT       LOAD     CONNECTOR

  -1     1.864E-02   0.          0.          0.           -0.
                                                                    0.
   0     0.          0.          0.         -2.282E-09    -0.
                                                                    0.
   1    -1.864E-02   0.          0.          2.189E+04    -0.
                                                                    0.
   2    -3.674E-02   0.          0.          4.147E+04    -0.
                                                                    0.
   3    -5.384E-02   0.          0.          5.875E+04    -0.
                                                                    0.
   4    -6.951E-02   0.          0.          7.373E+04    -0.
                                                                    0.
   5    -8.338E-02   0.          0.          8.640E+04    -0.
                                                                    0.
   6    -9.515E-02   0.          0.          9.677E+04    -0.
                                                                    0.
   7    -1.046E-01   0.          0.          1.048E+05    -0.
                                                                    0.
   8    -1.114E-01   0.          0.          1.106E+05    -0.
                                                                    0.
   9    -1.156E-01   0.          0.          1.140E+05    -0.
                                                                    0.
  10    -1.170E-01   0.          0.          1.152E+05    -0.
                                                                    0.
  11    -1.156E-01   0.          0.          1.140E+05    -0.
                                                                    0.
  12    -1.114E-01   0.          0.          1.106E+05    -0.
                                                                    0.
  13    -1.046E-01   0.          0.          1.048E+05    -0.
                                                                    0.
  14    -9.515E-02   0.          0.          9.677E+04    -0.
                                                                    0.
  15    -8.338E-02   0.          0.          8.640E+04    -0.
                                                                    0.
  16    -6.951E-02   0.          0.          7.373E+04    -0.
                                                                    0.
  17    -5.384E-02   0.          0.          5.875E+04    -0.
                                                                    0.
  18    -3.674E-02   0.          0.          4.147E+04    -0.
                                                                    0.
  19    -1.864E-02   0.          0.          2.189E+04    -0.
                                                                    0.
  20     0.          0.          0.          2.282E-09    -0.
                                                                    0.
  21     1.864E-02   0.          0.          0.           -0.
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   2A     SIMPLE BEAM, BEAM PROPERTIES ONLY


TABLE 10  -  COMPUTED RESULTS

 STA      SLAB          SLAB        BEAM         BEAM       SUPPORT       SLIP
       HORIZONTAL      SHEAR     HORIZONTAL     SHEAR      REACTION
         DISPLAC                   DISPLAC

 -1                                                         0.
          0.            0.          0.        -1.901E-10               -9.319E-03
  0                                                         1.920E+03
          0.            0.          0.         1.824E+03               -9.319E-03
  1                                                         0.
          0.            0.          0.         1.632E+03               -9.053E-03
  2                                                         0.
          0.            0.          0.         1.440E+03               -8.548E-03
  3                                                         0.
          0.            0.          0.         1.248E+03               -7.833E-03
  4                                                         0.
          0.            0.          0.         1.056E+03               -6.937E-03
  5                                                         0.
          0.            0.          0.         8.640E+02               -5.886E-03
  6                                                         0.
          0.            0.          0.         6.720E+02               -4.709E-03
  7                                                         0.
          0.            0.          0.         4.800E+02               -3.433E-03
  8                                                         0.
          0.            0.          0.         2.880E+02               -2.088E-03
  9                                                         0.
          0.            0.          0.         9.600E+01               -7.007E-04
 10                                                         0.
          0.            0.          0.        -9.600E+01                7.007E-04
 11                                                         0.
          0.            0.          0.        -2.880E+02                2.088E-03
 12                                                         0.
          0.            0.          0.        -4.800E+02                3.433E-03
 13                                                         0.
          0.            0.          0.        -6.720E+02                4.709E-03
 14                                                         0.
          0.            0.          0.        -8.640E+02                5.886E-03
 15                                                         0.
          0.            0.          0.        -1.056E+03                6.937E-03
 16                                                         0.
          0.            0.          0.        -1.248E+03                7.833E-03
 17                                                         0.
          0.            0.          0.        -1.440E+03                8.548E-03
 18                                                         0.
          0.            0.          0.        -1.632E+03                9.053E-03
 19                                                         0.
          0.            0.          0.        -1.824E+03                9.319E-03
 20                                                         1.920E+03
          0.            0.          0.        -1.901E-10                9.319E-03
 21                                                         0.


                        TIME FOR THIS PROBLEM =     0 MINUTES      .653 SECONDS

                        ELAPSED CPU TIME =     0 MINUTES   12.067 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118         CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
   2B     SIMPLE COMPOSITE BEAM, LIVE LOAD ONLY


TABLE 1 - PROGRAM-CONTROL DATA
                                                           TABLE NUMBER
                                                    2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)           1    1    0    1    0    0
     NUM CARDS INPUT THIS PROBLEM                   0    0    1    0    5    0


TABLE 2 - CONSTANTS

     USING DATA FROM THE PREVIOUS PROBLEM
     NUMBER OF INCREMENTS                                                   20
     INCREMENT LENGTH                                                1.200E+01
     NONLINEAR PROBLEM                                                      NO
     MAX NUM ITERATIONS                                                     -0
     CLOSURE TOLERANCE                                              -0.
     LIST OF MONITOR STATIONS                                     -0   -0    -0


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA     DEFLECTION

     USING DATA FROM THE PREVIOUS PROBLEM
       0      0.
      20      0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION   N.A. TO     SPRING     N.A. TO
             ELASTICITY   INERTIA     AREA     INTERFACE           HORZ SPRING

   0  20  0   2.300E+06  3.647E+02  2.160E+02  2.250E+00 -0.        -0.


TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION   N.A. TO     SPRING     N.A. TO
             ELASTICITY   INERTIA     AREA     INTERFACE           HORZ SPRING

     USING DATA FROM THE PREVIOUS PROBLEM
   0  20  0   2.900E+07  2.041E+02  7.970E+00  6.000E+00 -0.        -0.
   0   0  0 -0.        -0.        -0.        -0.        1.000E+06  0.
```

```
     ADDITIONAL DATA FOR THIS PROBLEM

               NONE


TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD   SHEAR   TRANSVERSE   SPRING
 STA STA      CONNECTOR    LOAD      SUPPORT
               MODULUS

   1  20  0   1.400E+06 -0.         -0.
   3   3  0  -0.         -1.000E+04 -0.
   8   8  0  -0.         -1.000E+04 -0.
  12  12  0  -0.         -1.000E+04 -0.
  17  17  0  -0.         -1.000E+04 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD   SLAB       BEAM       SLAB       BEAM       SLAB      BEAM
 STA STA     TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL LONGITUD. LONGITUD.
               COUPLE     COUPLE    RESTRAINT  RESTRAINT   LOAD      LOAD

               NONE


TABLE 8 - ITERATION MONITOR DATA

       STA     DISPLACEMENTS AT STATIONS
 ITER  NOT               -0                   -0                   -0
  NUM CLSD    U-SLAB     U-BEAM     U-SLAB     U-BEAM     U-SLAB     U-BEAM

               NONE
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE05111B          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   2B     SIMPLE COMPOSITE BEAM, LIVE LOAD ONLY


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL      SLAB         SLAB        BEAM         BEAM       LOAD ON
        DEFLECTION   BENDING       AXIAL      BENDING       AXIAL        SHEAR
                     MOMENT        LOAD       MOMENT        LOAD       CONNECTOR

  -1    8.268E-02   0.           0.          0.          -0.
                                                                      0.
   0    0.          0.           9.193E-09   0.           2.861E-08
                                                                     -1.581E+04
   1   -8.268E-02   1.360E+04   -1.581E+04   9.594E+04   -1.581E+04
                                                                     -1.525E+04
   2   -1.630E-01   2.777E+04   -3.107E+04   1.959E+05   -3.107E+04
                                                                     -1.397E+04
   3   -2.386E-01   4.325E+04   -4.504E+04   3.052E+05   -4.504E+04
                                                                     -1.162E+04
   4   -3.068E-01   4.624E+04   -5.666E+04   3.263E+05   -5.666E+04
                                                                     -1.002E+04
   5   -3.670E-01   5.088E+04   -6.668E+04   3.590E+05   -6.668E+04
                                                                     -8.712E+03
   6   -4.185E-01   5.685E+04   -7.539E+04   4.012E+05   -7.539E+04
                                                                     -7.347E+03
   7   -4.602E-01   6.422E+04   -8.274E+04   4.532E+05   -8.274E+04
                                                                     -5.547E+03
   8   -4.909E-01   7.344E+04   -8.829E+04   5.182E+05   -8.829E+04
                                                                     -2.815E+03
   9   -5.090E-01   7.056E+04   -9.110E+04   4.979E+05   -9.110E+04
                                                                     -8.594E+02
  10   -5.150E-01   6.968E+04   -9.196E+04   4.917E+05   -9.196E+04
                                                                      8.594E+02
  11   -5.090E-01   7.056E+04   -9.110E+04   4.979E+05   -9.110E+04
                                                                      2.815E+03
  12   -4.909E-01   7.344E+04   -8.829E+04   5.182E+05   -8.829E+04
                                                                      5.547E+03
  13   -4.602E-01   6.422E+04   -8.274E+04   4.532E+05   -8.274E+04
                                                                      7.347E+03
  14   -4.185E-01   5.685E+04   -7.539E+04   4.012E+05   -7.539E+04
                                                                      8.712E+03
  15   -3.670E-01   5.088E+04   -6.668E+04   3.590E+05   -6.668E+04
                                                                      1.002E+04
  16   -3.068E-01   4.624E+04   -5.666E+04   3.263E+05   -5.666E+04
                                                                      1.162E+04
  17   -2.386E-01   4.325E+04   -4.504E+04   3.052E+05   -4.504E+04
                                                                      1.397E+04
  18   -1.630E-01   2.777E+04   -3.107E+04   1.959E+05   -3.107E+04
                                                                      1.525E+04
  19   -8.268E-02   1.360E+04   -1.581E+04   9.594E+04   -1.581E+04
                                                                      1.581E+04
  20    0.         -1.293E-09    4.596E-09  -9.127E-09   -4.277E-09
                                                                      0.
  21    8.268E-02   0.           0.          0.          -0.
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   28     SIMPLE COMPOSITE BEAM, LIVE LOAD ONLY


TABLE 10  -  COMPUTED RESULTS

 STA      SLAB        SLAB        BEAM        BEAM       SUPPORT       SLIP
       HORIZONTAL     SHEAR    HORIZONTAL     SHEAR      REACTION
         DISPLAC                 DISPLAC

  -1                                                     0.
        4.555E-02   3.167E-11  -2.861E-14  -9.856E-11               -1.130E-02
   0                                                     2.000E+04
        4.555E-02   4.044E+03  -3.158E-14   1.596E+04               -1.130E-02
   1                                                     0.
        4.517E-02   3.884E+03   8.211E-04   1.612E+04               -1.089E-02
   2                                                     0.
        4.442E-02   3.670E+03   2.434E-03   1.633E+04               -9.980E-03
   3                                                     0.
        4.333E-02   2.140E+03   4.772E-03   7.860E+03               -8.302E-03
   4                                                     0.
        4.196E-02   1.955E+03   7.714E-03   8.045E+03               -7.155E-03
   5                                                     0.
        4.035E-02   1.827E+03   1.118E-02   8.173E+03               -6.223E-03
   6                                                     0.
        3.853E-02   1.717E+03   1.509E-02   8.283E+03               -5.248E-03
   7                                                     0.
        3.653E-02   1.589E+03   1.939E-02   8.411E+03               -3.962E-03
   8                                                     0.
        3.440E-02   1.524E+02   2.397E-02  -1.524E+02               -2.011E-03
   9                                                     0.
        3.220E-02   4.218E+01   2.870E-02  -4.218E+01               -6.139E-04
  10                                                     0.
        2.998E-02  -4.218E+01   3.347E-02   4.218E+01                6.139E-04
  11                                                     0.
        2.778E-02  -1.524E+02   3.820E-02   1.524E+02                2.011E-03
  12                                                     0.
        2.564E-02  -1.589E+03   4.279E-02  -8.411E+03                3.962E-03
  13                                                     0.
        2.364E-02  -1.717E+03   4.708E-02  -8.283E+03                5.248E-03
  14                                                     0.
        2.182E-02  -1.827E+03   5.100E-02  -8.173E+03                6.223E-03
  15                                                     0.
        2.021E-02  -1.955E+03   5.446E-02  -8.045E+03                7.155E-03
  16                                                     0.
        1.884E-02  -2.140E+03   5.740E-02  -7.860E+03                8.302E-03
  17                                                     0.
        1.776E-02  -3.670E+03   5.974E-02  -1.633E+04                9.980E-03
  18                                                     0.
        1.701E-02  -3.884E+03   6.135E-02  -1.612E+04                1.089E-02
  19                                                     0.
        1.662E-02  -4.044E+03   6.217E-02  -1.596E+04                1.130E-02
  20                                                     2.000E+04
        1.662E-02   9.195E-11   6.217E-02   7.458E-10                1.130E-02
  21                                                     0.


                              TIME FOR THIS PROBLEM =      0 MINUTES     1.628 SECONDS

                              ELAPSED CPU TIME =      0 MINUTES    13.695 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118        CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
   3     A CANTILEVER BEAM, SHEAR CONNECTORS SPACED ACCORDING TO SHEAR DIAGRAM


TABLE 1 - PROGRAM-CONTROL DATA
                                                             TABLE NUMBER
                                                      2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)             0    0    0    0    0    0
     NUM CARDS INPUT THIS PROBLEM                     1    1    2    2    8    1


TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                     20
     INCREMENT LENGTH                                                  6.000E+00
     NONLINEAR PROBLEM                                                        NO
     MAX NUM ITERATIONS                                                       -0
     CLOSURE TOLERANCE                                                 -0.
     LIST OF MONITOR STATIONS                                        -0   -0   -0


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA     DEFLECTION

       0       0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-     DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION     N.A. TO    SPRING      N.A. TO
              ELASTICITY  INERTIA      AREA     INTERFACE              HORZ SPRING

   0  20  0   2.300E+06  3.647E+02  2.160E+02  2.250E+00 -0.          -0.
   0   0  0  -0.        -0.         3.240E+02 -0.         1.000E+12 -0.


TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-     DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION     N.A. TO    SPRING      N.A. TO
              ELASTICITY  INERTIA      AREA     INTERFACE              HORZ SPRING

   0  20  0   2.900E+07  2.041E+02  7.970E+00  6.000E+00 -0.          -0.
   0   0  0  -0.        -0.         1.196E+01 -0.         1.000E+12 -0.
```

```
TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD    SHEAR    TRANSVERSE   SPRING
 STA STA       CONNECTOR    LOAD       SUPPORT
                MODULUS

   1  10  0    1.400E+06 -0.          -0.
  12  12  0    1.400E+06 -0.          -0.
  14  14  0    1.400E+06 -0.          -0.
  16  16  0    1.400E+06 -0.          -0.
  18  18  0    1.400E+06 -0.          -0.
  20  20  0    1.400E+06 -0.          -0.
  10  10  0   -0.           5.000E+03 -0.
  20  20  0   -0.           5.000E+03 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD    SLAB        BEAM        SLAB        BEAM        SLAB        BEAM
 STA STA      TRANSVERSE  TRANSVERSE  ROTATIONAL  ROTATIONAL  LONGITUD.   LONGITUD.
                COUPLE      COUPLE    RESTRAINT   RESTRAINT     LOAD        LOAD

   0   0  0   -0.         -0.          1.000E+13   1.000E+13 -0.         -0.


TABLE 8 - ITERATION MONITOR DATA

       STA     DISPLACEMENTS AT STATIONS
 ITER  NOT              -0                  -0                  -0
  NUM CLSD     U-SLAB      U-BEAM      U-SLAB      U-BEAM      U-SLAB      U-BEAM


               NONE
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR   -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB  (CONTD)
   3     A CANTILEVER BEAM, SHEAR CONNECTORS SPACED ACCORDING TO SHEAR DIAGRAM


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL      SLAB        SLAB       BEAM        BEAM       LOAD ON
        DEFLECTION    BENDING      AXIAL     BENDING      AXIAL       SHEAR
                      MOMENT       LOAD      MOMENT       LOAD      CONNECTOR

  -1     1.186E-03   0.          0.         0.          -0.
                                                                    0.
   0     0.          2.764E+04  -5.510E+04  1.951E+05  -5.510E+04
                                                                    8.171E+02
   1     1.187E-03   4.868E+04  -5.428E+04  3.435E+05  -5.428E+04
                                                                    1.948E+03
   2     4.462E-03   4.322E+04  -5.234E+04  3.050E+05  -5.234E+04
                                                                    2.732E+03
   3     9.593E-03   3.857E+04  -4.961E+04  2.722E+05  -4.961E+04
                                                                    3.277E+03
   4     1.638E-02   3.448E+04  -4.633E+04  2.433E+05  -4.633E+04
                                                                    3.659E+03
   5     2.464E-02   3.078E+04  -4.267E+04  2.172E+05  -4.267E+04
                                                                    3.929E+03
   6     3.423E-02   2.736E+04  -3.874E+04  1.930E+05  -3.874E+04
                                                                    4.127E+03
   7     4.499E-02   2.413E+04  -3.461E+04  1.703E+05  -3.461E+04
                                                                    4.277E+03
   8     5.679E-02   2.107E+04  -3.034E+04  1.487E+05  -3.034E+04
                                                                    4.402E+03
   9     6.949E-02   1.813E+04  -2.593E+04  1.279E+05  -2.593E+04
                                                                    4.519E+03
  10     8.297E-02   1.531E+04  -2.141E+04  1.080E+05  -2.141E+04
                                                                    0.
  11     9.711E-02   1.158E+04  -2.141E+04  8.175E+04  -2.141E+04
                                                                    4.460E+03
  12     1.117E-01   1.243E+04  -1.695E+04  8.770E+04  -1.695E+04
                                                                    0.
  13     1.269E-01   8.705E+03  -1.695E+04  6.142E+04  -1.695E+04
                                                                    4.401E+03
  14     1.424E-01   9.487E+03  -1.255E+04  6.695E+04  -1.255E+04
                                                                    0.
  15     1.584E-01   5.764E+03  -1.255E+04  4.067E+04  -1.255E+04
                                                                    4.324E+03
  16     1.746E-01   6.467E+03  -8.230E+03  4.563E+04  -8.230E+03
                                                                    0.
  17     1.911E-01   2.743E+03  -8.230E+03  1.936E+04  -8.230E+03
                                                                    4.208E+03
  18     2.077E-01   3.329E+03  -4.022E+03  2.349E+04  -4.022E+03
                                                                    0.
  19     2.244E-01  -3.949E+02  -4.022E+03 -2.787E+03  -4.022E+03
                                                                    4.022E+03
  20     2.411E-01  -2.069E-08   2.298E-09 -1.460E-07  -0.
                                                                    0.
  21     2.578E-01   0.          0.         0.          -0.
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
    3     A CANTILEVER BEAM, SHEAR CONNECTORS SPACED ACCORDING TO SHEAR DIAGRAM


TABLE 10  -  COMPUTED RESULTS
 STA        SLAB        SLAB        BEAM         BEAM       SUPPORT       SLIP
         HORIZONTAL     SHEAR    HORIZONTAL      SHEAR      REACTION
           DISPLAC                 DISPLAC

 -1                                                         0.
         -5.510E-08   4.602E+03   5.510E-08   3.252E+04                 -1.631E-03
  0                                                       -1.000E+04
         -3.328E-04   3.210E+03   7.150E-04   2.391E+04                  5.836E-04
  1                                                         0.
         -9.884E-04  -1.610E+03   2.124E-03  -8.390E+03                  1.391E-03
  2                                                         0.
         -1.621E-03  -1.756E+03   3.483E-03  -8.244E+03                  1.951E-03
  3                                                         0.
         -2.220E-03  -1.857E+03   4.771E-03  -8.143E+03                  2.341E-03
  4                                                         0.
         -2.779E-03  -1.928E+03   5.973E-03  -8.072E+03                  2.613E-03
  5                                                         0.
         -3.294E-03  -1.979E+03   7.081E-03  -8.021E+03                  2.807E-03
  6                                                         0.
         -3.762E-03  -2.019E+03   8.087E-03  -7.981E+03                  2.948E-03
  7                                                         0.
         -4.180E-03  -2.051E+03   8.985E-03  -7.949E+03                  3.055E-03
  8                                                         0.
         -4.547E-03  -2.081E+03   9.773E-03  -7.919E+03                  3.145E-03
  9                                                         0.
         -4.860E-03  -2.111E+03   1.045E-02  -7.889E+03                  3.228E-03
 10                                                         0.
         -5.119E-03  -5.702E+02   1.100E-02  -4.430E+03                  3.317E-03
 11                                                         0.
         -5.377E-03  -1.485E+03   1.156E-02  -3.515E+03                  3.186E-03
 12                                                         0.
         -5.582E-03  -5.778E+02   1.200E-02  -4.422E+03                  3.274E-03
 13                                                         0.
         -5.787E-03  -1.482E+03   1.244E-02  -3.518E+03                  3.143E-03
 14                                                         0.
         -5.938E-03  -5.873E+02   1.276E-02  -4.413E+03                  3.226E-03
 15                                                         0.
         -6.090E-03  -1.476E+03   1.309E-02  -3.524E+03                  3.088E-03
 16                                                         0.
         -6.189E-03  -5.980E+02   1.330E-02  -4.402E+03                  3.157E-03
 17                                                         0.
         -6.289E-03  -1.464E+03   1.352E-02  -3.536E+03                  3.006E-03
 18                                                         0.
         -6.337E-03  -6.094E+02   1.362E-02  -4.391E+03                  3.049E-03
 19                                                         0.
         -6.386E-03  -1.437E+03   1.373E-02  -3.563E+03                  2.873E-03
 20                                                         0.
         -6.386E-03   3.446E-09   1.373E-02   2.434E-08                  2.873E-03
 21                                                         0.


                              TIME FOR THIS PROBLEM =      0 MINUTES      .858 SECONDS

                              ELAPSED CPU TIME =      0 MINUTES   14.553 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
    4      A TWO-SPAN BEAM


TABLE 1 - PROGRAM-CONTROL DATA
                                                                 TABLE NUMBER
                                                       2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)              0    0    0    0    0    0
     NUM CARDS INPUT THIS PROBLEM                      1    3    5    8    6    0


TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                      60
     INCREMENT LENGTH                                                   1.200E+01
     NONLINEAR PROBLEM                                                         NO
     MAX NUM ITERATIONS                                                        -0
     CLOSURE TOLERANCE                                                -0.
     LIST OF MONITOR STATIONS                                       -0   -0    -0


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA      DEFLECTION

      0         0.
     30         0.
     60         0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS     MOMENT      CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF          OF       SECTION    N.A. TO    SPRING      N.A. TO
              ELASTICITY   INERTIA      AREA     INTERFACE             HORZ SPRING

   0  22   0    3.000E+06  2.401E+03  5.880E+02 -0.          -0.         -0.
   0  60   0  -0.         -0.        -0.         3.500E+00 -0.          -0.
  23  37   0  -0.          0.         6.320E+00 -0.          -0.         -0.
  23  37   0    3.000E+07 -0.        -0.        -0.          -0.         -0.
  38  60   0    3.000E+06  2.401E+03  5.880E+02 -0.          -0.         -0.


TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS     MOMENT      CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF          OF       SECTION    N.A. TO    SPRING      N.A. TO
              ELASTICITY   INERTIA      AREA     INTERFACE             HORZ SPRING
```

```
   0  60  0  3.000E+07 -0.        -0.        -0.        -0.        -0.
   0  26  0 -0.         1.141E+03  1.618E+01 -0.        -0.        -0.
   0  26 -0 -0.        -0.        -0.         1.040E+01 -0.        -0.
  26  34  0 -0.         1.394E+03  1.881E+01 -0.        -0.        -0.
  27  33  0 -0.        -0.        -0.         1.188E+01 -0.        -0.
  34  60  0 -0.         1.141E+03  1.618E+01 -0.        -0.        -0.
  34  60  0 -0.        -0.        -0.         1.040E+01 -0.        -0.
  60  60  0 -0.        -0.        -0.        -0.         1.000E+08  1.040E+01


TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD  SHEAR   TRANSVERSE  SPRING
 STA STA     CONNECTOR    LOAD     SUPPORT
              MODULUS

   1  60  0  2.100E+06 -0.        -0.
   0  60  0 -0.        -6.750E+02 -0.
  10  10  0 -0.        -1.320E+04 -0.
  24  24  0 -0.        -3.300E+03 -0.
  43  43  0 -0.        -1.320E+04 -0.
  57  57  0 -0.        -3.300E+03 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD  SLAB       BEAM       SLAB       BEAM       SLAB       BEAM
 STA STA    TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL LONGITUD.  LONGITUD.
              COUPLE     COUPLE     RESTRAINT  RESTRAINT    LOAD       LOAD


              NONE


TABLE 8 - ITERATION MONITOR DATA

      STA    DISPLACEMENTS AT STATIONS
 ITER NOT           -0                   -0                  -0
  NUM CLSD   U-SLAB    U-BEAM     U-SLAB    U-BEAM     U-SLAB    U-BEAM


              NONE
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
    4     A TWO-SPAN BEAM


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL      SLAB         SLAB         BEAM         BEAM        LOAD ON
        DEFLECTION    BENDING       AXIAL       BENDING       AXIAL        SHEAR
                      MOMENT        LOAD        MOMENT        LOAD       CONNECTOR

  -1     1.595E-02   0.           0.          0.          -0.
                                                                          0.
   0     0.          0.          -8.160E-09   0.           4.491E-09
                                                                       -7.413E+03
   1    -1.595E-02   1.314E+04   -7.413E+03   6.243E+04   -7.413E+03
                                                                       -7.265E+03
   2    -3.163E-02   2.523E+04   -1.468E+04   1.199E+05   -1.468E+04
                                                                       -7.010E+03
   3    -4.681E-02   3.652E+04   -2.169E+04   1.736E+05   -2.169E+04
                                                                       -6.669E+03
   4    -6.126E-02   4.723E+04   -2.836E+04   2.245E+05   -2.836E+04
                                                                       -6.250E+03
   5    -7.476E-02   5.755E+04   -3.461E+04   2.735E+05   -3.461E+04
                                                                       -5.742E+03
   6    -8.712E-02   6.768E+04   -4.035E+04   3.216E+05   -4.035E+04
                                                                       -5.122E+03
   7    -9.812E-02   7.791E+04   -4.547E+04   3.702E+05   -4.547E+04
                                                                       -4.344E+03
   8    -1.076E-01   8.861E+04   -4.981E+04   4.211E+05   -4.981E+04
                                                                       -3.333E+03
   9    -1.152E-01   1.003E+05   -5.315E+04   4.768E+05   -5.315E+04
                                                                       -1.972E+03
  10    -1.209E-01   1.140E+05   -5.512E+04   5.415E+05   -5.512E+04
                                                                       -7.914E+01
  11    -1.243E-01   1.032E+05   -5.520E+04   4.904E+05   -5.520E+04
                                                                        1.285E+03
  12    -1.256E-01   9.432E+04   -5.391E+04   4.482E+05   -5.391E+04
                                                                        2.303E+03
  13    -1.251E-01   8.650E+04   -5.161E+04   4.111E+05   -5.161E+04
                                                                        3.092E+03
  14    -1.228E-01   7.918E+04   -4.852E+04   3.763E+05   -4.852E+04
                                                                        3.731E+03
  15    -1.189E-01   7.200E+04   -4.479E+04   3.421E+05   -4.479E+04
                                                                        4.267E+03
  16    -1.136E-01   6.470E+04   -4.052E+04   3.075E+05   -4.052E+04
                                                                        4.731E+03
  17    -1.070E-01   5.711E+04   -3.579E+04   2.714E+05   -3.579E+04
                                                                        5.139E+03
  18    -9.922E-02   4.911E+04   -3.065E+04   2.334E+05   -3.065E+04
                                                                        5.498E+03
  19    -9.050E-02   4.056E+04   -2.515E+04   1.927E+05   -2.515E+04
                                                                        5.805E+03
  20    -8.096E-02   3.135E+04   -1.935E+04   1.490E+05   -1.935E+04
                                                                        6.049E+03
```

```
21   -7.079E-02   2.131E+04  -1.330E+04   1.013E+05  -1.330E+04
                                                                  6.205E+03
22   -6.020E-02   5.613E+03  -7.093E+03   5.335E+04  -7.093E+03
                                                                  6.180E+03
23   -4.938E-02   0.         -9.133E+02  -1.313E+04  -9.133E+02
                                                                  5.755E+03
24   -3.862E-02   0.          4.842E+03  -9.922E+04   4.842E+03
                                                                  5.635E+03
25   -2.827E-02   0.          1.048E+04  -2.347E+05   1.048E+04
                                                                  5.170E+03
26   -1.892E-02   0.          1.565E+04  -3.847E+05   1.565E+04
                                                                  5.480E+03
27   -1.102E-02   0.          2.113E+04  -5.073E+05   2.113E+04
                                                                  5.553E+03
28   -4.863E-03   0.          2.668E+04  -6.599E+05   2.668E+04
                                                                  4.175E+03
29   -9.821E-04   0.          3.085E+04  -8.419E+05   3.085E+04
                                                                  1.851E+03
30    0.          0.          3.271E+04  -1.068E+06   3.271E+04
                                                                 -2.237E+03
31   -2.694E-03   0.          3.047E+04  -8.386E+05   3.047E+04
                                                                 -4.598E+03
32   -8.276E-03   0.          2.587E+04  -6.539E+05   2.587E+04
                                                                 -6.065E+03
33   -1.611E-02   0.          1.981E+04  -4.999E+05   1.981E+04
                                                                 -5.943E+03
34   -2.566E-02   0.          1.386E+04  -3.725E+05   1.386E+04
                                                                 -5.629E+03
35   -3.663E-02   0.          8.234E+03  -2.197E+05   8.234E+03
                                                                 -6.355E+03
36   -4.852E-02   0.          1.878E+03  -8.498E+04   1.878E+03
                                                                 -6.878E+03
37   -6.077E-02   0.         -5.000E+03   3.435E+04  -5.000E+03
                                                                 -8.115E+03
38   -7.287E-02   1.222E+04  -1.312E+04   1.162E+05  -1.312E+04
                                                                 -7.982E+03
39   -8.448E-02   3.758E+04  -2.110E+04   1.786E+05  -2.110E+04
                                                                 -7.552E+03
40   -9.535E-02   5.247E+04  -2.865E+04   2.493E+05  -2.865E+04
                                                                 -6.897E+03
41   -1.052E-01   6.754E+04  -3.555E+04   3.209E+05  -3.555E+04
                                                                 -5.966E+03
42   -1.136E-01   8.344E+04  -4.151E+04   3.965E+05  -4.151E+04
                                                                 -4.656E+03
43   -1.204E-01   1.011E+05  -4.617E+04   4.805E+05  -4.617E+04
                                                                 -2.795E+03
44   -1.252E-01   9.432E+04  -4.896E+04   4.482E+05  -4.896E+04
                                                                 -1.450E+03
45   -1.281E-01   8.938E+04  -5.041E+04   4.248E+05  -5.041E+04
                                                                 -4.402E+02
46   -1.292E-01   8.547E+04  -5.085E+04   4.062E+05  -5.085E+04
                                                                  3.499E+02
47   -1.286E-01   8.207E+04  -5.050E+04   3.900E+05  -5.050E+04
                                                                  9.974E+02
48   -1.263E-01   7.881E+04  -4.950E+04   3.745E+05  -4.950E+04
                                                                  1.553E+03
49   -1.225E-01   7.549E+04  -4.795E+04   3.588E+05  -4.795E+04
                                                                  2.050E+03
50   -1.172E-01   7.197E+04  -4.590E+04   3.420E+05  -4.590E+04
                                                                  2.511E+03
51   -1.104E-01   6.815E+04  -4.339E+04   3.239E+05  -4.339E+04
                                                                  2.952E+03
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52   -1.023E-01   6.399E+04  -4.044E+04   3.041E+05  -4.044E+04
                                                                  3.387E+03
53   -9.286E-02   5.947E+04  -3.705E+04   2.826E+05  -3.705E+04
                                                                  3.826E+03
54   -8.225E-02   5.460E+04  -3.323E+04   2.595E+05  -3.323E+04
                                                                  4.282E+03
55   -7.056E-02   4.943E+04  -2.894E+04   2.349E+05  -2.894E+04
                                                                  4.769E+03
56   -5.788E-02   4.403E+04  -2.418E+04   2.092E+05  -2.418E+04
                                                                  5.310E+03
57   -4.432E-02   3.852E+04  -1.887E+04   1.831E+05  -1.887E+04
                                                                  5.934E+03
58   -2.998E-02   2.623E+04  -1.293E+04   1.247E+05  -1.293E+04
                                                                  6.354E+03
59   -1.513E-02   1.355E+04  -6.577E+03   6.440E+04  -6.577E+03
                                                                  6.577E+03
60    0.         -5.553E-09  -1.224E-08  -2.639E-08   9.923E-11
                                                                  0.
61    1.513E-02   0.          0.          0.         -0.
```

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PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CF051119        CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
   4     A TWO-SPAN BEAM


TABLE 10  -  COMPUTED RESULTS
 STA      SLAB        SLAB        BEAM        BEAM      SUPPORT       SLIP
       HORIZONTAL     SHEAR    HORIZONTAL     SHEAR     REACTION
         DISPLAC                 DISPLAC

  -1                                                      0.
          -1.829E-02  -5.422E-12  -3.323E-02  -2.984E-12               -3.530E-03
   0                                                      1.522E+04
          -1.829E-02   3.252E+03  -3.323E-02   1.163E+04               -3.530E-03
   1                                                      0.
          -1.834E-02   3.112E+03  -3.305E-02   1.110E+04               -3.459E-03
   2                                                      0.
          -1.844E-02   2.963E+03  -3.268E-02   1.057E+04               -3.338E-03
   3                                                      0.
          -1.859E-02   2.808E+03  -3.215E-02   1.005E+04               -3.176E-03
   4                                                      0.
          -1.878E-02   2.647E+03  -3.145E-02   9.537E+03               -2.976E-03
   5                                                      0.
          -1.902E-02   2.481E+03  -3.059E-02   9.029E+03               -2.734E-03
   6                                                      0.
          -1.929E-02   2.307E+03  -2.959E-02   8.528E+03               -2.439E-03
   7                                                      0.
          -1.960E-02   2.121E+03  -2.847E-02   8.038E+03               -2.068E-03
   8                                                      0.
          -1.994E-02   1.917E+03  -2.724E-02   7.567E+03               -1.587E-03
   9                                                      0.
          -2.030E-02   1.684E+03  -2.592E-02   7.125E+03               -9.389E-04
  10                                                      0.
          -2.068E-02  -8.891E+02  -2.456E-02  -4.177E+03               -3.769E-05
  11                                                      0.
          -2.105E-02  -1.120E+03  -2.320E-02  -4.621E+03                6.118E-04
  12                                                      0.
          -2.142E-02  -1.321E+03  -2.186E-02  -5.095E+03                1.096E-03
  13                                                      0.
          -2.177E-02  -1.502E+03  -2.059E-02  -5.588E+03                1.473E-03
  14                                                      0.
          -2.210E-02  -1.672E+03  -1.939E-02  -6.094E+03                1.777E-03
  15                                                      0.
          -2.240E-02  -1.834E+03  -1.828E-02  -6.607E+03                2.032E-03
  16                                                      0.
          -2.268E-02  -1.991E+03  -1.728E-02  -7.125E+03                2.253E-03
  17                                                      0.
          -2.292E-02  -2.145E+03  -1.640E-02  -7.646E+03                2.447E-03
  18                                                      0.
          -2.313E-02  -2.296E+03  -1.564E-02  -8.170E+03                2.618E-03
  19                                                      0.
          -2.330E-02  -2.443E+03  -1.502E-02  -8.697E+03                2.764E-03
  20                                                      0.
          -2.343E-02  -2.586E+03  -1.454E-02  -9.229E+03                2.880E-03
```

```
 21                                                       0.
      -2.352E-02  -3.109E+03  -1.421E-02  -9.382E+03                    2.955E-03
 22                                                       0.
      -2.362E-02  -2.267E+03  -1.403E-02  -1.090E+04                    2.943E-03
 23                                                       0.
      -2.374E-02  -1.680E+03  -1.401E-02  -1.216E+04                    2.741E-03
 24                                                       0.
      -2.343E-02  -1.650E+03  -1.413E-02  -1.617E+04                    2.683E-03
 25                                                       0.
      -2.277E-02  -1.518E+03  -1.439E-02  -1.697E+04                    2.462E-03
 26                                                       0.
      -2.178E-02  -1.610E+03  -1.475E-02  -1.529E+04                    2.610E-03
 27                                                       0.
      -2.044E-02  -1.632E+03  -1.520E-02  -1.821E+04                    2.644E-03
 28                                                       0.
      -1.875E-02  -1.227E+03  -1.576E-02  -1.929E+04                    1.988E-03
 29                                                       0.
      -1.680E-02  -5.425E+02  -1.642E-02  -2.065E+04                    8.815E-04
 30                                                       4.383E+04
      -1.473E-02   6.595E+02  -1.712E-02   2.130E+04                   -1.065E-03
 31                                                       0.
      -1.280E-02   1.354E+03  -1.776E-02   1.993E+04                   -2.190E-03
 32                                                       0.
      -1.116E-02   1.784E+03  -1.831E-02   1.883E+04                   -2.888E-03
 33                                                       0.
      -9.908E-03   1.747E+03  -1.874E-02   1.611E+04                   -2.830E-03
 34                                                       0.
      -9.031E-03   1.652E+03  -1.905E-02   1.761E+04                   -2.681E-03
 35                                                       0.
      -8.510E-03   1.859E+03  -1.926E-02   1.673E+04                   -3.026E-03
 36                                                       0.
      -8.391E-03   2.004E+03  -1.930E-02   1.591E+04                   -3.275E-03
 37                                                       0.
      -9.024E-03   3.376E+03  -1.918E-02   1.386E+04                   -3.864E-03
 38                                                       0.
      -9.202E-03   4.425E+03  -1.885E-02   1.214E+04                   -3.801E-03
 39                                                       0.
      -9.346E-03   3.421E+03  -1.833E-02   1.246E+04                   -3.596E-03
 40                                                       0.
      -9.541E-03   3.241E+03  -1.762E-02   1.197E+04                   -3.284E-03
 41                                                       0.
      -9.783E-03   3.038E+03  -1.675E-02   1.150E+04                   -2.841E-03
 42                                                       0.
      -1.006E-02   2.805E+03  -1.572E-02   1.106E+04                   -2.217E-03
 43                                                       0.
      -1.038E-02   2.310E+02  -1.458E-02  -2.453E+02                   -1.331E-03
 44                                                       0.
      -1.071E-02  -9.049E-01  -1.337E-02  -6.884E+02                   -6.903E-04
 45                                                       0.
      -1.106E-02  -2.021E+02  -1.212E-02  -1.162E+03                   -2.096E-04
 46                                                       0.
      -1.140E-02  -3.836E+02  -1.086E-02  -1.656E+03                    1.666E-04
 47                                                       0.
      -1.174E-02  -5.526E+02  -9.616E-03  -2.162E+03                    4.750E-04
 48                                                       0.
      -1.208E-02  -7.139E+02  -8.392E-03  -2.675E+03                    7.394E-04
 49                                                       0.
      -1.241E-02  -8.708E+02  -7.207E-03  -3.194E+03                    9.760E-04
 50                                                       0.
      -1.272E-02  -1.025E+03  -6.072E-03  -3.714E+03                    1.196E-03
 51                                                       0.
      -1.301E-02  -1.179E+03  -4.999E-03  -4.235E+03                    1.406E-03
```

```
52                                                      0.
      -1.329E-02  -1.334E+03  -3.999E-03  -4.755E+03                1.613E-03
53                                                      0.
      -1.354E-02  -1.490E+03  -3.083E-03  -5.274E+03                1.822E-03
54                                                      0.
      -1.377E-02  -1.650E+03  -2.262E-03  -5.790E+03                2.039E-03
55                                                      0.
      -1.396E-02  -1.813E+03  -1.546E-03  -6.301E+03                2.271E-03
56                                                      0.
      -1.413E-02  -1.983E+03  -9.487E-04  -6.806E+03                2.528E-03
57                                                      0.
      -1.426E-02  -2.736E+03  -4.823E-04  -1.003E+04                2.826E-03
58                                                      0.
      -1.435E-02  -2.898E+03  -1.626E-04  -1.054E+04                3.026E-03
59                                                      0.
      -1.439E-02  -3.043E+03   2.224E-15  -1.107E+04                3.132E-03
60                                                      1.445E+04
      -1.439E-02   4.705E-10   2.219E-15   2.199E-09                3.132E-03
61                                                      0.


                        TIME FOR THIS PROBLEM =     0 MINUTES    1.013 SECONDS


                        ELAPSED CPU TIME =     0 MINUTES   15.566 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE05111B          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
    5     A TWO-SPAN BEAM WITH TRACTIVE FORCES


TABLE 1 - PROGRAM-CONTROL DATA
                                                           TABLE NUMBER
                                                    2    3    4    5    6    7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)           0    1    1    1    1    0
     NUM CARDS INPUT THIS PROBLEM                   1    0    0    1    0    4


TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                   60
     INCREMENT LENGTH                                                1.200E+01
     NONLINEAR PROBLEM                                                     YES
     MAX NUM ITERATIONS                                                     30
     CLOSURE TOLERANCE                                               1.000E-06
     LIST OF MONITOR STATIONS                                     15   30   45


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA     DEFLECTION

     USING DATA FROM THE PREVIOUS PROBLEM
       0      0.
      30      0.
      60      0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION    N.A. TO    SPRING     N.A. TO
             ELASTICITY   INERTIA     AREA     INTERFACE           HORZ SPRING

     USING DATA FROM THE PREVIOUS PROBLEM
   0  22  0   3.000E+06  2.401E+03  5.880E+02 -0.        -0.        -0.
   0  60  0  -0.        -0.        -0.        3.500E+00 -0.        -0.
  23  37  0  -0.         0.        6.320E+00 -0.        -0.        -0.
  23  37  0   3.000E+07 -0.        -0.        -0.        -0.        -0.
  38  60  0   3.000E+06  2.401E+03  5.880E+02 -0.        -0.        -0.
     ADDITIONAL DATA FOR THIS PROBLEM

               NONE


TABLE 5  -  BEAM PROPERTIES
```

```
FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA          OF        OF       SECTION    N.A. TO    SPRING     N.A. TO
             ELASTICITY  .INERTIA     AREA     INTERFACE           HORZ SPRING

     USING DATA FROM THE PREVIOUS PROBLEM
   0  60  0   3.000E+07 -0.        -0.        -0.        -0.        -0.
   0  26  0  -0.         1.141E+03  1.618E+01 -0.        -0.        -0.
   0  26 -0  -0.        -0.        -0.         1.040E+01 -0.        -0.
  26  34  0  -0.         1.394E+03  1.881E+01 -0.        -0.        -0.
  27  33  0  -0.        -0.        -0.         1.188E+01 -0.        -0.
  34  60  0  -0.         1.141E+03  1.618E+01 -0.        -0.        -0.
  34  60  0  -0.        -0.        -0.         1.040E+01 -0.        -0.
  60  60  0  -0.        -0.        -0.        -0.         1.000E+08  1.040E+01
     ADDITIONAL DATA FOR THIS PROBLEM
  30  30  0  -0.        -0.        -0.        -0.         1.000E+05  9.297E+00


TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD   SHEAR   TRANSVERSE    SPRING
 STA STA      CONNECTOR    LOAD       SUPPORT
               MODULUS

     USING DATA FROM THE PREVIOUS PROBLEM
   1  60  0   2.100E+06 -0.        -0.
   0  60  0  -0.        -6.750E+02 -0.
  10  10  0  -0.        -1.320E+04 -0.
  24  24  0  -0.        -3.300E+03 -0.
  43  43  0  -0.        -1.320E+04 -0.
  57  57  0  -0.        -3.300E+03 -0.
     ADDITIONAL DATA FOR THIS PROBLEM

               NONE


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD   SLAB       BEAM       SLAB       BEAM       SLAB       BEAM
 STA STA     TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL  LONGITUD.  LONGITUD.
               COUPLE     COUPLE    RESTRAINT  RESTRAINT    LOAD       LOAD

  10  10  0   2.310E+04 -0.        -0.        -0.         6.600E+03 -0.
  24  24  0   5.775E+03 -0.        -0.        -0.         1.650E+03 -0.
  43  43  0   2.310E+04 -0.        -0.        -0.         6.600E+03 -0.
  57  57  0   5.775E+03 -0.        -0.        -0.         1.650E+03 -0.


TABLE 8 - ITERATION MONITOR DATA

       STA     DISPLACEMENTS AT STATIONS
 ITER  NOT              15                    30                    45
  NUM CLSD     U-SLAB    U-BEAM      U-SLAB    U-BEAM      U-SLAB     U-BEAM

    1   62  -1.259E-02 -1.020E-02  -9.994E-03 -7.921E-03  -5.532E-03 -7.585E-03
    2   62  -1.258E-02 -1.020E-02  -9.991E-03 -7.917E-03  -5.530E-03 -7.582E-03
    3    0  -1.258E-02 -1.020E-02  -9.991E-03 -7.917E-03  -5.530E-03 -7.582E-03
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR   -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT      RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM.


PROB (CONTD)
    5     A TWO-SPAN BEAM WITH TRACTIVE FORCES


TABLE 9  -  COMPUTED RESULTS

 STA    VERTICAL      SLAB        SLAB        BEAM        BEAM       LOAD ON
        DEFLECTION    BENDING     AXIAL       BENDING     AXIAL       SHEAR
                      MOMENT      LOAD        MOMENT      LOAD       CONNECTOR

  -1    1.632E-02    0.          0.          0.          -0.
                                                                     0.
   0    0.          -2.777E-09  -8.160E-09  -1.320E-08   2.245E-09
                                                                    -7.367E+03
   1   -1.632E-02    1.307E+04  -7.367E+03   6.209E+04  -7.367E+03
                                                                    -7.219E+03
   2   -3.238E-02    2.508E+04  -1.459E+04   1.192E+05  -1.459E+04
                                                                    -6.965E+03
   3   -4.794E-02    3.630E+04  -2.155E+04   1.725E+05  -2.155E+04
                                                                    -6.627E+03
   4   -6.277E-02    4.693E+04  -2.818E+04   2.230E+05  -2.818E+04
                                                                    -6.210E+03
   5   -7.667E-02    5.716E+04  -3.439E+04   2.716E+05  -3.439E+04
                                                                    -5.707E+03
   6   -8.942E-02    6.719E+04  -4.010E+04   3.193E+05  -4.010E+04
                                                                    -5.094E+03
   7   -1.008E-01    7.730E+04  -4.519E+04   3.674E+05  -4.519E+04
                                                                    -4.327E+03
   8   -1.107E-01    8.786E+04  -4.952E+04   4.175E+05  -4.952E+04
                                                                    -3.332E+03
   9   -1.[illegible]88E-01    9.941E+04  -5.285E+04   4.724E+05  -5.285E+04
                                                                    -1.997E+03
  10   -1.249E-01    1.148E+05  -6.145E+04   5.455E+05  -5.485E+04
                                                                    -1.402E+02
  11   -1.287E-01    1.057E+05  -6.159E+04   5.024E+05  -5.499E+04
                                                                     1.266E+03
  12   -1.305E-01    9.661E+04  -6.032E+04   4.591E+05  -5.372E+04
                                                                     2.313E+03
  13   -1.302E-01    8.864E+04  -5.801E+04   4.212E+05  -5.141E+04
                                                                     3.126E+03
  14   -1.282E-01    8.121E+04  -5.488E+04   3.859E+05  -4.828E+04
                                                                     3.785E+03
  15   -1.246E-01    7.397E+04  -5.110E+04   3.515E+05  -4.450E+04
                                                                     4.342E+03
  16   -1.195E-01    6.667E+04  -4.676E+04   3.168E+05  -4.016E+04
                                                                     4.831E+03
  17   -1.131E-01    5.913E+04  -4.192E+04   2.810E+05  -3.532E+04
                                                                     5.274E+03
  18   -1.055E-01    5.126E+04  -3.665E+04   2.436E+05  -3.005E+04
                                                                     5.684E+03
  19   -9.686E-02    4.297E+04  -3.097E+04   2.042E+05  -2.437E+04
                                                                     6.066E+03
  20   -8.737E-02    3.420E+04  -2.490E+04   1.625E+05  -1.830E+04
                                                                     6.423E+03
```

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 21   -7.719E-02   2.487E+04  -1.848E+04   1.182E+05  -1.188E+04
                                                                  6.752E+03
 22   -6.652E-02   8.179E+03  -1.172E+04   7.774E+04  -5.124E+03
                                                                  6.947E+03
 23   -5.552E-02   0.         -4.778E+03   2.336E+04   1.822E+03
                                                                  6.010E+03
 24   -4.442E-02   0.         -4.171E+02  -5.743E+04   7.833E+03
                                                                  5.774E+03
 25   -3.356E-02   0.          5.357E+03  -1.892E+05   1.361E+04
                                                                  5.256E+03
 26   -2.350E-02   0.          1.061E+04  -3.392E+05   1.886E+04
                                                                  5.585E+03
 27   -1.472E-02   0.          1.620E+04  -4.565E+05   2.445E+04
                                                                  5.736E+03
 28   -7.516E-03   0.          2.193E+04  -6.075E+05   3.018E+04
                                                                  4.369E+03
 29   -2.402E-03   0.          2.630E+04  -7.876E+05   3.455E+04
                                                                  2.109E+03
 30    0.          0.          2.841E+04  -1.018E+06   3.745E+04
                                                                 -1.876E+03
 31   -1.103E-03   0.          2.654E+04  -7.973E+05   3.558E+04
                                                                 -4.149E+03
 32   -4.951E-03   0.          2.239E+04  -6.199E+05   3.143E+04
                                                                 -5.515E+03
 33   -1.093E-02   0.          1.687E+04  -4.715E+05   2.591E+04
                                                                 -5.500E+03
 34   -1.854E-02   0.          1.137E+04  -3.612E+05   2.041E+04
                                                                 -5.351E+03
 35   -2.751E-02   0.          6.020E+03  -2.185E+05   1.506E+04
                                                                 -6.005E+03
 36   -3.741E-02   0.          1.443E+01  -9.304E+04   9.056E+03
                                                                 -6.485E+03
 37   -4.769E-02   0.         -6.471E+03   1.766E+04   2.571E+03
                                                                 -7.891E+03
 38   -5.790E-02   9.588E+03  -1.436E+04   9.112E+04  -5.320E+03
                                                                 -7.645E+03
 39   -6.773E-02   3.113E+04  -2.201E+04   1.480E+05  -1.297E+04
                                                                 -7.119E+03
 40   -7.693E-02   4.462E+04  -2.913E+04   2.120E+05  -2.008E+04
                                                                 -6.407E+03
 41   -8.524E-02   5.842E+04  -3.553E+04   2.776E+05  -2.649E+04
                                                                 -5.450E+03
 42   -9.239E-02   7.312E+04  -4.098E+04   3.475E+05  -3.194E+04
                                                                 -4.137E+03
 43   -9.807E-02   9.159E+04  -5.172E+04   4.353E+05  -3.608E+04
                                                                 -2.295E+03
 44   -1.019E-01   8.557E+04  -5.402E+04   4.066E+05  -3.837E+04
                                                                 -8.979E+02
 45   -1.041E-01   7.950E+04  -5.491E+04   3.778E+05  -3.927E+04
                                                                  1.451E+02
 46   -1.046E-01   7.454E+04  -5.477E+04   3.542E+05  -3.913E+04
                                                                  9.564E+02
 47   -1.037E-01   7.013E+04  -5.381E+04   3.333E+05  -3.817E+04
                                                                  1.617E+03
 48   -1.013E-01   6.591E+04  -5.219E+04   3.132E+05  -3.655E+04
                                                                  2.178E+03
 49   -9.768E-02   6.162E+04  -5.002E+04   2.929E+05  -3.437E+04
                                                                  2.676E+03
 50   -9.279E-02   5.713E+04  -4.734E+04   2.715E+05  -3.170E+04
                                                                  3.132E+03
 51   -8.675E-02   5.234E+04  -4.421E+04   2.487E+05  -2.857E+04
                                                                  3.563E+03
```

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 52   -7.967E-02   4.717E+04  -4.065E+04   2.241E+05  -2.500E+04
                                                                    3.978E+03
 53   -7.165E-02   4.159E+04  -3.667E+04   1.976E+05  -2.103E+04
                                                                    4.385E+03
 54   -6.280E-02   3.558E+04  -3.228E+04   1.691E+05  -1.664E+04
                                                                    4.790E+03
 55   -5.323E-02   2.915E+04  -2.749E+04   1.385E+05  -1.185E+04
                                                                    5.199E+03
 56   -4.309E-02   2.229E+04  -2.229E+04   1.059E+05  -6.652E+03
                                                                    5.620E+03
 57   -3.249E-02   1.554E+04  -1.832E+04   7.386E+04  -1.032E+03
                                                                    6.060E+03
 58   -2.159E-02   1.562E+03  -1.226E+04   7.421E+03   5.028E+03
                                                                    6.222E+03
 59   -1.066E-02  -1.394E+04  -6.042E+03  -6.623E+04   1.125E+04
                                                                    6.042E+03
 60    0.         -5.553E-09  -8.160E-09  -2.639E-08   5.263E-11
                                                                    0.
 61    1.066E-02   0.          0.          0.         -0.
```

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PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
    5     A TWO-SPAN BEAM WITH TRACTIVE FORCES


TABLE 10  -  COMPUTED RESULTS

 STA       SLAB        SLAB        BEAM        BEAM       SUPPORT      SLIP
        HORIZONTAL     SHEAR    HORIZONTAL     SHEAR      REACTION
          DISPLAC                  DISPLAC

 -1                                                       0.
        -8.570E-03  -2.369E-10  -2.397E-02  -1.101E-09                -3.508E-03
  0                                                       1.513E+04
        -8.570E-03   3.233E+03  -2.397E-02   1.156E+04                -3.508E-03
  1                                                       0.
        -8.620E-03   3.092E+03  -2.379E-02   1.103E+04                -3.438E-03
  2                                                       0.
        -8.720E-03   2.943E+03  -2.342E-02   1.050E+04                -3.317E-03
  3                                                       0.
        -8.866E-03   2.788E+03  -2.289E-02   9.984E+03                -3.156E-03
  4                                                       0.
        -9.058E-03   2.627E+03  -2.220E-02   9.469E+03                -2.957E-03
  5                                                       0.
        -9.292E-03   2.461E+03  -2.135E-02   8.960E+03                -2.718E-03
  6                                                       0.
        -9.565E-03   2.288E+03  -2.035E-02   8.459E+03                -2.426E-03
  7                                                       0.
        -9.872E-03   2.103E+03  -1.924E-02   7.969E+03                -2.060E-03
  8                                                       0.
        -1.021E-02   1.900E+03  -1.801E-02   7.497E+03                -1.587E-03
  9                                                       0.
        -1.057E-02   1.835E+03  -1.671E-02   7.849E+03                -9.510E-04
 10                                                       0.
        -1.099E-02  -7.352E+02  -1.535E-02  -3.456E+03                -6.677E-05
 11                                                       0.
        -1.141E-02  -1.136E+03  -1.399E-02  -4.692E+03                 6.028E-04
 12                                                       0.
        -1.182E-02  -1.338E+03  -1.266E-02  -5.165E+03                 1.102E-03
 13                                                       0.
        -1.221E-02  -1.521E+03  -1.139E-02  -5.657E+03                 1.489E-03
 14                                                       0.
        -1.258E-02  -1.691E+03  -1.020E-02  -6.162E+03                 1.802E-03
 15                                                       0.
        -1.293E-02  -1.854E+03  -9.098E-03  -6.674E+03                 2.068E-03
 16                                                       0.
        -1.325E-02  -2.013E+03  -8.105E-03  -7.190E+03                 2.301E-03
 17                                                       0.
        -1.353E-02  -2.169E+03  -7.232E-03  -7.709E+03                 2.512E-03
 18                                                       0.
        -1.378E-02  -2.324E+03  -6.489E-03  -8.229E+03                 2.707E-03
 19                                                       0.
        -1.399E-02  -2.479E+03  -5.887E-03  -8.750E+03                 2.889E-03
 20                                                       0.
        -1.416E-02  -2.632E+03  -5.434E-03  -9.271E+03                 3.059E-03
```

```
 21                                                       0.
      -1.429E-02  -3.347E+03  -5.141E-03  -9.231E+03                  3.215E-03
 22                                                       0.
      -1.445E-02  -2.700E+03  -5.014E-03  -1.055E+04                  3.308E-03
 23                                                       0.
      -1.505E-02  -1.751E+03  -5.059E-03  -1.194E+04                  2.862E-03
 24                                                       0.
      -1.508E-02  -1.686E+03  -5.253E-03  -1.598E+04                  2.750E-03
 25                                                       0.
      -1.474E-02  -1.540E+03  -5.589E-03  -1.704E+04                  2.503E-03
 26                                                       0.
      -1.407E-02  -1.639E+03  -6.020E-03  -1.494E+04                  2.659E-03
 27                                                       0.
      -1.304E-02  -1.684E+03  -6.540E-03  -1.824E+04                  2.731E-03
 28                                                       0.
      -1.166E-02  -1.285E+03  -7.182E-03  -1.932E+04                  2.080E-03
 29                                                       0.
      -9.991E-03  -6.206E+02  -7.917E-03  -2.066E+04                  1.004E-03
 30                                                       4.273E+04
      -8.193E-03   5.496E+02  -8.713E-03   2.023E+04                 -8.931E-04
 31                                                       0.
      -6.514E-03   1.218E+03  -9.470E-03   1.889E+04                 -1.976E-03
 32                                                       0.
      -5.097E-03   1.618E+03  -1.014E-02   1.781E+04                 -2.626E-03
 33                                                       0.
      -4.029E-03   1.613E+03  -1.069E-02   1.428E+04                 -2.619E-03
 34                                                       0.
      -3.310E-03   1.567E+03  -1.116E-02   1.651E+04                 -2.548E-03
 35                                                       0.
      -2.929E-03   1.754E+03  -1.153E-02   1.565E+04                 -2.860E-03
 36                                                       0.
      -2.928E-03   1.889E+03  -1.175E-02   1.484E+04                 -3.088E-03
 37                                                       0.
      -3.747E-03   3.092E+03  -1.182E-02   1.296E+04                 -3.758E-03
 38                                                       0.
      -3.942E-03   4.010E+03  -1.168E-02   1.137E+04                 -3.641E-03
 39                                                       0.
      -4.092E-03   3.181E+03  -1.136E-02   1.152E+04                 -3.390E-03
 40                                                       0.
      -4.290E-03   2.996E+03  -1.087E-02   1.103E+04                 -3.051E-03
 41                                                       0.
      -4.532E-03   2.792E+03  -1.021E-02   1.056E+04                 -2.595E-03
 42                                                       0.
      -4.810E-03   2.724E+03  -9.423E-03   1.092E+04                 -1.970E-03
 43                                                       0.
      -5.162E-03   1.506E+02  -8.531E-03  -3.839E+02                 -1.093E-03
 44                                                       0.
      -5.530E-03  -2.534E+02  -7.582E-03  -1.617E+03                 -4.276E-04
 45                                                       0.
      -5.903E-03  -4.581E+02  -6.611E-03  -2.088E+03                  6.908E-05
 46                                                       0.
      -6.276E-03  -6.423E+02  -5.644E-03  -2.579E+03                  4.554E-04
 47                                                       0.
      -6.642E-03  -8.134E+02  -4.700E-03  -3.082E+03                  7.698E-04
 48                                                       0.
      -6.997E-03  -9.766E+02  -3.797E-03  -3.594E+03                  1.037E-03
 49                                                       0.
      -7.337E-03  -1.135E+03  -2.947E-03  -4.111E+03                  1.274E-03
 50                                                       0.
      -7.659E-03  -1.291E+03  -2.163E-03  -4.630E+03                  1.492E-03
 51                                                       0.
      -7.960E-03  -1.445E+03  -1.457E-03  -5.151E+03                  1.697E-03
```

```
  52                                                      0.
      -8.237E-03  -1.599E+03  -8.388E-04  -5.672E+03                   1.894E-03
  53                                                      0.
      -8.486E-03  -1.754E+03  -3.190E-04  -6.192E+03                   2.088E-03
  54                                                      0.
      -8.706E-03  -1.910E+03   9.240E-05  -6.711E+03                   2.281E-03
  55                                                      0.
      -8.893E-03  -2.067E+03   3.854E-04  -7.229E+03                   2.476E-03
  56                                                      0.
      -9.044E-03  -2.184E+03   5.498E-04  -7.547E+03                   2.676E-03
  57                                                      0.
      -9.169E-03  -2.919E+03   5.753E-04  -1.079E+04                   2.886E-03
  58                                                      0.
      -9.252E-03  -3.098E+03   4.510E-04  -1.152E+04                   2.963E-03
  59                                                      0.
      -9.293E-03  -5.980E+02   1.729E-04  -1.470E+04                   2.877E-03
  60                                                      1.563E+04
      -9.293E-03   4.664E-10   1.729E-04   2.199E-09                   2.877E-03
  61                                                      0.


                          TIME FOR THIS PROBLEM =      0 MINUTES    1.200 SECONDS


                          ELAPSED CPU TIME =      0 MINUTES   16.766 SECONDS
```

```
PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051119          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB
   6     AN EXPERIMENTAL COMPOSITE BEAM


TABLE 1 - PROGRAM-CONTROL DATA
                                                             TABLE NUMBER
                                                   2     3     4     5     6     7

     HOLD FROM PRECEDING PROBLEM (1=HOLD)          0     0     0     0     0     0
     NUM CARDS INPUT THIS PROBLEM                  1     2     1     2     5     0


TABLE 2 - CONSTANTS

     NUMBER OF INCREMENTS                                                        40
     INCREMENT LENGTH                                                     6.000E+00
     NONLINEAR PROBLEM                                                           NO
     MAX NUM ITERATIONS                                                          -0
     CLOSURE TOLERANCE                                                  -0.
     LIST OF MONITOR STATIONS                                         -0    -0    -0


TABLE 3  -  SPECIFIED DEFLECTIONS

     STA      DEFLECTION

       0        0.
      40        0.


TABLE 4  -  SLAB PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION    N.A. TO    SPRING      N.A. TO
              ELASTICITY  INERTIA     AREA     INTERFACE              HORZ SPRING

   0  40  0   2.300E+06  3.647E+02  2.160E+02  3.750E+00 -0.          -0.


TABLE 5  -  BEAM PROPERTIES

FROM TO CONTD  MODULUS    MOMENT     CROSS-    DISTANCE, HORIZONTAL  DISTANCE,
 STA STA         OF         OF       SECTION    N.A. TO    SPRING      N.A. TO
              ELASTICITY  INERTIA     AREA     INTERFACE              HORZ SPRING

   0  40  0   2.900E+07  2.041E+02  7.970E+00  6.000E+00 -0.          -0.
   0   0  0  -0.        -0.        -0.        -0.         1.000E+06 -0.
```

```
TABLE 6  -  DATA COMMON TO THE SLAB AND BEAM

FROM TO CONTD   SHEAR   TRANSVERSE   SPRING
 STA STA       CONNECTOR    LOAD       SUPPORT
                MODULUS

   1  40  0   8.000E+05 -0.          -0.
   5   5  0  -0.         -6.000E+03 -0.
  15  15  0  -0.         -6.000E+03 -0.
  25  25  0  -0.         -6.000E+03 -0.
  35  35  0  -0.         -6.000E+03 -0.


TABLE 7  -  DATA FOR THE SLAB AND BEAM

FROM TO CONTD    SLAB        BEAM        SLAB        BEAM         SLAB        BEAM
 STA STA      TRANSVERSE TRANSVERSE ROTATIONAL ROTATIONAL  LONGITUD.  LONGITUD.
                COUPLE     COUPLE    RESTRAINT  RESTRAINT     LOAD        LOAD


                NONE


TABLE 8 - ITERATION MONITOR DATA

       STA      DISPLACEMENTS AT STATIONS
 ITER  NOT              -0                      -0                      -0
  NUM CLSD     U-SLAB      U-BEAM      U-SLAB      U-BEAM       U-SLAB      U-BEAM


                NONE
```

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PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP          RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM.


PROB (CONTD)
    6      AN EXPERIMENTAL COMPOSITE BEAM


TABLE 9  -  COMPUTED RESULTS

 STA     VERTICAL      SLAB        SLAB        BEAM        BEAM       LOAD ON
        DEFLECTION   BENDING      AXIAL      BENDING      AXIAL        SHEAR
                      MOMENT       LOAD       MOMENT       LOAD      CONNECTOR

  -1     1.879E-02   0.          0.          0.          -0.
                                                                     0.
   0     0.          1.293E-09   9.193E-09   9.127E-09   2.398E-08
                                                                    -4.530E+03
   1    -1.879E-02   3.455E+03  -4.530E+03   2.438E+04  -4.530E+03
                                                                    -4.475E+03
   2    -3.742E-02   6.976E+03  -9.005E+03   4.922E+04  -9.005E+03
                                                                    -4.360E+03
   3    -5.576E-02   1.064E+04  -1.337E+04   7.505E+04  -1.337E+04
                                                                    -4.173E+03
   4    -7.364E-02   1.452E+04  -1.754E+04   1.025E+05  -1.754E+04
                                                                    -3.897E+03
   5    -9.090E-02   1.874E+04  -2.144E+04   1.323E+05  -2.144E+04
                                                                    -3.503E+03
   6    -1.074E-01   1.897E+04  -2.494E+04   1.339E+05  -2.494E+04
                                                                    -3.204E+03
   7    -1.230E-01   1.956E+04  -2.814E+04   1.380E+05  -2.814E+04
                                                                    -2.968E+03
   8    -1.378E-01   2.044E+04  -3.111E+04   1.442E+05  -3.111E+04
                                                                    -2.775E+03
   9    -1.517E-01   2.155E+04  -3.389E+04   1.521E+05  -3.389E+04
                                                                    -2.603E+03
  10    -1.647E-01   2.287E+04  -3.649E+04   1.614E+05  -3.649E+04
                                                                    -2.438E+03
  11    -1.767E-01   2.439E+04  -3.893E+04   1.721E+05  -3.893E+04
                                                                    -2.262E+03
  12    -1.877E-01   2.612E+04  -4.119E+04   1.843E+05  -4.119E+04
                                                                    -2.058E+03
  13    -1.976E-01   2.810E+04  -4.325E+04   1.983E+05  -4.325E+04
                                                                    -1.806E+03
  14    -2.062E-01   3.038E+04  -4.505E+04   2.144E+05  -4.505E+04
                                                                    -1.482E+03
  15    -2.135E-01   3.306E+04  -4.653E+04   2.332E+05  -4.653E+04
                                                                    -1.053E+03
  16    -2.195E-01   3.178E+04  -4.759E+04   2.243E+05  -4.759E+04
                                                                    -7.284E+02
  17    -2.240E-01   3.090E+04  -4.831E+04   2.180E+05  -4.831E+04
                                                                    -4.746E+02
  18    -2.272E-01   3.032E+04  -4.879E+04   2.140E+05  -4.879E+04
                                                                    -2.674E+02
  19    -2.292E-01   3.000E+04  -4.906E+04   2.117E+05  -4.906E+04
                                                                    -8.631E+01
  20    -2.298E-01   2.990E+04  -4.914E+04   2.110E+05  -4.914E+04
                                                                     8.631E+01
```

```
21   -2.292E-01   3.000E+04  -4.906E+04   2.117E+05  -4.906E+04
                                                                  2.674E+02
22   -2.272E-01   3.032E+04  -4.879E+04   2.140E+05  -4.879E+04
                                                                  4.746E+02
23   -2.240E-01   3.090E+04  -4.831E+04   2.180E+05  -4.831E+04
                                                                  7.284E+02
24   -2.195E-01   3.178E+04  -4.759E+04   2.243E+05  -4.759E+04
                                                                  1.053E+03
25   -2.135E-01   3.306E+04  -4.653E+04   2.332E+05  -4.653E+04
                                                                  1.482E+03
26   -2.062E-01   3.038E+04  -4.505E+04   2.144E+05  -4.505E+04
                                                                  1.806E+03
27   -1.976E-01   2.810E+04  -4.325E+04   1.983E+05  -4.325E+04
                                                                  2.058E+03
28   -1.877E-01   2.612E+04  -4.119E+04   1.843E+05  -4.119E+04
                                                                  2.262E+03
29   -1.767E-01   2.439E+04  -3.893E+04   1.721E+05  -3.893E+04
                                                                  2.438E+03
30   -1.647E-01   2.287E+04  -3.649E+04   1.614E+05  -3.649E+04
                                                                  2.603E+03
31   -1.517E-01   2.155E+04  -3.389E+04   1.521E+05  -3.389E+04
                                                                  2.775E+03
32   -1.378E-01   2.044E+04  -3,111E+04   1.442E+05  -3.111E+04
                                                                  2.968E+03
33   -1.230E-01   1.956E+04  -2.814E+04   1.380E+05  -2.814E+04
                                                                  3.204E+03
34   -1.074E-01   1.897E+04  -2.494E+04   1.339E+05  -2.494E+04
                                                                  3.503E+03
35   -9.090E-02   1.874E+04  -2.144E+04   1.323E+05  -2.144E+04
                                                                  3.897E+03
36   -7.364E-02   1.452E+04  -1.754E+04   1.025E+05  -1.754E+04
                                                                  4.173E+03
37   -5.576E-02   1.064E+04  -1.337E+04   7.505E+04  -1.337E+04
                                                                  4.360E+03
38   -3.742E-02   6.976E+03  -9.005E+03   4.922E+04  -9.005E+03
                                                                  4.475E+03
39   -1.879E-02   3.455E+03  -4.530E+03   2.438E+04  -4.530E+03
                                                                  4.530E+03
40    0.          0.          6.894E-09   0.         -4.277E-09
                                                                  0.
41    1.879E-02   0.          0.          0.         -0.
```

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PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -    REVISION DATE = 29 DEC 66
CHG TO CE051118          CODED BY TPT     RE-PCH BY JJP           RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


PROB (CONTD)
    6      AN EXPERIMENTAL COMPOSITE BEAM


TABLE 10  -  COMPUTED RESULTS

 STA        SLAB         SLAB        BEAM         BEAM       SUPPORT       SLIP
         HORIZONTAL     SHEAR     HORIZONTAL     SHEAR      REACTION
           DISPLAC                  DISPLAC

  -1                                                        0.
          2.486E-02   2.300E-10  -2.398E-14   1.484E-09                -5.663E-03
   0                                                        1.200E*04
          2.486E-02   3.400E+03  -2.522E-14   8.600E+03                -5.663E-03
   1                                                        0.
          2.481E-02   3.363E+03   1.176E-04   8.637E+03                -5.594E-03
   2                                                        0.
          2.470E-02   3.301E+03   3.514E-04   8.699E+03                -5.450E-03
   3                                                        0.
          2.454E-02   3.210E+03   6.983E-04   8.790E+03                -5.217E-03
   4                                                        0.
          2.433E-02   3.083E+03   1.154E-03   8.917E+03                -4.871E-03
   5                                                        0.
          2.407E-02   2.164E+03   1.710E-03   3.836E+03                -4.379E-03
   6                                                        0.
          2.377E-02   2.032E+03   2.357E-03   3.968E+03                -4.004E-03
   7                                                        0.
          2.343E-02   1.928E+03   3.088E-03   4.072E+03                -3.710E-03
   8                                                        0.
          2.305E-02   1.844E+03   3.896E-03   4.156E+03                -3.468E-03
   9                                                        0.
          2.264E-02   1.770E+03   4.775E-03   4.230E+03                -3.254E-03
  10                                                        0.
          2.220E-02   1.701E+03   5.722E-03   4.299E+03                -3.047E-03
  11                                                        0.
          2.173E-02   1.629E+03   6.733E-03   4.371E+03                -2.827E-03
  12                                                        0.
          2.123E-02   1.546E+03   7.802E-03   4.454E+03                -2.572E-03
  13                                                        0.
          2.071E-02   1.446E+03   8.925E-03   4.554E+03                -2.257E-03
  14                                                        0.
          2.017E-02   1.316E+03   1.009E-02   4.684E+03                -1.852E-03
  15                                                        0.
          1.961E-02   3.995E+02   1.130E-02  -3.995E+02                -1.317E-03
  16                                                        0.
          1.903E-02   2.719E+02   1.254E-02  -2.719E+02                -9.105E-04
  17                                                        0.
          1.845E-02   1.748E+02   1.379E-02  -1.748E+02                -5.933E-04
  18                                                        0.
          1.786E-02   9.745E+01   1.506E-02  -9.745E+01                -3.342E-04
  19                                                        0.
          1.727E-02   3.128E+01   1.633E-02  -3.128E+01                -1.079E-04
  20                                                        0.
          1.667E-02  -3.128E+01   1.761E-02   3.128E+01                 1.079E-04
```

```
 21                                                         0.
         1.608E-02  -9.745E+01   1.888E-02   9.745E+01                      3.342E-04
 22                                                         0.
         1.549E-02  -1.748E+02   2.015E-02   1.748E+02                      5.933E-04
 23                                                         0.
         1.491E-02  -2.719E+02   2.140E-02   2.719E+02                      9.105E-04
 24                                                         0.
         1.433E-02  -3.995E+02   2.264E-02   3.995E+02                      1.317E-03
 25                                                         0.
         1.377E-02  -1.316E+03   2.385E-02  -4.684E+03                      1.852E-03
 26                                                         0.
         1.323E-02  -1.446E+03   2.501E-02  -4.554E+03                      2.257E-03
 27                                                         0.
         1.270E-02  -1.546E+03   2.614E-02  -4.454E+03                      2.572E-03
 28                                                         0.
         1.221E-02  -1.629E+03   2.721E-02  -4.371E+03                      2.827E-03
 29                                                         0.
         1.174E-02  -1.701E+03   2.822E-02  -4.299E+03                      3.047E-03
 30                                                         0.
         1.130E-02  -1.770E+03   2.916E-02  -4.230E+03                      3.254E-03
 31                                                         0.
         1.089E-02  -1.844E+03   3.004E-02  -4.156E+03                      3.468E-03
 32                                                         0.
         1.051E-02  -1.928E+03   3.085E-02  -4.072E+03                      3.710E-03
 33                                                         0.
         1.017E-02  -2.032E+03   3.158E-02  -3.968E+03                      4.004E-03
 34                                                         0.
         9.870E-03  -2.164E+03   3.223E-02  -3.836E+03                      4.379E-03
 35                                                         0.
         9.611E-03  -3.083E+03   3.279E-02  -8.917E+03                      4.871E-03
 36                                                         0.
         9.400E-03  -3.210E+03   3.324E-02  -8.790E+03                      5.217E-03
 37                                                         0.
         9.238E-03  -3.301E+03   3.359E-02  -8.699E+03                      5.450E-03
 38                                                         0.
         9.129E-03  -3.363E+03   3.382E-02  -8.637E+03                      5.594E-03
 39                                                         0.
         9.075E-03  -3.400E+03   3.394E-02  -8.600E+03                      5.663E-03
 40                                                         1.200E+04
         9.075E-03  -1.079E-11   3.394E-02  -6.695E-12                      5.663E-03
 41                                                         0.


                              TIME FOR THIS PROBLEM =      0 MINUTES      .794 SECONDS


                              ELAPSED CPU TIME =      0 MINUTES   17.560 SECONDS
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PROGRAM COMBM 1 - DECK 2 -  MATLOCK-TAYLOR  -     REVISION DATE = 29 DEC 66
CHG TO CE051118           CODED BY TPT     RE-PCH BY JJP            RUN 02 JAN 67
EXAMPLE PROBLEMS FOR COMBM


RETURN THIS PAGE TO TIME RECORD FILE -- HM
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```
11.52.20. AB25752. READ.
11.53.12. AB25752. PP 052 SEC.
11.53.13. AB25752. FRANK,1,30,100000,6000,CE051118,MATLOCK.
11.53.13. AB25752.
11.53.14. AB25752. RUN(S)
11.53.33. AB25752. UNUSED JOB SPACE  -  014700
11.53.35. AB25752.         COMBM1.
11.53.52. AB25752. END
11.53.53. AB25752. CP  017.580 SEC.
11.53.53. AB25752. PP  036.769 SEC.
2JAN67.    UNIVERSITY OF TEXAS  CDC 6600  CHIP 1.1.28Y
```