TOWARDS SIMPLIFIED COMPUTER-BASED ANALYSIS OF SKEWED-BRIDGES

BY

ABUBAKAR, ALIYU AZIZ

A thesis submitted to the
Postgraduate School, Ahmadu Bello
University, in partial fulfillment of
the requirements for the degree of

M.Sc. Structural Engineering.

Department of Civil Engineering,

Ahmadu Bello University, Zaria.

September, 1987.

DECLARATION

I hereby declare that this thesis is a record of the research work carried out by me under the supervision of Dr. A. O. Abatan. To the best of my knowledge, it has not been previously published or accepted any where for the award of any degree.

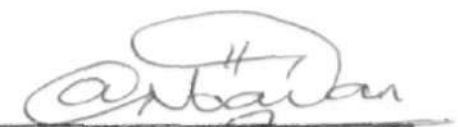
All works, opinions and ideas, other than mine have been fully acknowledged.

Abubakar, Aliyu Aziz

September, 1987

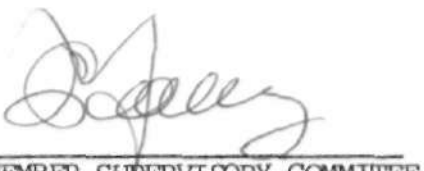
CERTIFICATION

This thesis entiled "Towards Simplified Computer-Based Analysis of Skewed-Bridges", by Abubakar, Aliyu Aziz meets with the regulations governing the award of the degree of Master of Science (Structural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.



CHAIRMAN SUPERVISORY COMMITEE
Dr A. O. Abatan

DATE: 12/11/87



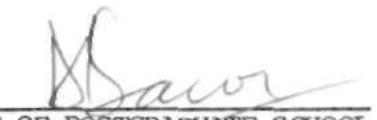
MEMBER SUPERVISORY COMMITEE
Mr B. K. Yanney

DATE: 13/11/87



HEAD OF DEPARTMENT
Dr A. O. Abatan

DATE: 12/11/87



DEAN OF POSTGRADUATE SCHOOL

DATE: 18-2-88

DEDICATION

- To Iya and late Addada, who deligently moulded me and instilled the basic software;

- To Kawu, Yaya, Hamma, Bappa and their families - my socio-psychological back-bones, who accepted my preoccupation with fortitude;

- To Ayodele, from whom I inherited the thankless tasks of fighting daily with the Computer, and finally,

- To Almighty ALLAH, an Eminent Programmer who defined the entire future of the universe at the time of creation as a sort of infinite sets of bugs-free, user friendly and compatible programs.

ACKNOWLEGEMENTS

This work is a result of the excitement and challenge that I've experienced in working in the field of Computer-based analysis of structures. Therefore, my greatest debt of gratitude must go to my supervisor and Head of Department, Dr. A. O. Abatan - for providing me with an environment in which my interest could grow and his continued support and interest in my work.

After being introduced to the field, there still remains the hardest problem: to become comfortable with these ideas, and to make them one's own. Here, I would like to thank two engineers - who helped to over come this problem. One is Engr. H. Samaila, whose influence led me to abandon an earlier work on Dynamics of Structures, and to study instead the real thing - Skewed-Bridges. The other is Engr. R. V. Perera, whose remarkable intuitions changed my initial fear of bridges. My appreciation also goes to Engr. B. K. Yanney for his suggestions and criticisms which helped in the completion of this work.

My gratitude is extended to Alhaji Dogo, Dr. Sheikh, Dr. Mohammed, Nenne, Lami and Bilkisu for their encouragement and support througout this study.

Special thanks goes to my friends: Aisha, Arabi, Ayinke, Ayo, Bash, Doris, Fatima, Funmi, Hajja Gana, Hauwa'u, Helen, Ileni, Kabir, Koko, Loureine, Mahey, Meera 1, Mosey, Musah, Rufa'i, Sege, Seye, Sulagna, Y square & Zainab, in sincere appreciation of their company.

I am also grateful for the assistance rendered by the entire staff of Iya Abubakar Computer Centre and Samaila Consultants.

Finally, truly unbounded thanks are due to 'her', MEERA who with her love and patience supported me in writing this thesis.

ABSTRACT

Needs for aesthetics, protection of abutments, and safety requirements of greater speeds on highways, demand better alignment. In order to achieve these, skew bridges are frequently built. The analysis of such structures poses specific difficulties to bridge designers, for example, response to torsional motions when the skew angle is greater than 20°.

In this study the structural behavior of skew bridge decks of various configurations and loading conditions is presented. Element models of the structure are discussed through the matrix displacement method. In addition, discretisation of the deck through its representation as a plane grillage of discrete interconnected elements is fully discussed. Loadings to BS5400 and load cases and combinations at both ultimate and serviceability limit states are provided. Special attention is given to the formulation of the problem in a systematic manner, which makes it suitable for computerized analysis of any bridge deck that is represented as an assemblage of discrete interconnected elements.

Further, an attempt has been made to provide a simplified approach to the use of these tools, so that their fruits may be made available to the designer without the need to perform complicated analysis in the design office. Having preselected a structure, the engineer can then identify a particular chart

and read directly the value of the structural response concerned without performing any rigorous analysis. Clearly, a great economy of time and effort is achieved, if for many structures such as highway skew bridges that might not be analysed conventionally, much detailed analysis can be replaced by the use of suitable charts.

Finally, a FORTRAN 77 computer program, GRID, is presented for the transverse analysis of bridge decks. It allows reinforcement to be proportioned for transverse as well as stirrups to be proportioned for longitudinal shear and torsion. Documentation, sample input and output, and a source listing as well as analysis aid charts are provided. It is hoped that bridge designers would find it convenient to use these charts.

TABLE OF CONTENTS

CHAPTER	PAGE
Title Page	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgements	v
Abstract	vii
Table of Contents	ix
List of Tables	xiii
List of Figures	xiv
List of Appendices	xvi
Definition of Symbols	xvii
1. INTRODUCTION	1
2. MODELING SKEWED BRIDGE DECKS	5
2.1 Introduction	5
2.2 Fundamentals of Mathematical Models	6
2.3 Formulation of the Model	6
2.4 Development of Continuum Models of Elements	8
2.4.1 Flexural Deformation Model	10
2.4.2 Torsional Deformation Model	14
3. DISCRETISATION OF THE MODEL	18
3.1 Introduction	18
3.2 Idealisation of Skewed Bridge Decks	18

CHAPTER		PAGE
	3.2.1 Elastic Stiffnesses	21
	3.2.2 Composite Materials	24
3.3	Discrete Models	25
	3.3.1 Flexural Deformation Model	25
	3.3.2 Torsional Deformation Model	30
3.4	Discrete Models in Matrix Form	32
	3.4.1 Flexural Deformation Model	34
	3.4.2 Torsional Deformation Model	36
	3.4.3 Torsional + Flexural Deformation Model	37
4.	CONCEPTS OF MATRIX DISPLACEMENT METHOD	39
4.1	Introduction	39
4.2	Notation and conventions	39
	4.2.1 Grillage Geometry	40
	4.2.2 Joint Coordinates	40
	4.2.3 Joint Numbering	44
	4.2.4 Element Connectivity	44
	4.2.5 Element Numbering	47
4.3	Generalised Displacements	47
4.4	Components of the Model	48
	4.4.1 Compatibility	48
	4.4.2 Equilibrium	50
4.5	Joint Forces	51
4.6	Coordinate Transformation	52
4.7	Assembly Process	54

CHAPTER		PAGE
4.8	Formulation of Global Element	56
4.9	Element Actions	58
4.9.1	Resolution of Actions	58
4.10	Review	61
5.	COMPUTER IMPLEMENTATION OF THE MATRIX DISPLACEMENT METHOD	63
5.1	Introduction	63
5.2	Computer Program Organisation	64
5.3	Program Information Flow	75
6.	BRIDGE DECK LOADING TO BS5400	78
6.1	Introduction	78
6.2	Highway Carriageways and Lanes	79
6.2.1	Carriageway	79
6.2.2	Traffic Lane	79
6.2.3	Notional Lanes	79
6.3	Load Modeling	79
6.3.1	Element Loads	80
6.3.2	Joint Loads	80
6.3.3	Other Loads Modeling	83
6.3.4	Load Modeling Limitations	83
6.4	Permanent Loads	87
6.4.1	Dead Load	87
	Modeling Dead Load	87
6.4.2	Superimposed Dead Load	87

CHAPTER		PAGE
	Modeling Superimposed Dead Load	89
6.5	Primary Highway Loading	89
6.5.1	HA Loading	89
	Uniformly Distributed Load (UDL)	91
	Knife Edge Load (KEL)	91
	Application of HA Loading	92
	Modeling HA Loading	92
6.5.2	HB Loading	92
	Application of HB Loading	95
	Modeling HB Loading	96
6.5.3	Footway Loading	96
6.6	Load Cases and Combinations	98
7	SIMPLIFIED ANALYSIS OF SKEWED BRIDGE DECKS	102
7.1	Introduction	102
7.2	Research Procedure	104
7.3	Methodology of Determining Responses	107
8	CONCLUSION	110
9	RECOMMENDATION	113
REFERENCES		117

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
5.1	Description of Program Modules	73
5.2	Description of Low - Speed Storage Allocations	74
IV-1	Maximum/Minimum Span Bending Moments	244
IV-2	Maximum/Minimum Torsional Moments	245
IV-3	Maximum/Minimum Shear Forces	246
IV-4	Maximum/Minimum Bending Moments for Slab/diaphragm	247

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
2.1	Formulation of the Model	7
2.2	Modeling Process , Holzer(1985)	9
2.3	Flexural Deformation Model	11
2.4	Torsional Deformation Model	15
3.1	Possible Grillage Layouts for Skew Decks	20
3.2	Beam and Slab Geometry	22
3.3	Torsional Inertia of Beam	23
3.4	Flexural Deformaton Model	26
3.5	Torsional Deformation Model	31
3.6	Torsional + Flexural Deformation Model	33
3.7	Deformation Models	35
4.1	Typical Modelled Grillage: A Skew Bridge Deck	41
4.2	Coordinate Systems	42
4.3	Suggested Orientation of Global Coordinates: A Skewed Bridge Deck	43
4.4	Joint Numbering Scheme	45
4.5	Element Connectivity and Numbering	46
4.6	Local and Global Coordinates for an Element of a Plane Grillage	53
4.7	Matrix Displacement Method with Element Actions, Holzer(1985)	62
5.1	Program Modules	66

FIGURE	DESCRIPTION	PAGE
5.2a	Module-1 : Input Processing	67
5.2b	Module-2 : Assembly Process	68
5.2c	Module-3 : Solution Process	69
5.2d	Module-4 : Computation of Element-End Forces	70
5.2e	Mcdule-5 : Computation of Joint Forces	71
5.2f	Module-6 : Output Processing	72
6.1	Element Uniformly Distributed Load on a 20° - Skew Deck	81
6.2	Element Point Loads on a 20° - Skew Deck	82
6.3	Joint Load Sign Convention	84
6.4	Solving Equivalent Fixed-End-Forces	85
6.5	Load Modeling Limitations - Non-gravity Parallel Loads	86
6.6	Dead Load Modeling	88
6.7	Superimposed Dead Load Modeling	90
6.8	HA Load Model	93
6.9	Dimensions of HB vehicle, BS5400(1978)	94
6.10	HB Vehicle Modeling	97
6.11	Footway Load Modeling	99
7.1	iterative Design/Analysis Process in Civil Engineering	106
7.2	Steps in Determining Bridge Responses using Simplified Approach	109

LIST OF APPENDICES

APPENDIX	DESCRIPTION	PAGE
I	User's Guide to Program GRID	120
II	Sample Input and Output	133
III	Source Listings of Program GRID	200
IV	SAMPLE - Bridge Response Determination Using Simplified Approach	243

DEFINITION OF SYMBOLS

SYMBOL	DEFINITION
α	EI/L^3
β	$GJ*L^2/EI$
γ	Shear strain = GJ/L
ε	Normal strain
σ	Normal stress
θ	Rotation angle
(r, θ)	Polar coordinates
λ	Rotation Matrix
Λ	Transformation Matrix
τ	Shear stress
ϕ	Coefficient of generalised displacements
Ψ	Coefficient of generalised displacements
ξ	Coordinate transformation
A	Cross sectional area
Ci,i=0,3	Generalised displacement coefficients
D	Global element-end displacement vector
E	Young's Modulus
F	Global element-end force vector, Internal generalised force vector
G	Shear Modulus
I	Moment of inertia
J	Torsion constant

K	Global Stiffness Matrix,
	Coefficient of aspect ratio
L	Span
M	Member Code Matrix,
	Bending moment
Ma,Mb	Concentrated moments
N	Normal force
NC	Number of joint constraints
NE	Number of elements
NI	Number of degrees of indeterminancy of a model
NJ	Number of joints
NM	Number of internal forces
P	Joint force vector
P(x)	Distributed transverse load
Q	Applied joint force vector
R	Generalised force
Sx,Sg,Sy	Dimensions of cross section
T	Torque
V	Shear force
Va,Vb	Concentrated forces
X,Y,Z	Global coordinates
b	breath of section
c1	cos θ
c2	sin θ

d	local displacement vector
f	local element-end force vector
gi,i=1,9	coefficients of global stiffness matrix
h	heigth of section
i,j,k	summation counters
$\dot{l}$	equivalent actions
$\bar{l}$	actual actions
$\hat{l}$	fixed-joint actions
m	elements number of degree of freedom
m(x)	distributed torque
n	number of degrees of freedom of a system model, number of physical beams
qk	joint displacements corresponding to the systems degree of freedom
v	transverse deflection
w	angle of twist
x,y,z	local coordinates

Chapter 1

1.1 INTRODUCTION

This work represents a modest response to the need for simplified methods of analysing skewed-bridge decks. The analysis of such structures poses specific difficulties to bridge designers. The specific difficulties are bridge response to torsional motions when the skew angle is greater than 20°. Before the advent of the electronic computer, such structures were analysed by the classical methods. Classical methods are treated by Hall and Kabaila (1977). However, these methods lay less proper emphasis on these difficulties.

Following the appearance of electronic digital computers in design offices, the necessity for analytical tools specifically directed towards its use became apparent. Consequently, a number of powerful analytical tools in the so-called refined methods of analysis are presently available to the bridge designer. These methods are well established and treated in a large number of technical literature, Bakht and Jeager (1985). One of these methods is the matrix displacement method. Others include grillage analogy method, orthotropic plate method, articulated plate method and Finite Element method (FEM), including its finite strip formulation.

It is important to realise that most of these refined methods have limitations as to the kinds of bridge superstructures which they are capable of representing. The grillage analogy method for example is suitable for the analysis of bridges in which load distribution takes place mainly through flexure and torsion in the longitudinal and

transverse directions, with deflections due to shear being negligibly small (see Bakht and Jeager (1985) for more details). Bridge types which fall within this category include the slab-on-girder types whose skew angle does not exceed 20°. When a skew bridge is analysed by the classical methods, its skew span is usually used in the analysis as if it were the right span. The limitations of 20° on the skew angle is imposed to ensure that twisting moments, which are customarily not calculated directly by these methods, are not so large as to be troublesome. With the convenience of the computer together with matrix displacement method, specialised for grillages, this limitation could be eased, since the twisting moments could be computed directly. In contrast, the FEM, when properly handled, is capable of representing bridge superstructures of all types.

A principal objective of this study is to provide a simplified approach to the use of these tools so that their fruits may be made available to the designer without the need for performing complicated analysis in the design office. One intent is to formulate procedures for assessing the effect of modest structural design changes without incurring the computational costs of a complete reanalysis. One of such changes is usually associated with revising structural properties in the light of the results of preliminary analysis. The research is concerned with situations in which the arrangement and proportions of the structural members and the support conditions are known. In practice, the designer must first estimate the member sizes, analyse the structure, and compare the calculated and allowable stresses and displacements. Then, if certain values are greater than the

allowables, or if the allowables are unacceptably greater than the calculated values, changes will be made in the assumed configuration of the structure. Indeed, it may prove necessary to repeat this cycle a number of times. It is useful therefore to develop procedures alternative to complete conventional reprocessing by which the results for the modified structure can be obtained immediatly.

This objective might be achieved through the use of standard prestressed beams used in current construction practices. These standard beams in conjuction with known practical parameters such as support conditions, spans, and angles of skew, together with matrix displacement method, may conveniently be used to formulate the simplified method. Once these parameters are known, they are used as axes of suitable design charts. Having preselected a structure, the engineer can then identify a particular chart and read directly the value of the structural response concerned without performing any rigorous analysis. Clearly, a great economy of time and effort is achieved, if, for many structures such as highway skewed-bridges that might not be analysed conventionally, much detailed analysis can be replaced by the use of suitable charts.

The organisation of the thesis takes the following form: First, specific aspects of mathematical modelling are discussed in chapter 2, as they apply to the present model. Then Chapter 3 briefly discusses the idealisation of skewed bridges and formulates discrete element models, which relate element-end displacements to element-end forces through stiffness matrices. Next, the matrix displacement method is presented in a form that makes it suitable for the automatic computer

analysis of any bridge deck that is represented as an assemblage of discrete interconnected elements in chapter 4. In chapter 5, important computational aspects pertaining to the implementation of the matrix displacement method are discussed. Though, this chapter is more in the realm of computer programming than in structural engineering , however, since primary responsibility for the entire analysis generally belongs to the structural engineer, one should have more than superficial knowledge of these important aspects.

Bridge deck loadings, load cases and combinations necessary to aid design at both ultimate and serviceability limit states are then presented in chapter 6. To achieve the objectives of the study, the research procedure and simplified methods of determining bridge responses are discussed in chapter 7. In chapter 8, conclusions stating the usefulness and limtations of the entire process are presented. Chapter 9 presents recommendations for present and future research.

Finally, documentation, sample input and output, and a source listing are provided in the appendices.

Chapter 2

MODELING SKEWED BRIDGE DECKS

2.1 Introduction

Skewed bridge decks pose an especially challenging problem to a structural analyst. The specific difficulty of the analysis of such structures is their response to torsional motions when the skew angle is greater than 20°. An extensive discussion of this aspect could be found in Bakht and Jeager (1985), and Cusens and Pama (1975).

The matrix displacement method, specialised for grillages offers an efficient and practical tool for the analysis of skewed bridge decks. In grillage analysis, the structure is idealised as a grillage of interconnected elements. The elements are assigned flexural and torsional stiffnesses appropriate to the part of the structure which they represent. Matrix stiffness method, is then used to calculate the vertical displacements and the rotations about two horizontal axes at the joints. Hence the bending moments, torques and shear forces of the grillage elements at the joints can be determined.

In this Chapter, specific aspects of grillage modelling of skewed bridge decks are discussed. The modelling technique is based on the analysis of a mathematical model. As a first step in the construction of the model, generalised displacements have been selected. These defined the configuration and determined the degrees of freedom of the model. Next, the three basic components of the model, the conditions of compatibility, the conditions of equilibrium,

and the constitutive laws, are formulated. The synthesis of these components yield the mathematical model. In addition, the concepts of modelling process has been introduced and applied to obtain one-dimensional continuum models representing flexural and torsional deformations.

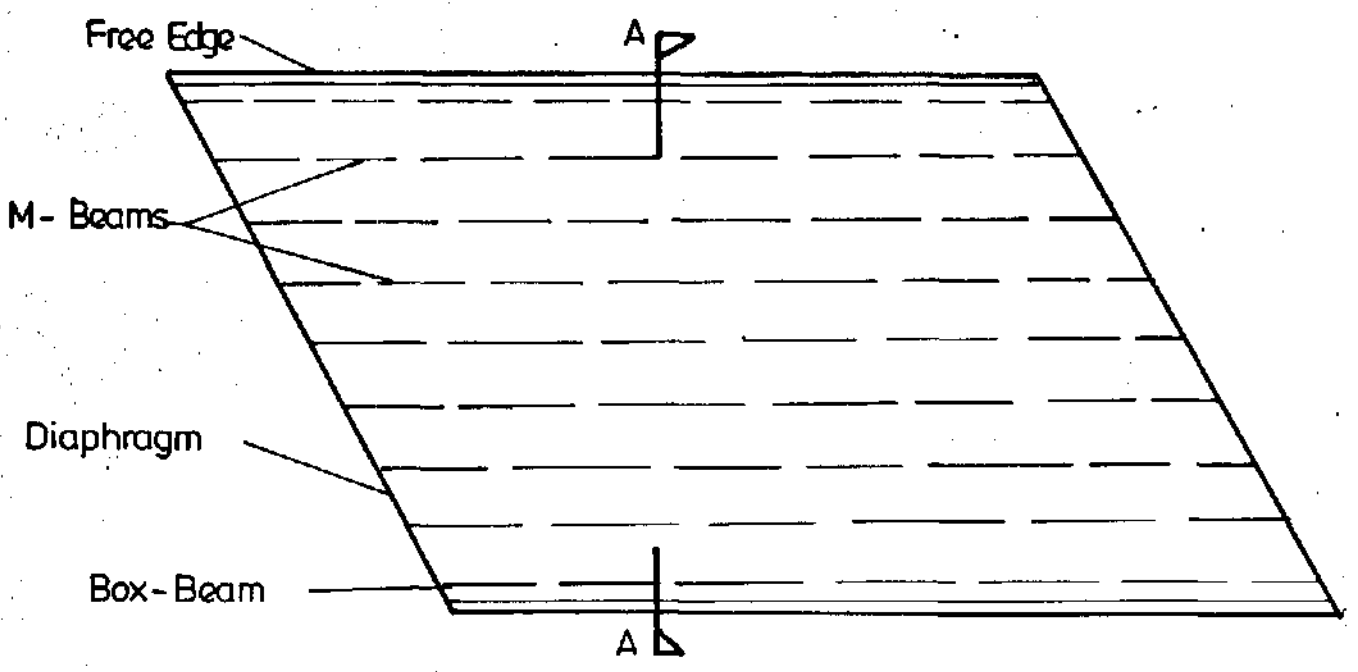
2.2. Fundamentals of Mathematical Models

Structural analysis is concerned with the modelling of structural behaviour where the model is mathematical rather than physical. The objective is to assess the adequacy of a proposed design with respect to strength and stiffness by methods more economical than the obvious way, which is to construct and test a prototype.

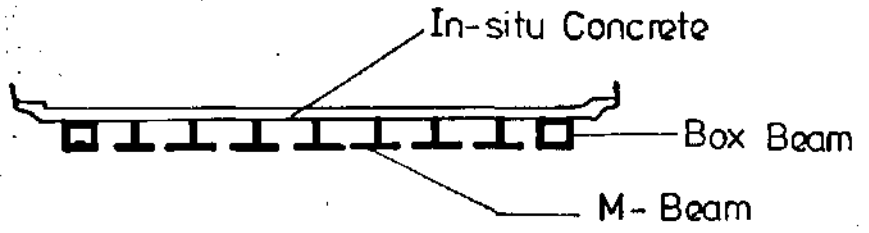
A mathematical model of a structure has three distinct components that represent significant features of the structure: conditions of compatibility, conditions of equilibrium, and constitutive laws. Holzer (1985) states that "the conditions of compatibility reflect geometric properties of a structure, such as continuity of deformations of elements and assemblages of elements, and boundary constraints. The conditions of equilibrium express the state of balance of a structure at rest, while the constitutive laws model the behaviour of materials".

2.3 Formulation of the Model

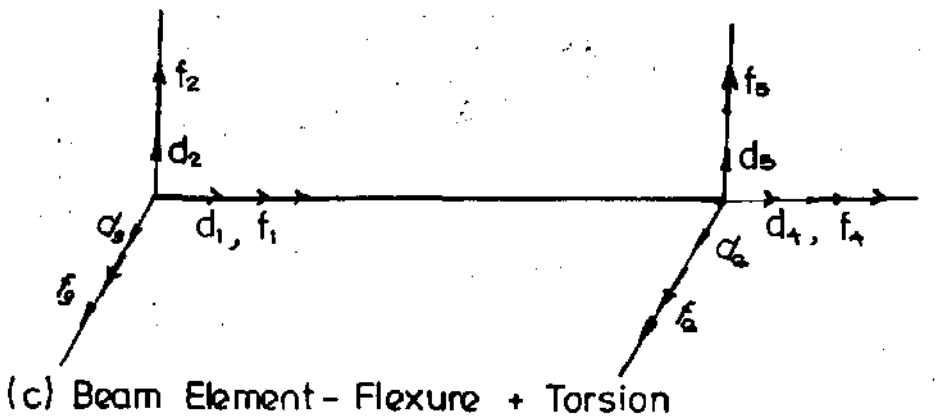
The major structural components of a skewed bridge deck as shown in figure 2.1a, are the stiffening girders along with the deck



(a) PLAN- Skewed Bridge Deck



(b) SECTION A-A - Skewed Bridge Deck



(c) Beam Element - Flexure + Torsion

Fig. 2.1 : Formulation of the Model

and diaphragms. The grillage modelling of these components can be accomplished with the aid of a linear beam element of combined flexural and torsional deformation model as illustrated in figure 2.1c.

The formulation of the mathematical model centres on the selection of parameters that define the configuration of the model. Holzer (1985) states that "the configuration is characterised by the simultaneous location of all material points". The number of independent parameters required to define the configuration represents the degrees of freedom of the model. These parameters are called the generalised displacements of the model.

In engineering analysis, the configuration of a model is generally described relative to its initial state, a reference configuration in which the model is not subjected to actions. Specifically, the configuration is defined by the displacements of each point from its initial position. This is illustrated in the following development of one-dimensional elements without reference to actions that may correspond to these configurations.

2.4 Development of Continuum Models of Elements

The field of structural mechanics contains a variety of continuum models, from simple strings models to complex shell models, Holzer (1985). Although these models may appear unrelated, they have a common basis, which is displayed in the modelling process of figure 2.2. This process defines the mathematical relations (steps 1 - 3) that form the components of the model, and it shows how these

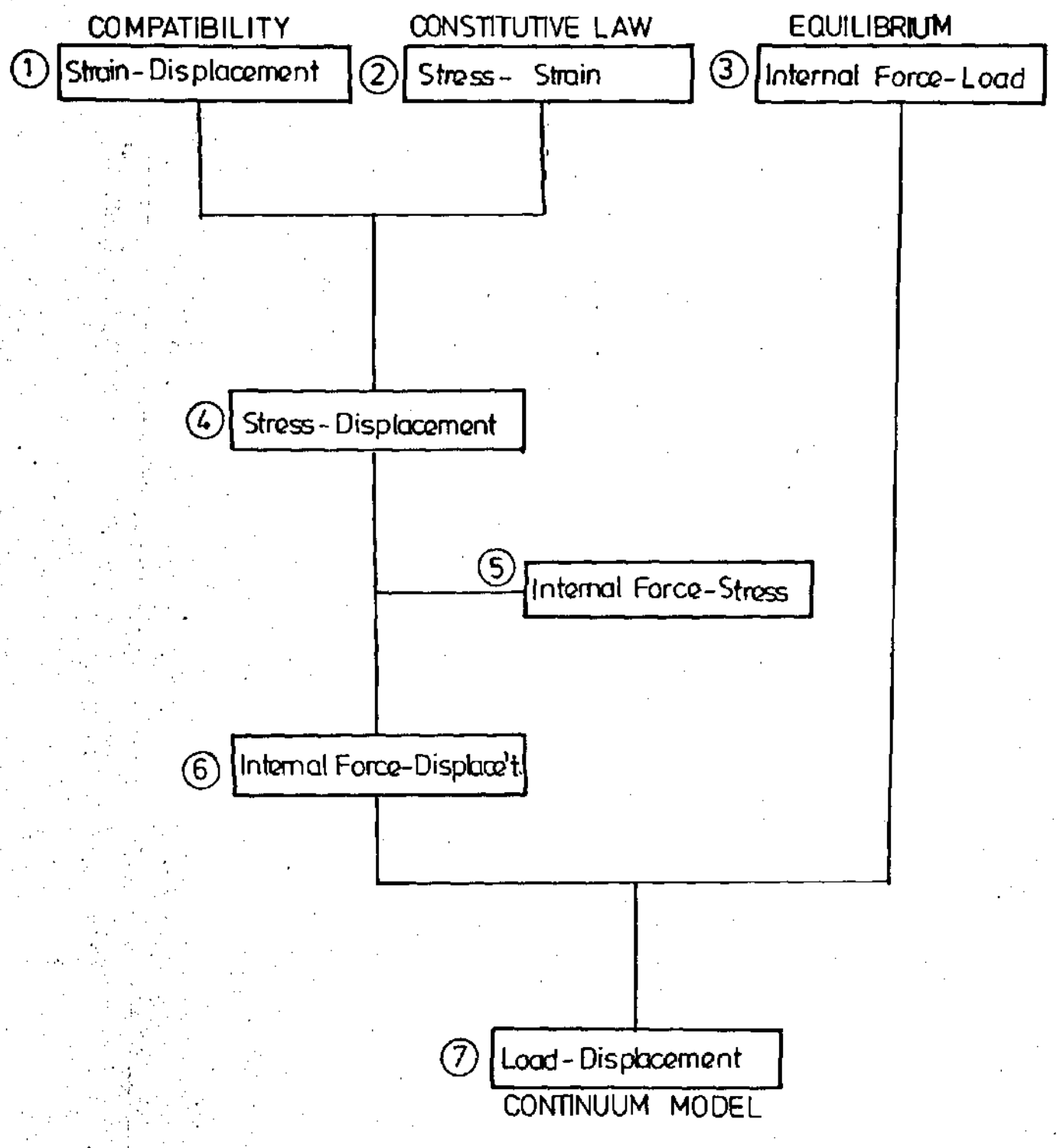


Fig. 2.2: Modelling process [Holzer(1985)]

relations may be combined to produce the continuum model. Moreover, it identifies the geometric and material limitations of linear models. Specifically, the deformations must be sufficiently small to justify linear strain - displacement relations (step 1) and the formulation of equilibrium for the undeformed state (step 3); in addition, the stresses must be sufficiently small to justify linear stress-strain relations (step 2).

The construction of continuum models according to figure 2.2 is illustrated for members experiencing flexural, and torsional deformations, which are the basic deformations of grillage structures. The mathematical relations representing conditions of compatibility, conditions of equilibrium, and Hooke's law can be found in Crandall and et all (1978).

2.4.1 Flexural Deformation Model

The beam in figure 2.3a is subjected to the distributed transverse load P(x) and the concentrated forces Va, Ma, Vb, Mb; the term force is generalised to refer to forces and moments of forces. All forces act in the longitudinal plane of symmetry of the beam, which lies in the xy-plane of the frame of reference. The initial configuration of the centroidal axis of the beam coincides with the X-axis. The beam is prismatic, homogeneous, and composed of linearly elastic material. Hence, the deformation of the beam is governed by the assumptions of the elementary beam theory. It follows that the configuration of the beam is determined by the configuration of the centroidal axis.

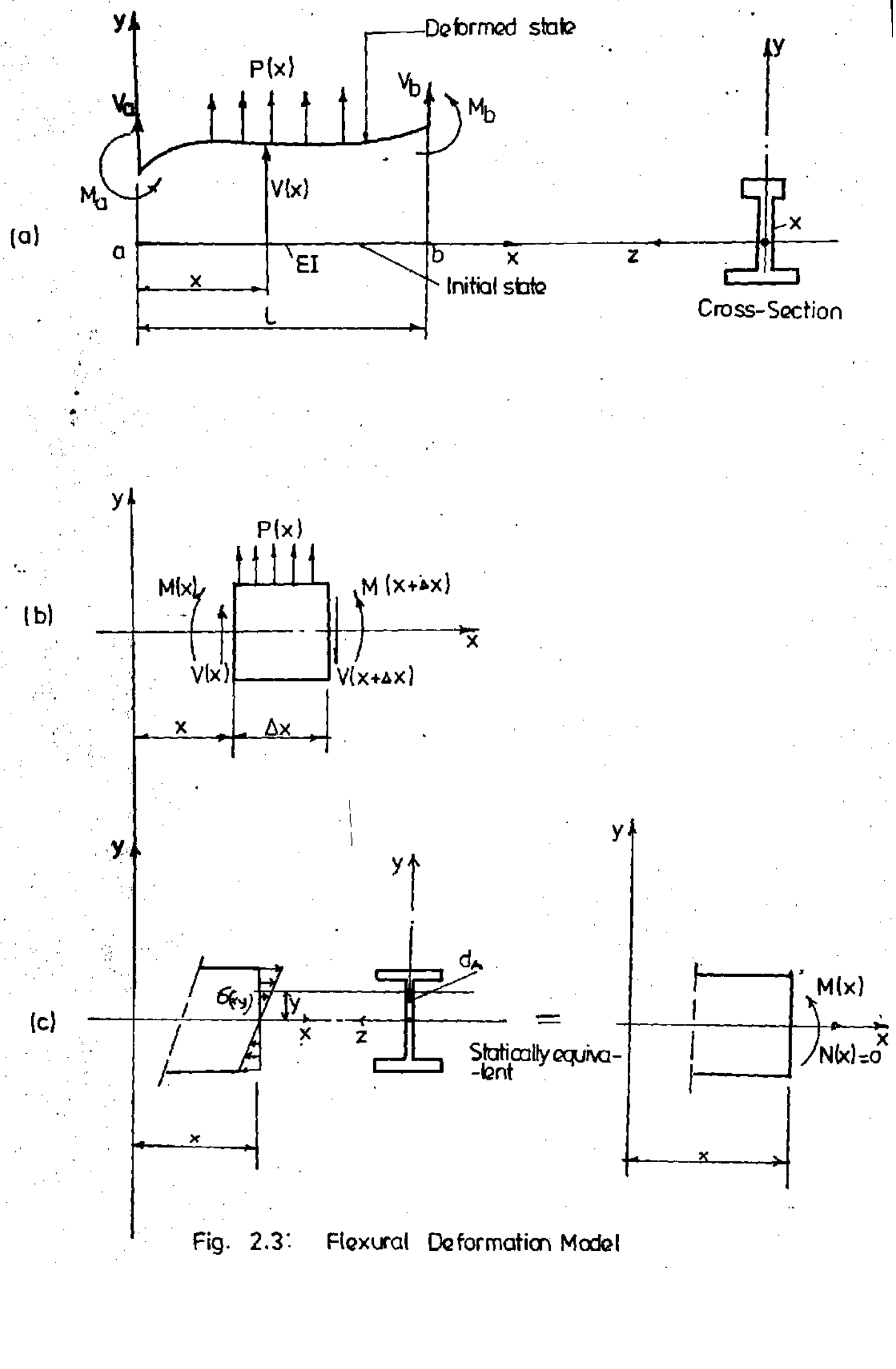


Fig. 2.3: Flexural Deformation Model

The mathematical model of the beam is formulated on the basis of the flow chart in figure 2.2.

Strain - Displacement Relation

$$\epsilon(x,y,z) = \epsilon(x,y) = -y\,d^2 v(x)/dx^2 \qquad (2.1)$$

ϵ is the normal strain, which is positive in tension, and $v(x)$ defines the transverse deflection of the centroidal axis. Eq. 2.1 is only valid for infinitesimal deformations, Holzer (1985).

Stress - Strain Relation

It follows from Hooke's law that

$$\sigma = E\epsilon \qquad (2.2)$$

σ is the normal stress, and E is the modulus of elasticity.

Internal Force - Load Relations

$$dV/dx = P\,, \quad dM/dx = V \qquad (2.3a)$$

or

$$d^2 M/dx^2 = P \qquad (2.3b)$$

V is the shear force, and M is the bending moment. The positive sense of the external and internal forces of Eqs. 2.3 is shown in figure 2.3b.

Stress - Displacement Relation

Eqs. 2.1 and 2.2 yield

$$\sigma = -Ed^2v/d^2y \qquad (2.4)$$

Internal Force - Stress Relations

Figure 2.3c indicates that

$$N = \iint_A \sigma\, dA = 0 \qquad (2.5a)$$

and

$$M = -\iint_A \sigma\, dAy \qquad (2.5b)$$

Internal Force - Displacement Relations

Eqs. 2.4 & 2.5 yield

$$N = -Ed^2v/dx^2 \int_A ydA = 0 \qquad (2.6a)$$

and

$$M = Ed^2v/dx^2 \iint_A y^2\, dA = EId^2v/dx^2 \qquad (2.6b)$$

I is the moment of inertia of the cross - sectional area with respect to the centroidal axis. It follows from Eq. 2.6a that

$$\iint_A ydA = 0 \qquad (2.7)$$

Which varifies that the neutral axis passes through the centroidal axis.

Load - Displacement Relation

The substitution of Eq. 2.6b into Eq. 2.3b yields the

continuum model of a prismatic, homogeneous, elastic beam:

$$EI\,d^4v/dx^4 = P \tag{2.8}$$

Observe that the configuration of the centroidal axis of the beam, which is defined by V(x), determines any desired measure of response reflected by the model of the beam. For example, from Eqs. 2.6b, 2.3b, and 2.4 we obtain

$$M(x) = EI\,d^2V(x)/dx^2 \tag{2.9a}$$

$$V(x) = EI\,d^3V(x)/dx^3 \tag{2.9b}$$

$$\sigma(x,y) = -M(x)y/I \tag{2.9c}$$

Note that when there are no applied forces, the model is defined by the homogeneous differential equation:

$$d^4v/dx^4 = 0 \tag{2.10}$$

2.4.2 Torsional Deformation Model

The circular shaft shown in figure 2.4a is subjected to the distributed torque m(x) and the end torques Ta and Tb. The lines of action of all torques are collinear with the centroidal axis of the shaft. The sense of a torque is determined by the right-hand rule (Figure 2.4b). The material of the shaft is linearly elastic.

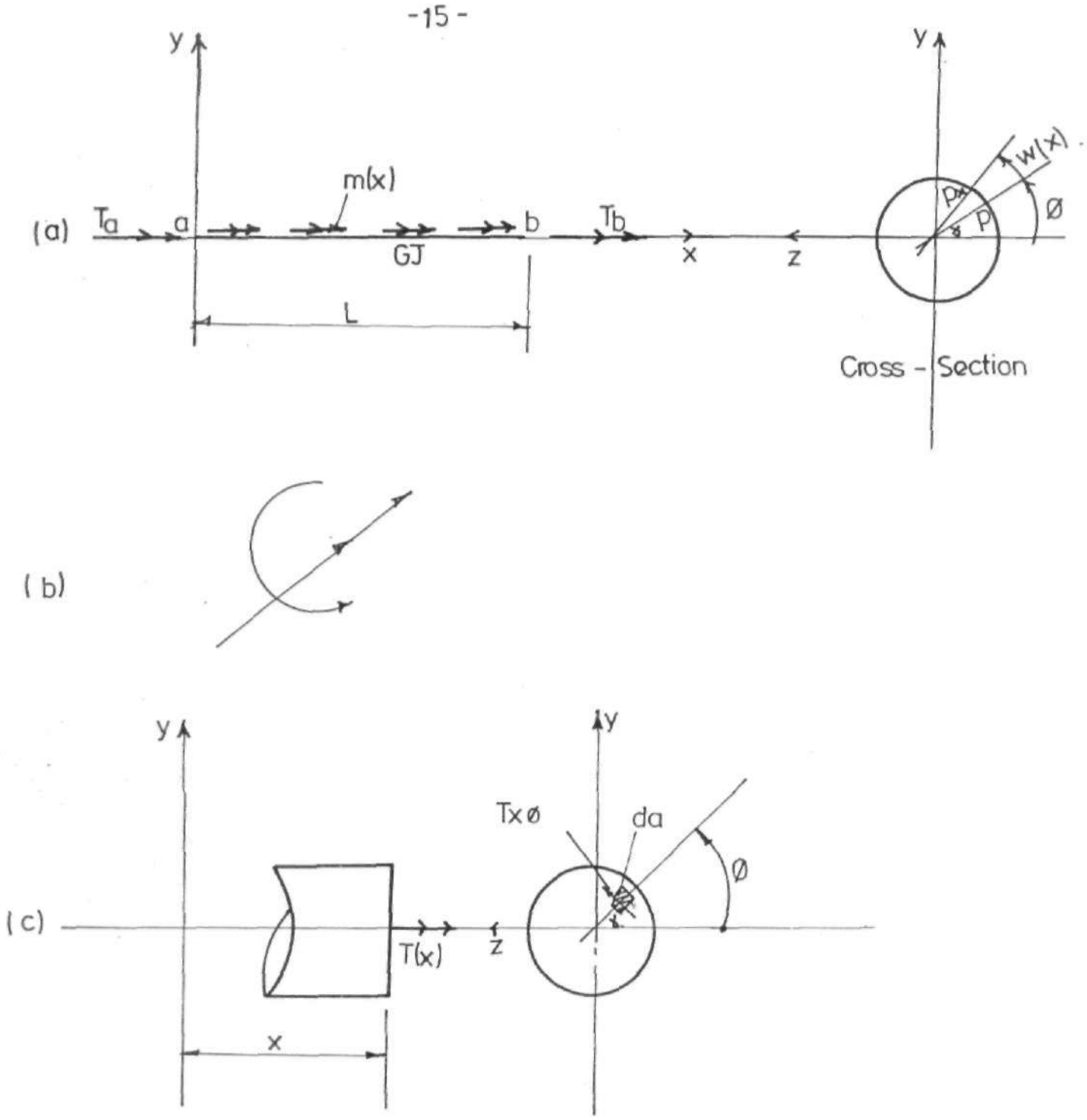


Fig. 2.4: Torsional Deformation Model

The deformations of the shaft are governed by the following, Holzer (1985) assumptions: (1) The Centroidal axis remains straight, and (2) All radii of a cross section remain straight and rotate through the same angle about the centroidal axis.

The formulation of the mathematical model is based on the flow chart in figure 2.2.

Strain - Displacement Relations

$$\gamma_{x\theta} = r\,dw(x)/dx \qquad (2.11)$$

$\gamma_{x}\theta$ is the shear strain at any point (r,θ) of the cross section, and $w(x)$ is the angle of twist of the cross-section (figure 2.4a).

Stress - Strain Relation

It follows from Hooke's law that

$$\tau_{x\theta} = G\,\gamma_{x\theta} \qquad (2.12)$$

$\tau_{x\theta}$ is the shear stress, and G is the shear modulus of elasticity.

Internal Force - Load Relation

$$dT/dx = -m \qquad (2.13)$$

Eq. 2.13 represents a positive condition of equilibrium, which is based on the sign convention in figure 2.4d.

Stress - Displacement Relation

Eqs. 2.11 and 2.12 yield

$$\tau_{x\theta} = G dw/dx\, r \qquad (2.14)$$

Internal Force - Stress Relation

Figure 2.4c indicates that

$$T = \iint_A \tau_{x\theta} \, dA_r \qquad (2.15)$$

Internal Force - Displacement Relation

Eqs. 2.14 and 2.15 yield

$$T = G dw/dx \iint_A r^2 \, dA = GJ dw/dx \qquad (2.16)$$

J is the polar moment of inertia of the Cross - section.

Load - Displacement Relation

Combining Eqs. 2.13 and 2.16, we obtain the continuum model of a circular, elastic shaft subjected to a distributed torque:

$$GJ \, d^2w/dx^2 = -m \qquad (2.17)$$

Observe that when there is no applied distributed torque, Eq. 2.17 reduces to the homogeneous differential equation:

$$d^2w/dx^2 = 0 \qquad (2.18)$$

Chapter 3

DISCRETISATION OF THE MODEL

3.1 Introduction

After some brief discussions on the idealisation of skewed bridge decks, discretes element models, which relate elements - end displacements to element - end forces through stiffness matrices are formulated by the solution of the continuum models (presented in section 2.4). These element models are then expressed in matrix form, which permits one to unify distinct structural elements in a mathematical form that reveals their common characteristics.

3.2 Idealisation of Skewed Bridge Decks

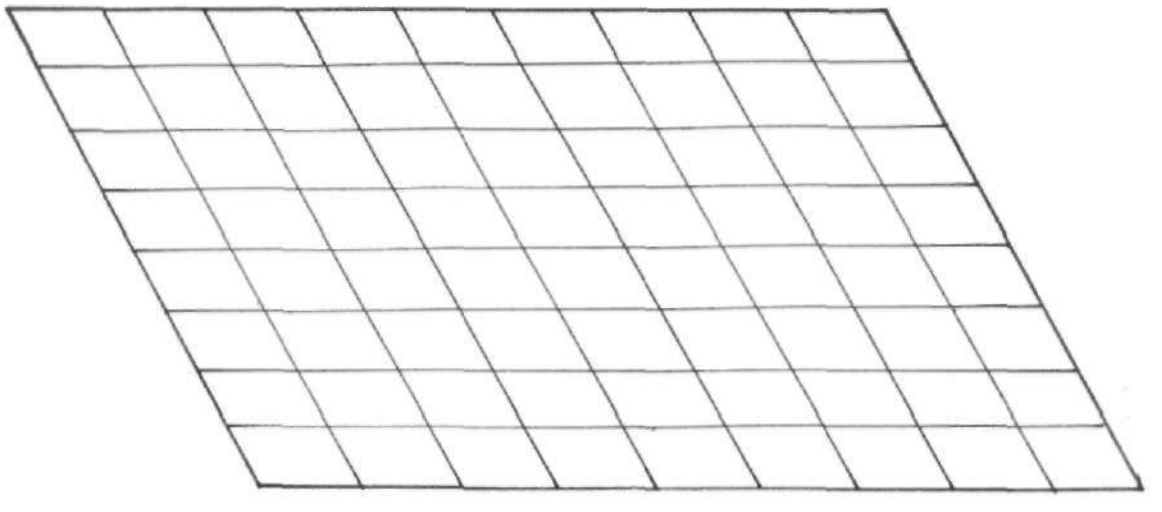
The method of grillage analysis involves the idealisation of the bridge deck through its representation as a plane grillage of discrete interconnected elements. Although the method is necessarily approximate, it has the great advantage of almost complete generality and gives acceptable solutions. At the joints of the grillage any normal form of restraint to movement may be applied so that any support condition may be represented. Fixed supports, discrete columns, elastic foundations may all be included without difficulty. The planform of the deck presents no real problems and skewed, curved and irregular shapes may all be handled with comparative ease.

The program (GRID) developed in this study have been written for grillages having straight members of uniform cross section. If a

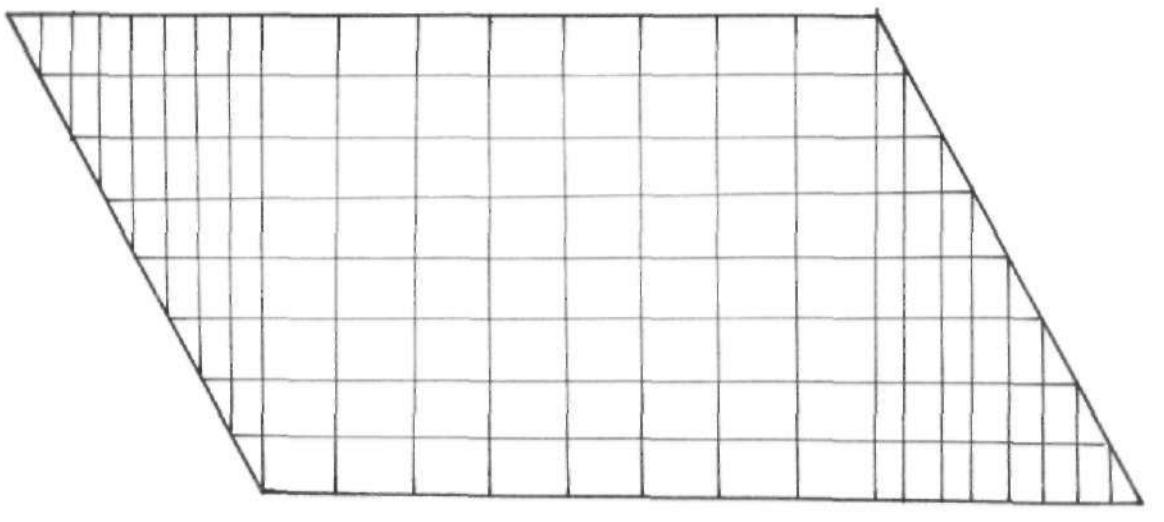
change of cross-section occurs in the span of a member, a dummy joint is nominated at that joint; a tapered member may be considered in steps. A curved member is approximated by a series of short straight members, although Martin (1966) has derived the stiffness matrix for a curved beam. In addition, GRID also makes allowance for internal members with pinned ends.

For beam and slab decks, the logical selection of longitudinal grillage beams is for them to coincide with the actual beams. For slabs stiffened by U-beams or boxes, the longitudinal grillage beams should be taken to coincide with individual webs. With only a top slab in the transverse direction, West (1973) suggests that transverse grillage beams be positioned (a) at the abutments (where in most cases there will be diaphragms) and (b) at intermediate positions so that spacing is approximately 1.5 times spacing of longitudinals.

Each grillage beam represents a particular width of bridge deck and its rigidities are calculated accordingly. For skewed decks of slab construction there is clearly a choice between the selection of an orthogonal or a skew system of grillage beams, although the direction chosen should correspond with the reinforcement layout, Cusen and Pama (1975). Figure 3.1 shows two possibilities for a wide skew deck. The skew system of beams is clearly simpler in concept and provides easier data preparation, although care must be taken to express the support restraints and member rigidities correctly. Alternatively an orthogonal grid system may be employed. This will create more problems at the stage of data preparation and since there are intrinsically more members and joints, the computing time, memory



(a) Skew System



(b) Orthogonal System

Fig. 3.1: Possible Grillage Layouts for skew Desks

and cost will be greater.

3.2.1 Elastic Stiffnesses

Guidance on the evaluation of elastic stiffnesses for various types of deck, for use with grillage analysis, has been given by West (1973). In general a longitudinal grillage beam can represent part of the top slab plus either a single physical, or a number of physical beams. If a longitudinal grillage beam represent n physical beams, where n is not necessarily an integer, then its inertias are given, with notation of figure 3.2, by

$$\text{Flexural} = nIx \qquad (3.1a)$$

$$\text{Torsional} = n(Jx + Sxh^3/6) \qquad (3.1b)$$

A transverse grillage beam can represent either part of the top slab, or part of the top slab with a transverse physical diaphragm. The shear area is taken to be infinity and the flexural and torsional inertias, to be with the notation of figure 3.2, and Sg being the spacing of the transverse grillage beams,

$$\text{Flexural} = Sg/Sy * Iy \qquad (3.2a)$$

$$\text{Torsional} = Sg(Jy/Sy + h^3/6) \qquad (3.2b)$$

The torsional inertias (Jx and Jy) of the individual longitudinal and, if present, transverse beams can be calculated by dividing the actual beam into a number (n) of component rectangles as shown in figure 3.3. The torsional inertia of the ith component

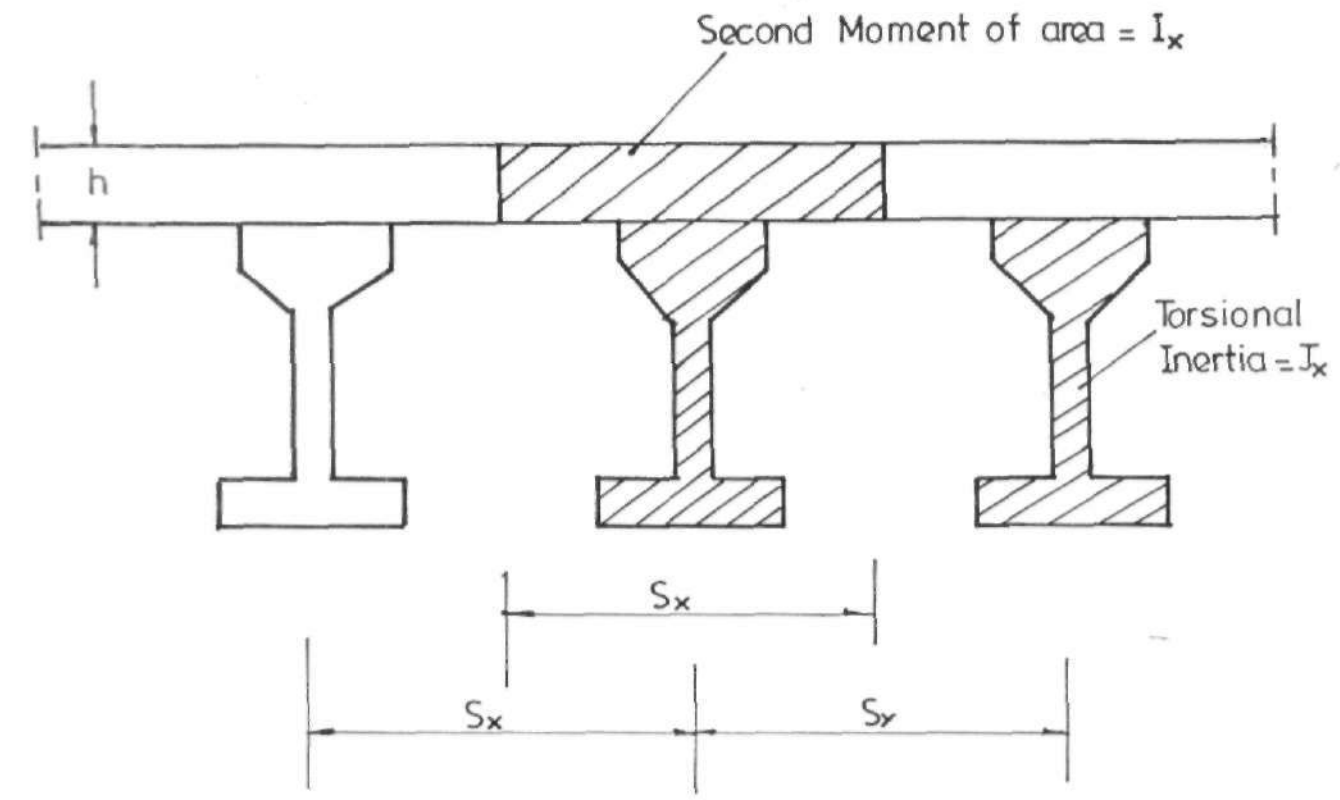
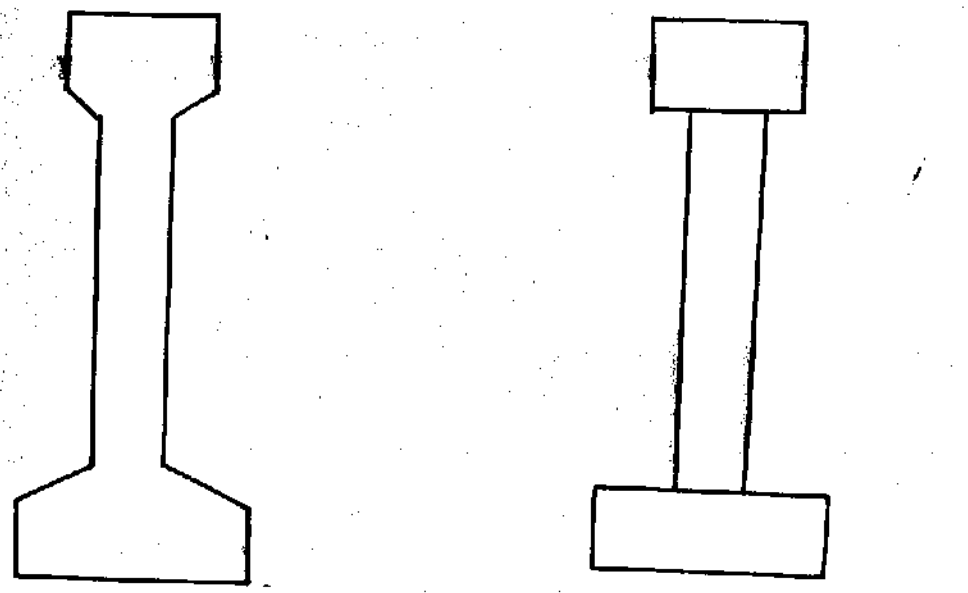


Fig. 3.2: Beam and slab Geometry



(a) Actual

(b) Component Rectangles

Fig. 3.3: Torsional Inertia of Beam

rectangle of size bi by hi is given by

$$Ji = Kb_i h_i^3 \quad ; \quad \text{for } bi <= hi \qquad (3.3)$$

When bi -> hi, exchange bi for hi and hi for bi. The coefficient (K) is dependent upon the aspect ratio of the rectangle, where the aspect ratio is always greater than or equal to unity and is defined as hi/bi. Values of K may be read from tables as in Bakht and Jeager (1985) or calculated approximately by:

$$K = 1/3 - 0.21(b/h)[1 - 1/12*(b/h)^4] \qquad (3.4)$$

The total torsional inertia of a beam is then obtained by summing those of the individual rectangles:

$$Jx \text{ or } Jy = \sum_{i=1}^{n} Ji \qquad (3.5)$$

3.2.2 Composite Materials

A bridge deck may include members with different material properties. For example, a composite prestressed concrete beams with reinforced concrete slab. For successful analysis all material is converted to either prestressed or reinforced concrete. For example, prestressed conversion is achieved by multiplying the reinforced concrete areas and moment of inertias by the ratio Erc/Epc where E = Young's modulus of elasticity and subscripts "rc" and "pc" refer to reinforced and prestressed concrete respectively. Similarly, reinforced concrete conversion is achieved by multiplying prestressed concrete areas and inertias by Epc/Erc.

3.3 Discrete Models

In the absence of interior loads, the continuum models (section 2.4) become homogeneous differential equations of order n, whose solutions contain n arbitrary constants. Since the solutions define element configurations, the constants represent n generalised displacements. Accordingly, the flexural and torsional continuum models can be reduced exactly to discrete models.

This reduction is carried out in the following way: First, the element configurations are expressed in terms of the element - end displacements by imposing geometric boundary conditions on the solutions of the homogeneous differential equations. Then, the element - end forces are related to the element end - displacement relations of the continuum models (step 6 of figure 2.2). The resulting sets of algebraic equations form the basic element models used in displacement method analysis of grillage structures.

3.3.1 Flexural Deformation Model

Figure 3.4 depicts a beam under the action of end forces but without interior loads. To formulate relations between the end forces and the corresponding end displacements, we start with the homogeneous differential equation

$$d^4 v/dx^4 = 0 \qquad (3.6)$$

Which is obtained from equation 2.8 by setting P = 0. The geometric boundary conditions are

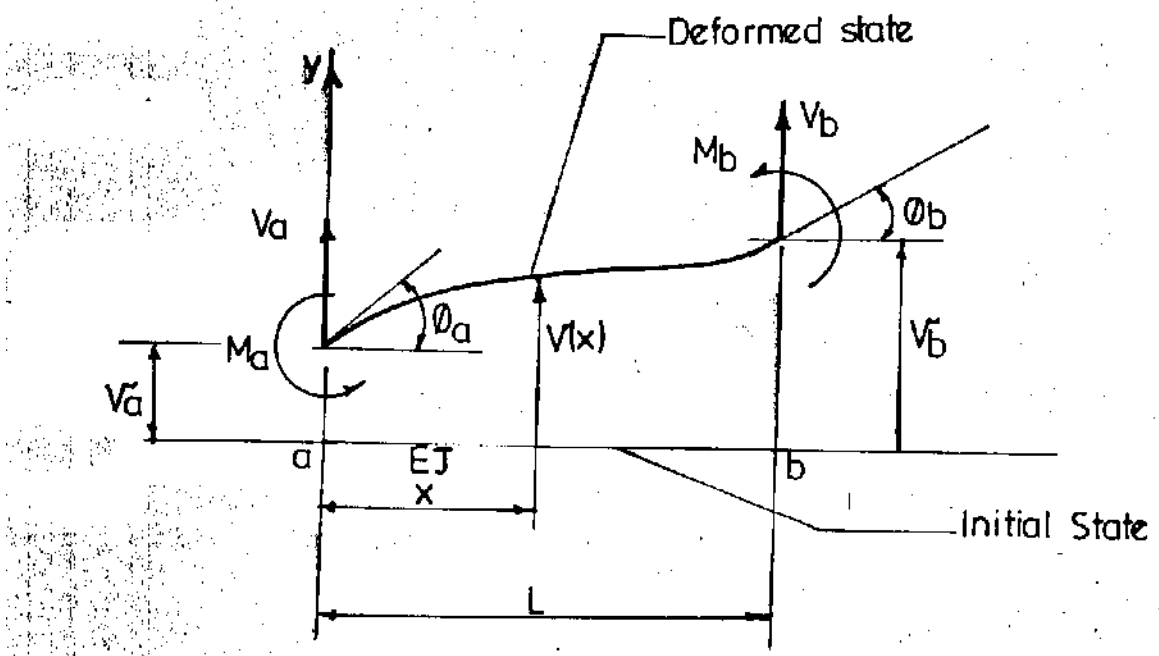


Fig. 3.4: Flexural Deformation Model

$$v(0) = va \;, \quad dv(0)/dx = \Theta a$$
$$v(L) = vb \;, \quad dv(L)/dx = \Theta b \qquad (3.7)$$

Eq. 3.6 has the solution

$$v = C0 + C1x + C2x^2 + C3x^3 \qquad (3.8)$$

By definition, the coefficients of eq. 3.8 represent generalised displacements and the element has four degrees of freedom. The reasons for introducing eq. 3.8 were given by Holzer (1985) as: (1) It satisfies the homogeneous differential equation of a beam; hence, eq. 3.8 characterises the configurations of beams subjected to boundary actions. (2) Polynomials form basic building blocks of many interpolation functions - also used in the finite element method.

Selecting the element - end displacements, Va, Θa, Vb, Θb, as generalised displacements and expressing the configuration in terms of them can be accomplished by imposing the boundary conditions (eq. 3.7) on eq. 3.8, which yield the set of albebraic equations:

$$\begin{aligned} C0 &= va \\ C1 &= \Theta a \\ C0 + LC1 + L^2 C2 + L^3 C3 &= vb \\ C1 + 2LC2 + 3L^2 C3 &= \Theta b \end{aligned} \qquad (3.9)$$

Whose solution is:

$$
\begin{aligned}
C0 &= va \\
C1 &= \theta a \\
C2 &= 1/L^2\,(-3va - 2L\theta a + 3vb - L\theta b) \\
C3 &= 1/L^3\,(2va + L\theta - 2vb + L\theta b)
\end{aligned}
\qquad (3.10)
$$

Substituting eqs. 3.10 into eq. 3.8 and collecting terms of like displacements, the configuration of the beam can be expressed in the form:

$$v = \phi\, ava + \psi a\theta a + \phi\, bvb + \psi\, b\theta b \qquad (3.11)$$

Where

$$
\begin{aligned}
\phi\ a &= 1 - 3\xi^2 + 2\xi^3 \\
\psi\ a &= (\xi - 2\xi^2 + \xi^3)L \\
\phi\ b &= 3\xi^2 - 2\xi^3 \\
\psi\ b &= (-\xi^2 + \xi^3)L
\end{aligned}
\qquad (3.12)
$$

and

$$\xi = x/L \quad , \quad 0 <= \xi <= 1 \qquad (3.13)$$

The coordinate transformation in Eq. 3.13 was introduced to simplify the solution; it results in the following transformation of derivatives as given by Holzer (1985):

$$d^n v/dx^n = (1/L)^n\, d^n v/d\xi^n \quad ; n = 1, 2, 3, ... \qquad (3.14)$$

With the aid of Eqs. 2.9, 3.11, and 3.14, the bending moment and shear force can be expressed as

$$M(\xi) = EI/L^2 (\phi_a'' va + \psi_a'' \Theta a + \phi_b'' vb + \psi_b'' \Theta b) \qquad (3.15)$$

$$V(\xi) = EI/L^3 (\phi_a''' va + \psi_a''' \Theta a + \phi_b''' vb + \psi_b''' \Theta b)$$

Where

$$\phi_a'' = -6 + 12\xi \quad , \quad \phi_a''' = 12$$
$$\psi_a'' = (-4 + 6\xi)L \quad , \quad \psi_a''' = 6L \qquad (3.16)$$
$$d\phi'' = 6 - 12\xi \quad , \quad \phi_b''' = -12$$
$$\psi_b'' = (-2 + 6u\xi)L \quad , \quad \psi_b''' = 6L$$

On the basis of the beam sign convention of figure 2.3b, the end forces of the beam in figure 3.4 are defined as

$$Ma = -M(0) \quad , \quad Va = V(0)$$
$$Mb = M(1) \quad , \quad Vb = V(1) \qquad (3.17)$$

The evaluation of Eqs. 3.15 and 3.16 according to Eqs. 3.17 results in the force - displacement relations.

$$Va = \alpha (12va + 6L\Theta a - 12vb + 6L\Theta b)$$
$$Ma = \alpha (6Lva + 4L^2 \Theta a - 6Lvb + 2L^2 \Theta b)$$
$$Vb = \alpha (-12va - 6L\Theta a + 12vb - 6L\Theta b) \qquad (3.18)$$
$$Mb = \alpha (6Lva + 2L^2 \Theta a - 6Lvb + 4L^2 \Theta b)$$

Where

$$\alpha = EI/L^3$$

3.3.2 Torsional Deformation Model

Consider the bar in figure 3.5 that is subjected to the end torques Ta and Tb. We seek to establish relations between the end torques and the corresponding end rotations wa and wb.

Without interior loads, the differential equation of the bar in Eq. 2.17 becomes

$$d^2 w/dx^2 = 0 \tag{3.19}$$

The geometric boundary conditions are

$$w(0) = wa \quad , \quad w(L) = wb \tag{3.20}$$

The solution to Eq. 3.19

$$w = C0 + C1x \tag{3.21}$$

can be specialised by imposing the geometric boundary conditions. This gives:

$$\begin{aligned} C0 &= wa \\ C1 &= 1/L*(wb - wa) \end{aligned} \tag{3.22}$$

and, hence

$$w = wa + x/L*(wb - wa) \tag{3.23}$$

The substitution of Eq. 3.23 into Eq. 2.16 results in the internal force - displacement relation

$$T(x) = GJ/L*(wb - wa) \tag{3.24}$$

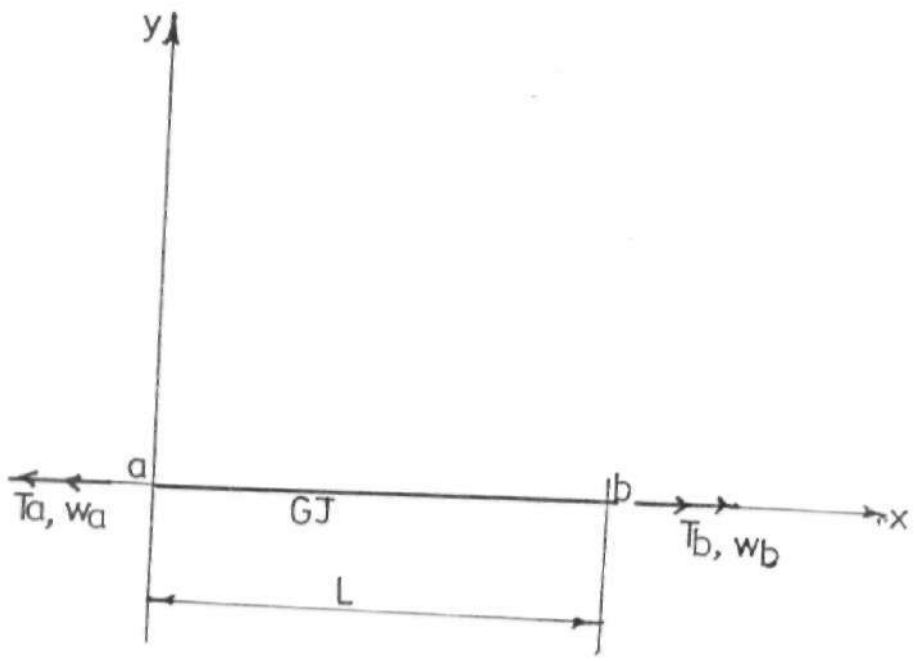


Fig. 3.5: Torsional Deformation Model

The evaluation of Eq. 3.24 at x = 0 and L consistent with the sign convention in figure 2.4d, that is Ta = -T(o) and Tb = T(L), yields the desired torque - rotation relations:

$$\begin{aligned} Ta &= GJ/L*(wa - wb) \\ Tb &= GJ/L*(-wa + wb) \end{aligned} \qquad (3.25)$$

Note that the models in Eqs. 3.18 and 3.25 are linear algebraic equations in the element - end displacements, which represent generalised displacements. As a consequence of linearity, the Principle of Superposition is valid.

3.4 Discrete Models in Matrix Form

In preparation for matrix methods of analysis, the discrete element models (section 3.3) are now expressed in matrix form. Matrix notation permits one to unify distinct structural elements in a mathematical form that reveals their common characteristics.

In matrix notation, the conventional x,y,z designations of the element coordinate axes shown in figures 2.3, 2.4 and 3.5 are replaced by the integers 1, 2, 3. Thus, the 1 - axis, which is directed from the a-end to the b-end of the element, concides with the centroidal axis of the element, and the 2 and 3 - axes correspond to principal axes of the cross section (figure 3.6). Since this coordinate system is intrinsic to the geometry of the element, it is called the local coordinate system or the local frame of reference.

The element - end displacements and forces, denoted di and fi, are numbered in the sequence of the coordinate axes from the a-end to

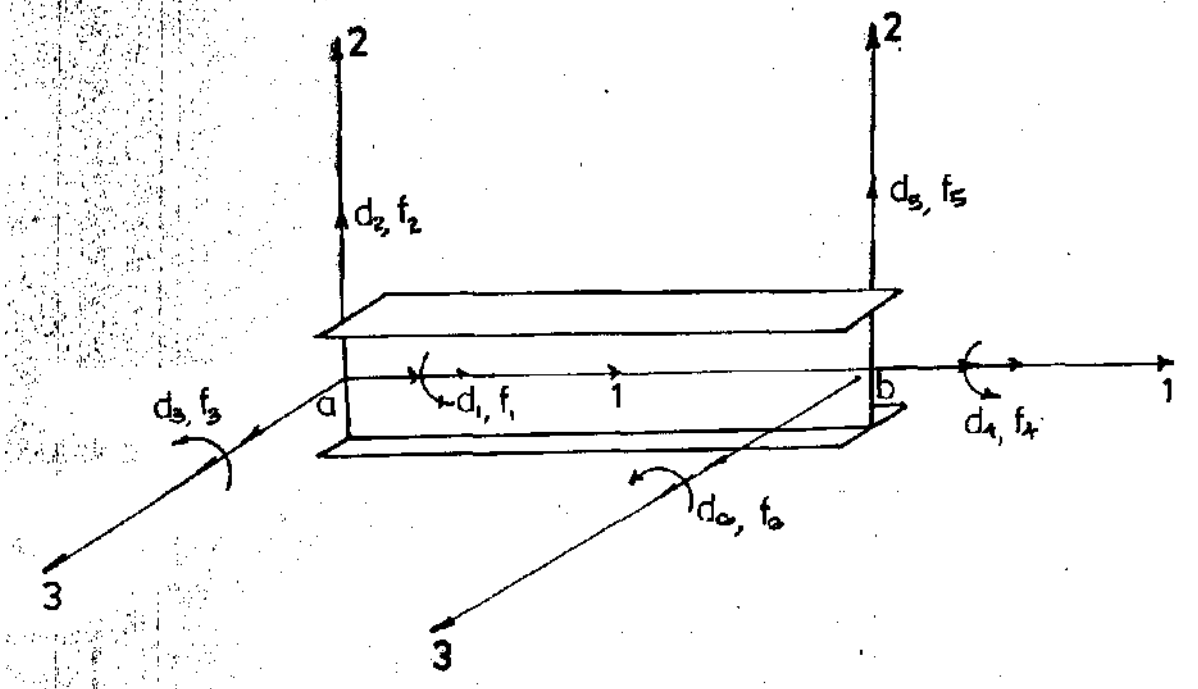


Fig. 3.6. Torsional + Flexural Deformation Model

the b-end of the element. i = 1, 2, 3, ..., m; where m is the number of degrees of freedom of the element. This is illustrated in figure 3.7 a and b for elements with torsional and flexural deformations, respectively, and in figures 3.6 and 3.7c for element with both torsional and flexural deformations. Moreover, to regard the element end displacements and forces as coordinates, a local reference frame is assigned to each end of the element (figure 3.6). This provides a simple sign convention: A displacement or force is positive in the direction of the coordinate axis. The positive sense of a rotation or moment about the 3 - axis is determined by the right - hand rule; hence, the positive sense is counter-clockwise in the 1, 2 - plane, the plane of the element.

According to these conventions, the elements in figures 3.4 and 3.5 are represented as shown in figures 3.7b and a and their models are expressed as

$$fi = \sum_{i=1}^{m} kij\ dj \quad ; \quad i = 1,2,...,m \tag{3.26a}$$

or

$$f = kd \tag{3.26b}$$

Where kij is a stiffness coefficient (by Eq. 3.26a kij has units of force/displacement), k is the stiffness matrix, d is the displacement vector, and f is the force vector.

3.4.1 Flexural Deformation Model

From figure 3.7b, the substitutions

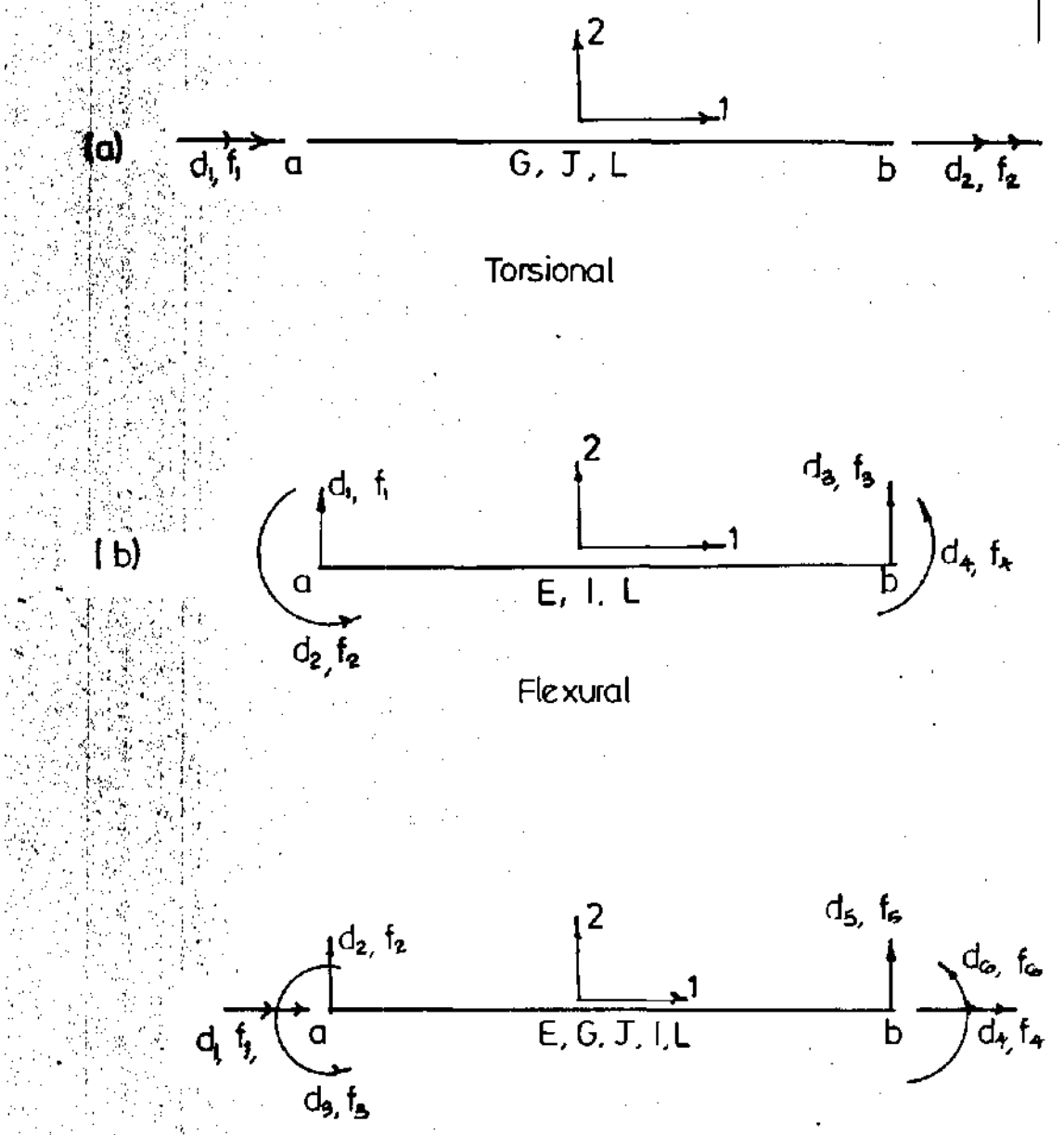


Fig. 3.7: Deformation Models

$$\text{and} \quad \begin{aligned} d1 &= va\ ,\ d2 = \Theta a\ ,\ d3 = vb\ ,\ d4 = \Theta b \\ f1 &= Va\ ,\ f2 = Ma\ ,\ f3 = Vb\ ,\ f4 = Mb \end{aligned} \tag{3.27}$$

transform Eqs. 3.18 into

$$\begin{aligned} f1 &= \alpha\,(12d1 + 6Ld2 - 12d3 + 6Ld4) \\ f2 &= \alpha\,(6Ld1 + 4L^2 d2 - 6Ld3 + 2L^2 d4) \\ f3 &= \alpha\,(-12d1 - 6Ld2 + 12d3 - 6Ld4) \\ f4 &= \alpha\,(6Ld1 + 2L^2 d2 - 6Ld3 + 4L^2 d4) \end{aligned} \tag{3.28a}$$

or

$$\begin{bmatrix} f1 \\ f2 \\ f3 \\ f4 \end{bmatrix} = \alpha \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} d1 \\ d2 \\ d3 \\ d4 \end{bmatrix} \tag{3.28b}$$

where

$$\alpha = EI/L^3$$

3.4.2 Torsional Deformation Model

From figure 3.7a, the substitution $\gamma = GJ/L$ and

$$\begin{aligned} d1 &= wa\ ,\ d2 = wb \\ f1 &= Ta\ ,\ f2 = Tb \end{aligned} \tag{3.29}$$

transform Eq. 3.25 into

$$f1 = \gamma\,(d1 - d2)$$
$$f2 = \gamma\,(-d1 + d2) \qquad (3.30a)$$

or

$$\begin{bmatrix} f1 \\ f2 \end{bmatrix} = \gamma \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} d1 \\ d2 \end{bmatrix} \qquad (3.30b)$$

where

$$\gamma = GJ/L$$

3.4.3 Torsional + Flexural Deformation Model

When these two deformations occur simultaneously as in a grillage - it is necessary to combine them into a single element. To superimpose the models of the elements in figures 3.7a, b to obtain the model of element in figure 3.7c, we introduce the following change in subscripts: The subscript 2 in Eqs. 3.30 is replaced by the subscript 4, and the subscripts 1,2,3,4 in Eqs. 3.28 are replaced by subscripts 2,3,5,6, respectively. This yields the combined element model

$$\begin{bmatrix} f1 \\ f2 \\ f3 \\ f4 \\ f5 \\ f6 \end{bmatrix} = \alpha \begin{bmatrix} \beta & 0 & 0 & -\beta & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ \beta & 0 & 0 & \beta & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} d1 \\ d2 \\ d3 \\ d4 \\ d5 \\ d6 \end{bmatrix} \qquad (3.31)$$

Where

$$\alpha = EI/L^3 \quad , \quad \beta = GJ/EI*L^2 \quad , \quad \gamma = \alpha\beta = GJ/L$$

Chapter 4

CONCEPTS OF MATRIX DISPLACEMENT METHOD

4.1 Introduction

A general approach to the matrix displacement method is presented in a form, which makes it suitable for the automatic computer analysis of any bridge deck represented as an assemblage of discrete elements. Specifically, the chapter develops and reviewed the foundation for the matrix displacement method as applied to grillages. Conventions are introduced to represent grillages in a form suitable for computer analysis. Next, the degrees-of-freedom are enumerated. Conditions of compatibility and equilibrium are formulated without reference to a visual image of the structure and coordinate transformation required in the assembly process is presented. Finally, an efficient procedure is formulated for the assembly of element models into the system model and element actions are incorporated in section 4.9.

4.2 Notation and Conventions

In order to represent a grillage in a form suitable for computer analysis, it is convenient to image the grillage as composed of joints and elements. A joint is a point to which at least one element is incident. It is used to connect an element to another, while an element is a structural component represented by a straight line connecting two joints. A joint is placed at each element end.

Several elements can have a common joint. For a typical modelled grillage see figure 4.1.

4.2.1 Grillage Geometry

The location and orientation of the global frame of reference is arbitrary; however, the structure is assumed to lie in the 1, 3 - global coordinate plane. The global coordinate axes are represented by dashed lines to differentiate them from the solid local coordinate axes (figure 4.2). The positive element (local) 1 - axis is located from the lower joint number to the greater joint number. The positive 2 - axis is located 90 degrees counter clockwise to the element positive 1 - axis. Both the global and local 3 - axes are chosen to make the frame of reference right - handed.

4.2.2 Joint Co-ordinates

Each joint must be properly located with respect to the global system. For most grillage problems such as bridge decks it is convenient, but not necessary, to orient the positive 2-axis such that it runs parallel but opposite to the direction of gravity. The positive 1 - axis is then located by drawing a line 90 degrees clockwise with respect to the positive 2-axis (see figure 4.3) and finally the positive 3-axis is chosen to make the global frame of reference right - handed. The reason for this particular selection of co-ordinate orientation will become more apparent when entering joint loads data (Appendix I). Finally the joint coordinates are given by the 1, 3 - axes, similar to conventional X,Y - axes.

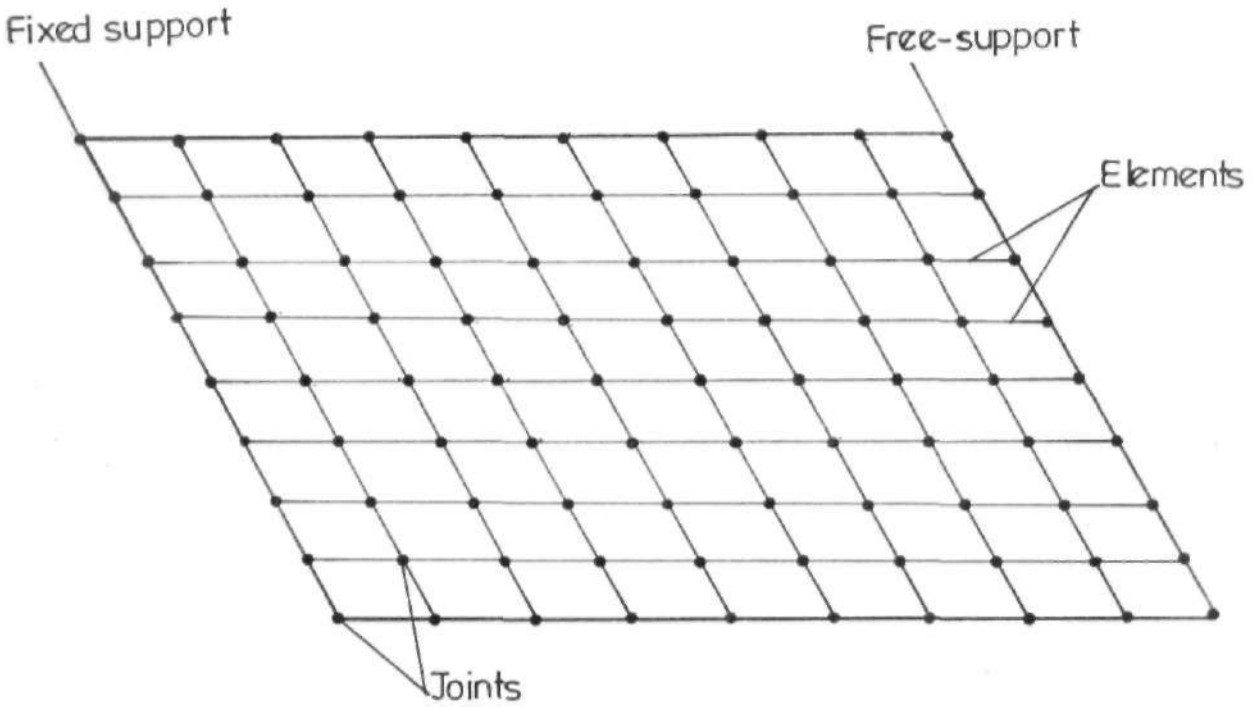


Fig. 4.1: Typical Modelled Grillage: A skewed Bridge Deck

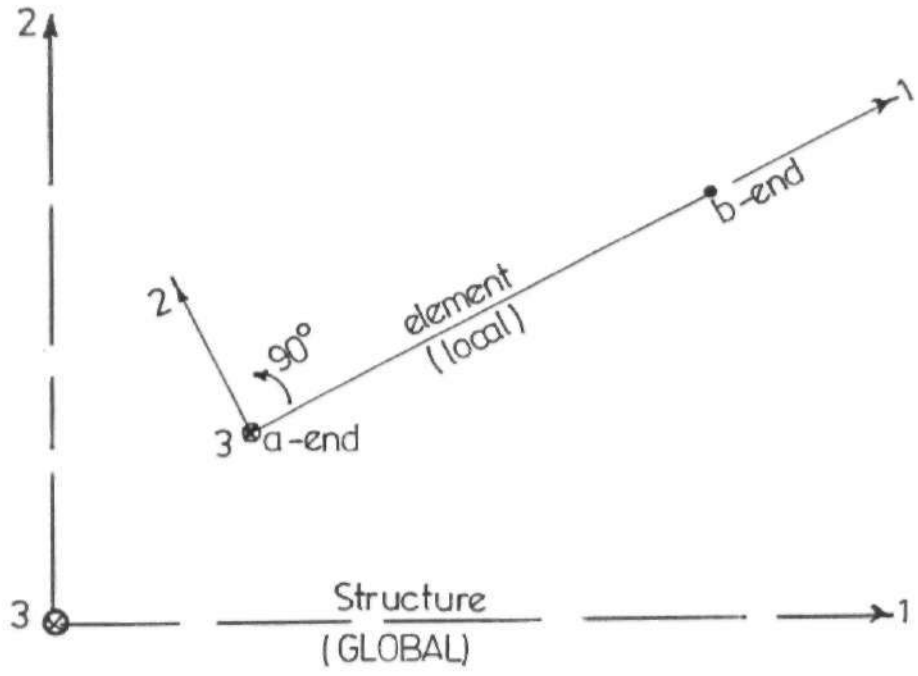


Fig. 4.2. Co-ordinate Systems

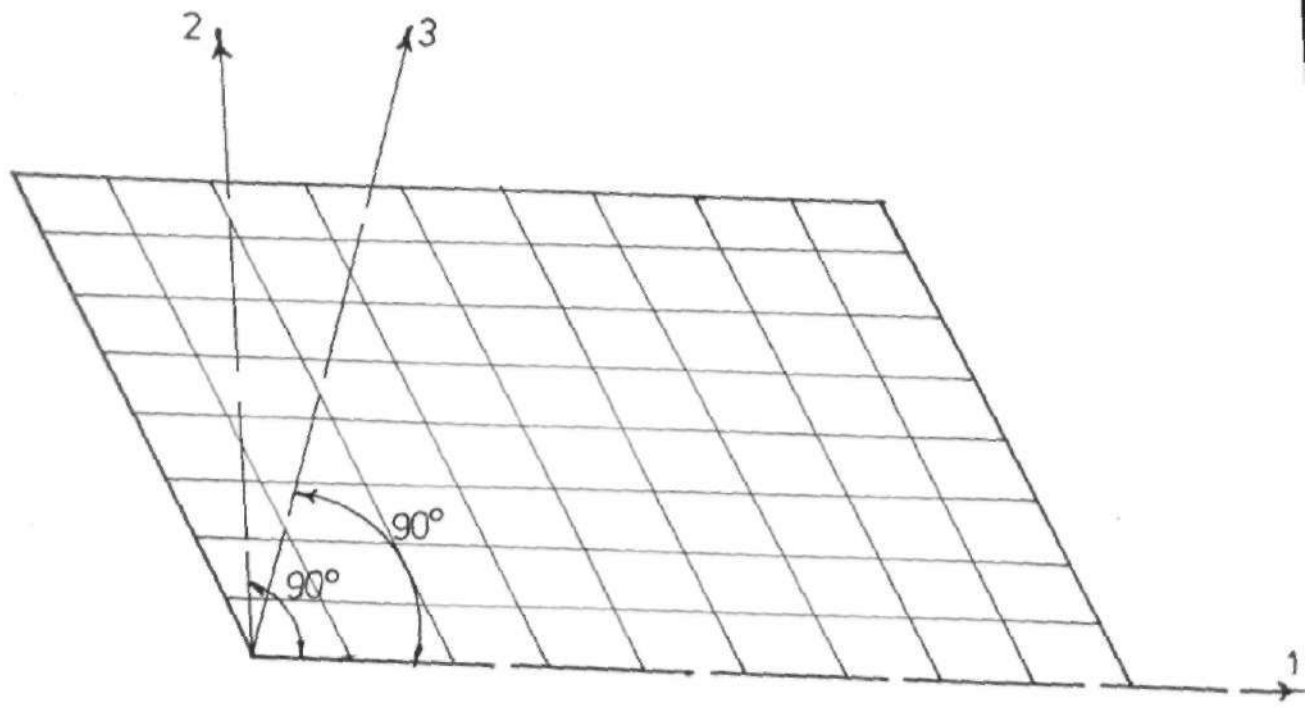


Fig. 4.3: Suggested Orientation of Global Coordinates - A skewed Bridge Deck

4.2.3 Joint Numbering

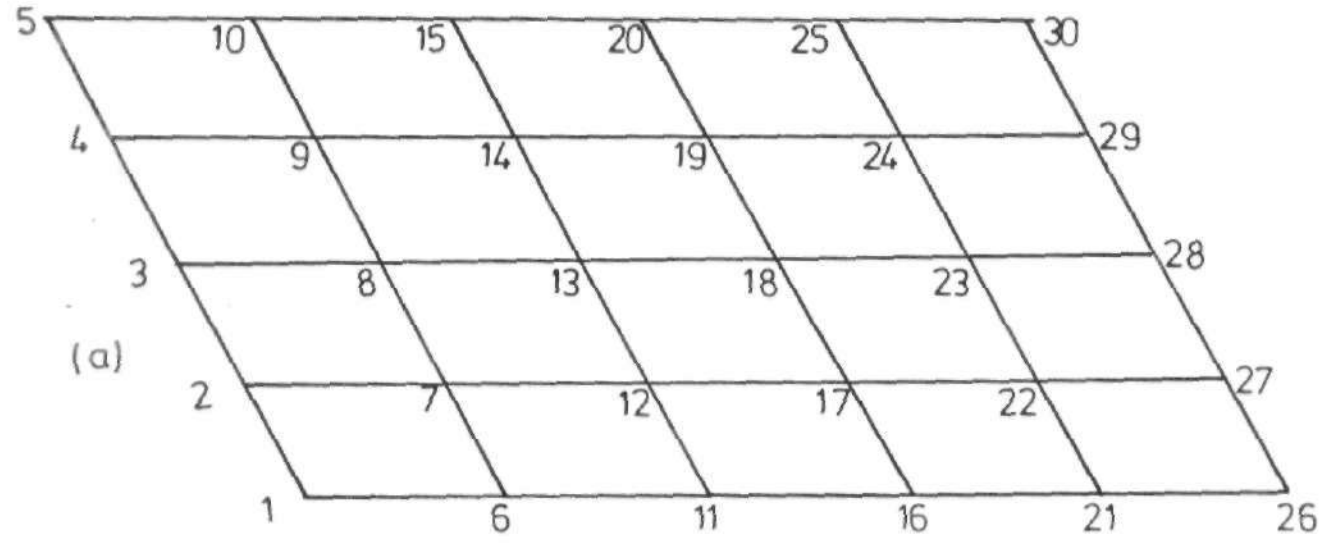
Each joint must be numbered for identification. It is necessary to number the joints in a particular sequence. Random numbering is allowed but will require that a large amount of computer memory (Random Access Memory - RAM) be devoted to storing the structure stiffness matrix. This will require a longer analysis run time and decrease the maximum size of structure that can be analysed.

To decrease the stiffness matrix storage requirements (hence, decrease the analysis run time) an optimal numbering scheme can be employed. Joint numbering optimization is achieved when the maximum numerical difference of all the element joint pairs are minimised. Example of joint numbering is shown in figure 4.4

The best joint numbering scheme for minimum half-bandwidth is to have adjacent joint numbers as close together as possible. Often structures are predominately longer in one direction. Such structures have inherently small half-bandwidth if numbered along the shorter direction.

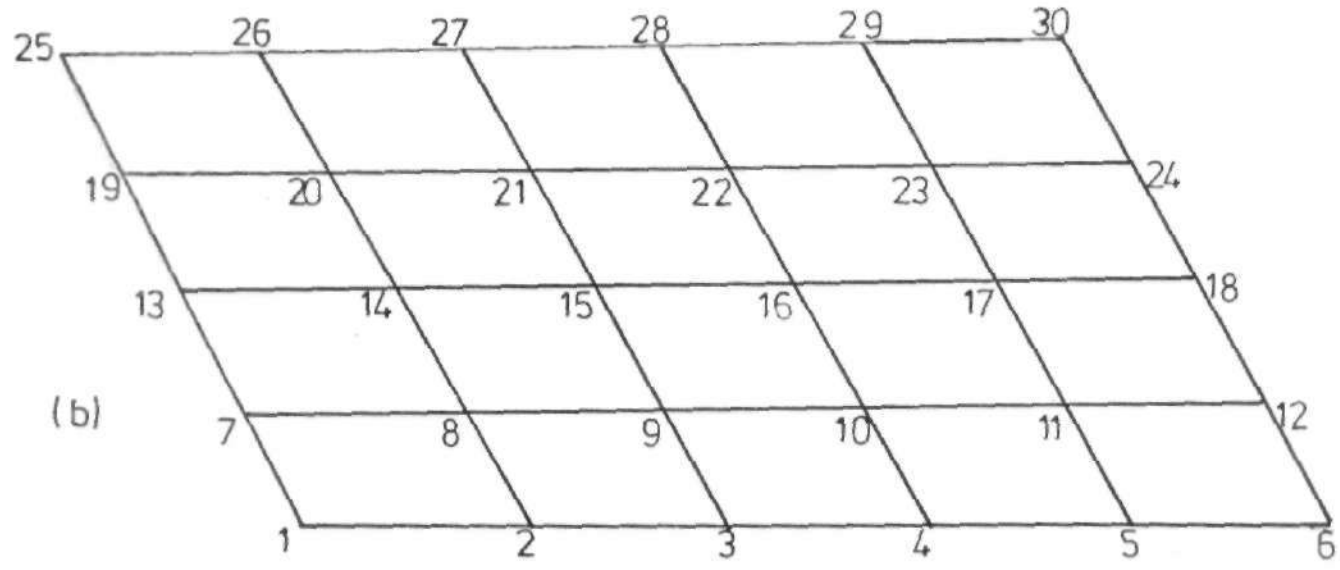
4.2.4 Element Connectivity

An element is connected to its joint pairs. The local 1-axis is directed from the lower to the higher numbered joint to which the element is incident. The numerically smaller joint number is termed the 'a-end' while the numerically larger joint is termed the 'b-end'. Connectivity is achieved by drawing an arrow on each element, pointing to the higher numbered joint to which the element is incident. See figure 4.5.



Maximum Joint Difference = 5

RECOMMENDED



Maximum Joint Difference = 6

NOT - RECOMMENDED

Fig. 4.4: Joint Numbering Scheme

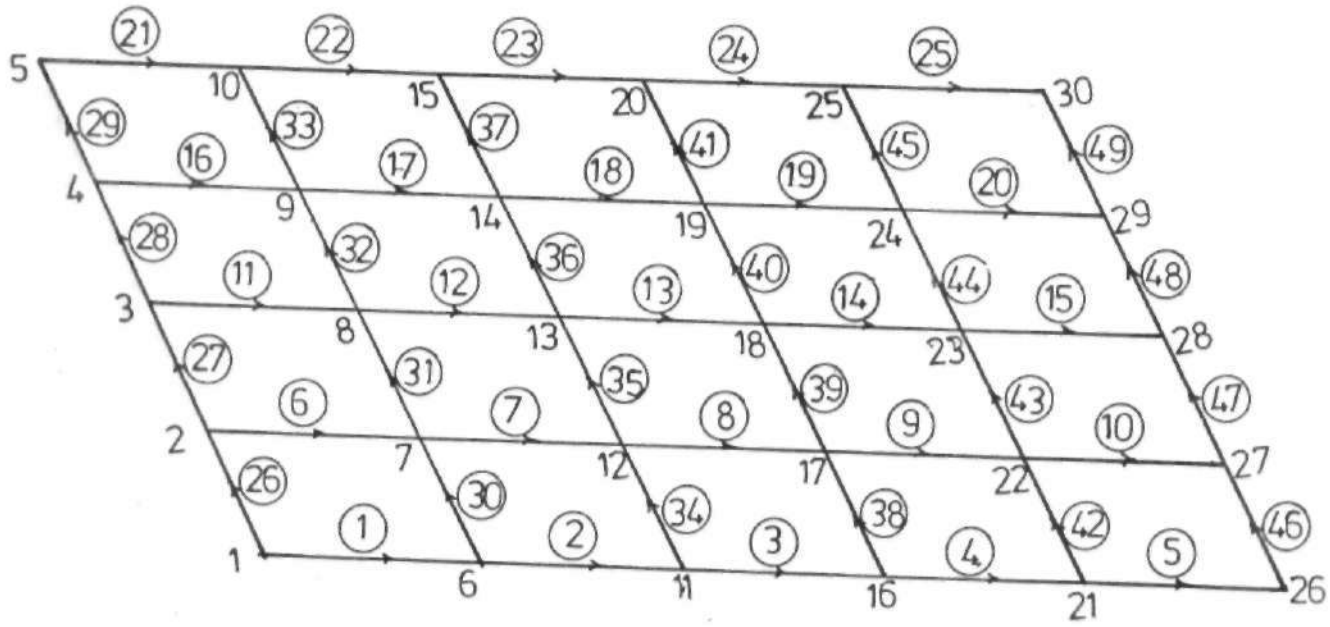


Fig. 45: Element Connectivity and Numbering

4.2.5 Element Numbering

Each element must be numbered for identification. Elements can be numbered at random. No time or storage space is saved by special numbering schemes. However, elements can be numbered in such way as to facilitate data input. See figure 4.5.

4.3 Generalised Displacements

By definition (section 2.3), generalised displacements are independent parameters required to define the configuration of a model. The number of generalised displacements is equal to the number of degrees-of-freedom of the model. If the discrete element models of chapter 3 are assembled into grillages, the resulting system model is also discrete; that is, it has a finite number of degrees-of-freedom, Holzer (1985):

$$n = l*NJ - NC \qquad (4.1)$$

Where

l = degrees-of-freedon of a free joint (= 3 for grillages)

NJ = number of joints

NC = number of joint constraints

Eq. 4.1 follows from conditions of compatibility, which are boundary conditions, expressed as joint constraints, and continuity conditions between element and joint displacements. Particularly, if an element has l degrees-of-freedom at each end, a free joint of an assemblage composed of these elements has l degrees-of-freedom. Thus, the number of degrees-of-freedom of the assemblage is equal to l

times the number of joints minus the number of joint constraints.

Each element require 3 independent unknown internal forces (Wang (1983), thus making the degrees of indeterminacy of the model;

$$NI = 3 * NM - n \tag{4.2}$$

Since the discrete element models do not represent element actions, assemblages of these elements can only represent joint actions such as joint loads and prescribed joint displacements. Element actions will be incorporated in section 4.9.

4.4 Components of the Model

A mathematical model of a structure is composed of conditions of compatibility, conditions of equilibrium, and constitutive laws (section 2.2). The constitutive laws, representing material behaviour, are inherent in the element models (section 3.3). Hence, to assemble element models into a system model, only the conditions of compatibility and equilibrium need to be formulated.

For the automatic computer assembly of element models, the conditions of compatibility and equilibrium will be formulated by the code number technique which was introduced by Tezcan (1963).

4.4.1 Compatibility

The conditions of compatibility can be expressed in compact form by the member code matrix, M, which is defined as in Holzer (1985).

$$\underset{(NE,m)}{M} = [Mij] \tag{4.3}$$

Where

$$Mij = \begin{cases} k & \text{if } D_j^i = qk \;;\; k = 1,2,\ldots,n \\ 0 & \text{otherwise} \end{cases}$$

qk = Joint displacement corresponding to the system degree-of-freedom, k.

D_j^i = Element-end displacement referred to global coordinate axes.

Thus, the ith row of M corresponds to the ith element, the jth column of M corresponds to the jth element displacement, and the entry in the location defined by the ith row and jth column of M is k if the element displacement D_j^i corresponds to any joint displacement qk. Otherwise it is zero.

The significance of the member code matrix is that once it is defined, no visual reference to the structure is required to formulate conditions of compatibility or equilibrium for the assemblage. Specifically, the displacement vector of the ith element can be defined by the following transformation.

DISPLACEMENT TRANSFORMATION: $q^M \rightarrow D^i$

1. Match the rows of D^i with the entries of the ith row of M
2. Assign the value qk to each component of D^i that corresponds to a positive integer k.
3. Assign the value zero to each component of D^i that corresponds to a zero integer.

4.4.2 Equilibrium

Any configuration of a system for which all generalised forces vanish is an equilibrium configuration [Holzer (1985)]. Since generalised forces correspond to generalised displacements in a work sense, the generalised forces of the assemblages are the net forces in the directions of the joint displacements. Particularly, the Kth generalised force, Rk, is equal to the sum of the external force, Qk, and the internal forces corresponding to the joint displacement, qk.

Therefore, for an n-degree-of-freedom system composed of NE elements, the condition of equilibrium gives:

$$Q = \sum_{i=1}^{NE} Fq^{i} \qquad (4.4)$$

Where

Q = n - dimensional applied joint force vector, that is, generalised external force vector.

Fq^{i} = n - dimensional internal force vector supplied by element i, that is the generalised force vector of element i.

Since the member code matrix identifies the element displacements, Dj^{i}, that are equated with the joint displacements, qk, it also serves to identify the corresponding element forces, Fj^{i}, that balance that applied joint force, Qk.

Accordingly, the generalised force vector of element i, Fq^{i}, can be obtained from the global force vector of element i, F^{i}, as follows.

FORCE TRANSFORMATION: $F_i \xrightarrow{M} Fq_i$

1. Match the rows of F_i with the entries of the ith row of M.
2. Transfer every component of F_i that corresponds to a positive integer k to the k-th row of Fq_i.
3. Assign the value zero to every row of Fq_i that does not receive a contribution from F_i.

4.5 Joint Forces

The joint forces, the applied and reactive external forces at a joint, can be computed from element forces by conditions of joint equilibrium. In vector form, the conditions of joint equilibrium can be expressed as

$$Pj = \sum_{i=1}^{NE} Fj_i \quad ; \quad j = 1,2,\ldots,NJ \qquad (4.5)$$

Where

Pj = Force vector at joint j, whose components are ordered in the sequence of the global coordinate axes.

$$Fj_i = \begin{cases} Fa_i & \text{, if the a-end of element i is incident to joint j.} \\ Fb_i & \text{, if the b-end of element i is incident to joint j.} \\ 0 & \text{, othewise} \end{cases}$$

NE and NJ are the number of elements and the number of joints respectively.

4.6 Coordinate Transformation

Since element models are expressed in local coordinates and assembled in global coordinates, coordinate transformations are required.

Figure 4.6 depicts the local and global coordinate axes for an element of a plane grillage. The local 1 and 3 axes are assumed to remain in the horizontal global plane 1 - 3, so that both local and global 2 axes are coincident, Livesley (1975). From figure 4.6, the rotation matrix is:

$$= \begin{bmatrix} C1 & 0 & C2 \\ 0 & 1 & 0 \\ -C2 & 0 & C1 \end{bmatrix} \quad , \quad C1 = \cos\theta \quad , \quad C2 = \sin\theta \qquad (4.6)$$

The rotation angle θ is measured from the global 1 - axis to the local 1 - axis; its positive sense is counterclockwise. The rotation matrix (Eq. 4.6) is used in transformation between local and global coordinates to formulate displacement and force transformations required in the matrix displacement analysis technique. Specifically, these transformations are of the form:

$$d = \Lambda D \qquad (4.7a)$$

and

$$F = \Lambda^{T} f \qquad (4.7b)$$

Where d and D are the local and global element displacement vectors; f and F are the local and global element force vectors; and Λ is the transformation matrix from global to local coordinates:

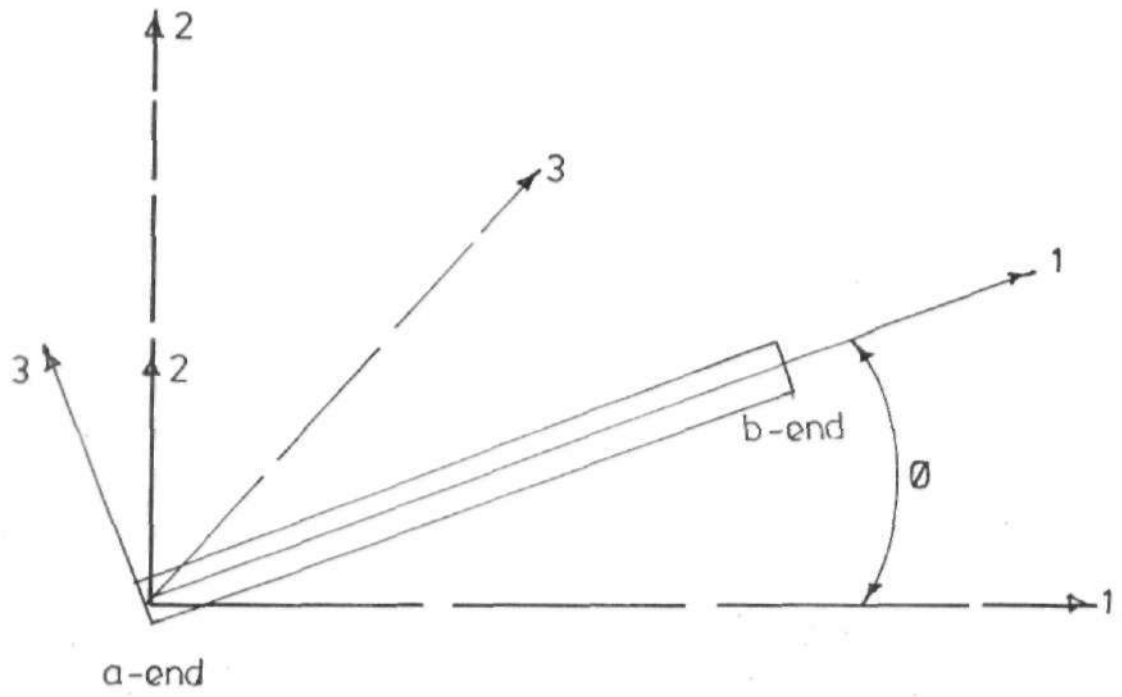


Fig. 4.6: Local and Global Coordinates for an Element of a plane Grillage

$$\Lambda = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix} \qquad (4.8)$$

λ is as defined in Eq. 4.6.

4.7 Assembly Process

In this section, the matrix displacement method is presented in a form which makes it suitable for automatic computer analysis of grillage represented as an assemblage of discrete interconnected elements. Specifically, conditions of compatibility and equilibrium are formulated without reference to a visual image of the structure, and an efficient procedure is employed for the assembly of element models into the system model.

If the local and global reference frames are distinct, the local element model

$$\overset{i}{f} = \overset{i}{k}\,\overset{i}{d} \quad ; \quad i = 1,2,\ldots,NE \qquad (4.9)$$

must be transformed into the global element model

$$\overset{i}{F} = \overset{i}{K}\,\overset{i}{D} \qquad (4.10)$$

where the global element stiffness matrix

$$\overset{i}{K} = \overset{iT}{\Lambda}\,\overset{i}{k}\,\overset{i}{\Lambda} \qquad (4.11)$$

Eqs. 4.10 and 4.11 are obtained from Eq. 4.9 and the contragredient transformation Eq. 4.7, as follows:

$$\overset{i}{F} = \overset{iT}{\Lambda}\,\overset{i}{f} = \overset{iT}{\Lambda}\,\overset{i}{k}\,\overset{i}{d} = \overset{iT}{\Lambda}\,\overset{i}{k}\,\overset{i}{\Lambda}\,\overset{i}{D} = \overset{i}{K}\,\overset{i}{D} \qquad (4.12)$$

The global element model is next transformed into the generalised element model

$$Fq^{i} = Kq^{i}\, q \tag{4.13}$$

by conditions of compatibility. Finally, the substitution of Eq. 4.13 into the equation of equilibrium, Eq. 4.4, yields the system model

$$Kq = Q \tag{4.14}$$

where the system stiffness matrix

$$K = \sum_{i=1}^{NE} Kq^{i} \tag{4.15}$$

The generalised element stiffness matrix, Kq^{i}, can be constructed efficiently from the global element stiffness matrix, K^{i}, with the aid of the member code matrix as follows, Holzer (1985):

STIFFNESS MATRIX TRANSFORMATION: $K^{i} \xrightarrow{M} Kq^{i}$

1. Match the rows and columns of K^{i} with the entries of the ith row of M.
2. Transfer every coefficient of K^{i} whose row and column correspond to positive integers j and k to the j-th row and k-th column of Kq^{i}.
3. Assign the value zero to every location of Kq^{i} that does not receive a contribution from K^{i}.

Eq. 4.14 represents a set of simultaneous, nonhomogeneous, algebraic equations in the unknown joint displacements. The solution to Eq. 4.14 is unique if the system stiffness matrix is nonsingular, that is, if K has rank n. Physically, this means that the assemblage is sufficiently constrained to prevent (finite or infinitesimal) rigid-body displacements. Accordingly, the initial configuration is a configuration of stable equilibrium.

4.8 Formulation of Global Element

To apply the matrix displacement method to interconnected grillages, the global element stiffness matrix need to be formulated. The local element model (Eq. 3.31)

$$f = kd \tag{4.16a}$$

where

$$k = \begin{bmatrix} kaa & kab \\ kba & kbb \end{bmatrix}$$

$$= \alpha \begin{bmatrix} \beta & 0 & 0 & \beta & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ \beta & 0 & 0 & \beta & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix} \tag{4.16b}$$

and

$$\alpha = EI/L^3 \quad , \quad \beta = GJ/EI*L^2 \quad , \quad \gamma = \alpha\beta = GJ/L$$

The substitution of the partitioned Λ - matrix (Eq. 4.8) and the partitioned k - matrix (Eq. 4.16b) yield the global element stiffness matrix in the form.

$$K = \begin{bmatrix} Kaa & Kab \\ Kba & Kbb \end{bmatrix} \tag{4.17}$$

where

$$\begin{aligned} Kaa &= \lambda^T kaa\ \lambda \\ Kab &= \lambda^T kab\ \lambda \\ Kba &= \lambda^T kba\ \lambda \\ Kbb &= \lambda^T kbb\ \lambda \end{aligned} \tag{4.18}$$

Since K is symmetric, it is sufficient to compute the coefficients of Kab and the upper triangular portions of Kaa and Kbb. For example, by Eqs. 4.6, 4.16, and 4.18

$$Kaa = \alpha \begin{bmatrix} C1 & 0 & -C2 \\ 0 & 1 & 0 \\ C2 & 0 & C1 \end{bmatrix} \begin{bmatrix} \beta & 0 & 0 \\ 0 & 12 & 6L \\ 0 & 6L & 4L^2 \end{bmatrix} \begin{bmatrix} C1 & 0 & C2 \\ 0 & 1 & 0 \\ -C2 & 0 & C1 \end{bmatrix}$$

$$= \alpha \begin{bmatrix} C1^2 + 4L^2 C2^2 & -6LC2 & C1C2(\beta - 4L^2) \\ & 12 & 6LC1 \\ \text{Sym.} & & C2^2 + 4L^2 C1^2 \end{bmatrix} \tag{4.19}$$

The resulting global stiffness matrix of the grillage element can be expressed as

$$K = \begin{bmatrix} g1 & g2 & g4 & g7 & -g2 & g8 \\ & g3 & g5 & g2 & -g3 & g5 \\ & & g6 & g8 & -g5 & g9 \\ & & & g1 & -g2 & g4 \\ & & & & g3 & -g5 \\ & \text{Sym.} & & & & g6 \end{bmatrix} \tag{4.20}$$

where

$$g1 = \alpha\,(\beta C1^2 + 4L^2 C2^2)$$

$$g2 = -\alpha\,6LC2$$

$$g3 = 12\,\alpha$$

$$g4 = \alpha\,C1*C2(\beta^2 - 4L^2)$$

$$g5 = \alpha\,6LC1 \qquad (4.21)$$

$$g6 = \alpha\,(\beta C2^2 + 4L^2 C1^2)$$

$$g7 = -\alpha(\beta C1^2 - 2L^2 C2^2)$$

$$g8 = -\alpha C1*C2(\beta^2 + 2L^2)$$

$$g9 = -\alpha(\beta C2^2 - 2L^2 C1^2)$$

$$\alpha = EI/L^3 \quad , \quad \beta = GJ/EI*L^2$$

4.9 Element Actions

In the presence of element loads, the joint displacement no longer represent generalised displacements of the assemblage, Holzer (1985); that is, the joint displacements are not sufficient to define the configurations of elements subjected to loads.

However, the joint displacements, the element-end forces, and the joint forces can be computed by a procedure known as resolution of actions. It includes load resolution, analysis of an equivalent joint load system, and response superposition.

4.9.1 Resolution of Actions

Element actions may consist of loads, temperature changes, element imperfections, prescribed displacements (such as support

settlements), etc. specifically, the actions of the structure are transformed into equivalent joint loads by the resolution

$$\bar{I} = \hat{I} + \hat{1} \tag{4.22}$$

where $\bar{I}$ = actual actions of the structure; they may consist of element and joint actions.

$\hat{I}$ = fixed-joint actions; they are composed of the actual element actions and joint loads required to prevent joint displacements.

1 = equivalent joint loads.

Since the joints corresponding to $\hat{1}$ do not experience displacements, the element-end forces are fixed-end forces that can be computed from formulas developed for specific element loads.

Note that 1 contains only joint loads because the element actions are introduced in $\hat{1}$ and it follows from Eq. 4.22 that

$$1 = \bar{I} - \hat{1} \tag{4.23}$$

Thus, the equivalent joint loads can be obtained by substracting the fixed joint loads from the actual loads. Hence, the response to 1 can be determined by the matrix displacement method.

In matrix form, the equivalent joint loads can be expressed as

$$Q = \bar{Q} - \hat{Q}$$

where

$\bar{Q}$ = actual joint load vector

$\hat{Q}$ = fixed joint load vector

Q = equivalent joints load vector

$\bar{Q}$ is prescribed and $\hat{Q}$ can be computed as follows:-

1. For each element subjected to actions, the local fixed-end force vector, $\hat{\hat{f}}^{i}$, is computed and transformed into the global fixed-end force vector, $\hat{F}^{i}$.

2. The generalised fixed-end force vector, Fq^{i}, is determined by the force transformation (section 4.4.2):

$$\hat{F}^{i} \xrightarrow{M} \hat{Fq}^{i} \tag{4.25}$$

3. The condition of equilibrium, Eq. 4.4, is imposed to yield

$$Q = \sum_{i=1}^{NE} Fq^{i} \tag{4.26}$$

Once the responses to $\hat{1}$ and 1 are determined, they are superimposed, Eq. 4.22, to yield the actual response. In particular the actual element force vectors can be expressed as

$$\bar{f}^{i} = f^{i} + \hat{f}^{i} \tag{4.27}$$

where

$$f^{i} = k^{i} d^{i}$$

Then the actual joint force vector, $\bar{P}j$, can be computed by Eq. 4.5.

Note that the joint displacements corresponding to $\bar{1}$ and 1 are identical because the joint displacements corresponding to $\hat{1}$ are zero by definition; that is,

$$\bar{q} = q + \hat{q} = q \tag{4.28}$$

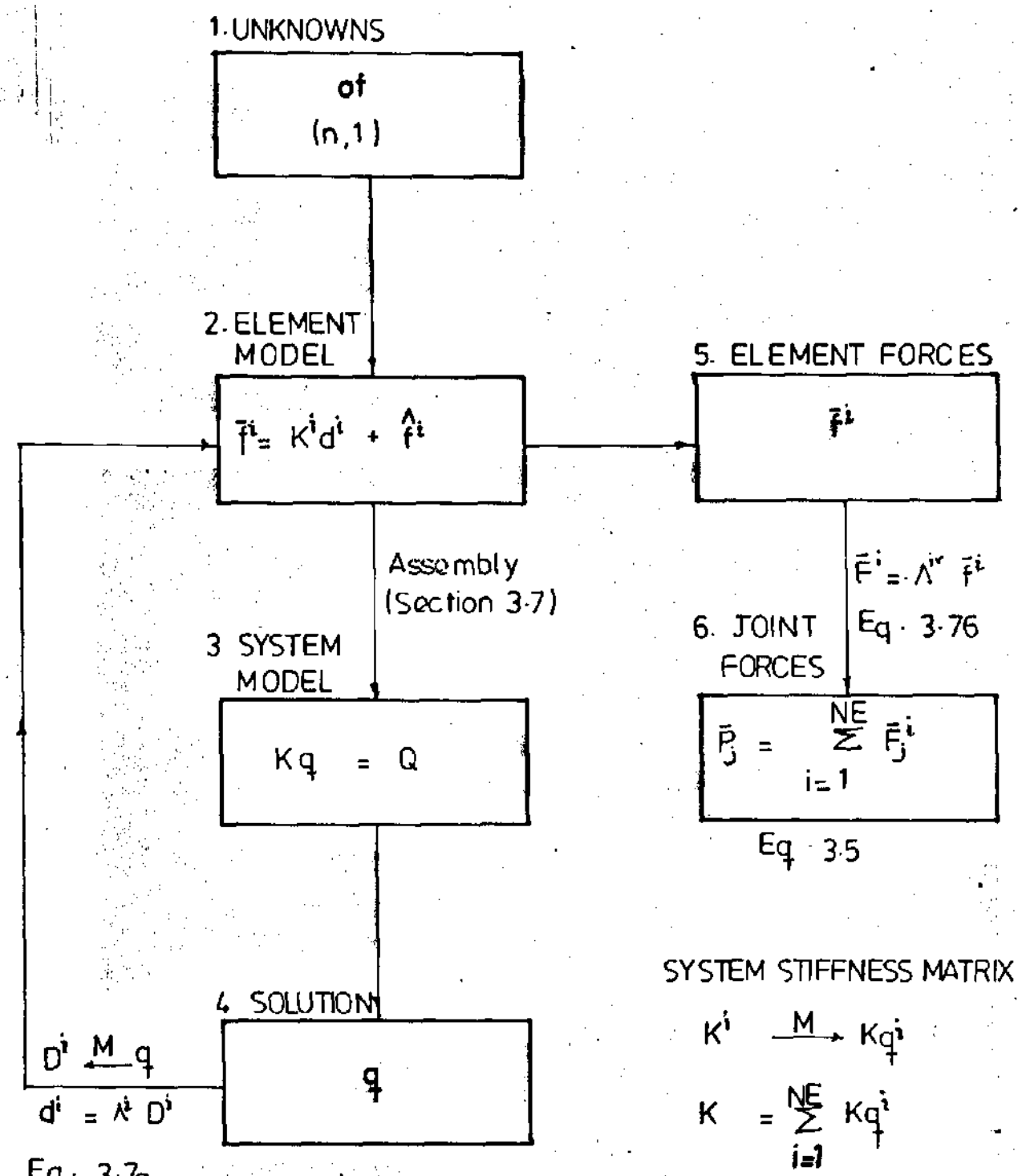
because

$$\hat{q} = 0$$

4.10 Review

The complete process of matrix displacement method with element actions is presented in a form, Figure 4.7, that facilitates automatic computerization. The key steps are (figure 4.7):

1. The unknown joint displacements are selected as the independent variables.
2. The element models are formulated Eq. 4.27.
3. The element models are assembled into the system model, the model of the structure, by imposing the conditions of compatibility and equilibrium. The conditions of equilibrium balance the applied joint forces and the element forces in the directions of the unknown joint displacements. This assures equilibrium of the assemblage. The system model represents a set of simultaneous algebraic equations in the unknown joint displacements.
4. The system model is solved for the joint displacements.
5. The element-end forces are computed by substituting the values of the joint displacements into the element models equations.
6. The joint forces, the applied and reactive external forces at a joint, are then computed from element forces by conditions of joint equilibrium, Eq. 4.5.



n = number of system dof

m = number of element dof

NE = number of elements

Fig. 4.7: Matrix Displacement method with Element Actions [Holzer(1985)]

Chapter 5

COMPUTER IMPLEMENTATION OF THE MATRIX DISPLACEMENT METHOD

5.1 Introduction

General theories and formulations of matrix displacement method of grillage analysis have been so far presented in this study. The objective in this chapter is to discuss some important computational aspects pertaining to the implementation of the matrix displacement method.

It seems possible, by using many elements, to virtually approximate any bridge deck with complex boundary and loading conditions to such a degree that an accurate analysis be carried out. In practice, however, obvious engineering limitations arise, a most important one being the cost of the analysis. As the number of elements used is increased, the manpower required to prepare the relevent data and interpret the results increases, and also a larger amount of computer time is needed for the analysis. Furthermore, the limitations of the program and the computer may prevent the use of a larger number of elements to idealise the structure. The limitations may be due to high - speed and back-up (low-speed) storage available, or the round-off and truncation errors occuring in the analysis because of finite precision arithmetic. Also the malfunctioning of a hardware component, if the analysis is carried out using many computer hours, is possible. It is therefore desirable to use efficient programming techniques.

The effectiveness of a program depends largely on efficient programming methods and sophisticated use of the available computer hardware and software. Although this aspect of program development is computer - dependent, using standard FORTRAN 77 and high- and low-speed storage in a system - independent manner, very effective computer programs could be developed. In the following, the design of matrix displacement method of analysis program, in which largely computer - independent procedures are used is discuss.

Assuming that an actual grillage structure has been idealised as an assemblage of interconnected elements. The analysis process can be understood to consist of essentially three phases:

1. Computation of the system stiffness matrix, K
2. Solution of equilibrium equations, and
3. Evaluation of element-end and joint forces.

The objective in this chapter is to describe a program implementation of the first and third phases. A computer program that has all the important features is presented in Appendix III. As might be imagined, there is no unique optimum program organisation and various different and effective strategies are currently followed as in Bathe and et al (1974), Bathe(1975), and Harrison(1980), Parts I and II. In addition, new ideas may be developed, particularly as new computer equipment becomes available.

5.2 Computer Program Organisation

The listing of the program GRID is presented in Appendix III. Although, the Code is simplified in various areas, it shows all the

important features of more general codes. The main objective in the presentation of the program is to show the overall flow of a typical matrix displacement method program.

Figure 5.1 shows a flow chart of the program modules, and figures 5.2 a-f give the details of each module storage allocations used during the various modules phases. The user's guide is presented in Appendix I.

The program can be understood to consist of essentially six modules:

1. INPUT PROCESSING (figure 5.2a) - This module accepts all input data, computes system degree of freedom and half-bandwidth, Establishes member-code-matrix, calculates fixed-end forces, resolves applied actions and finally stores data into appropriate tapes for further processes.
2. ASSEMBLY PROCESS (figure 5.2.b) - At this module, all data required for assembly process are read from tapes. Next, the module computes global element stiffness matrix, and finally stores the results into tape 7.
3. SOLUTION PROCESS (figure 5.2c) - This module reads K and Q, solves the equilibrium equations using triple matrix decomposition technique and stores the resulting displacements, q, into tape 8.
4. COMPUTATION OF ELEMENT FORCES (figure 5.2d) - Reads data required for displacement transformation and computation of element-end forces. Performs the computations and stores the resulting element-end forces into tape 9.

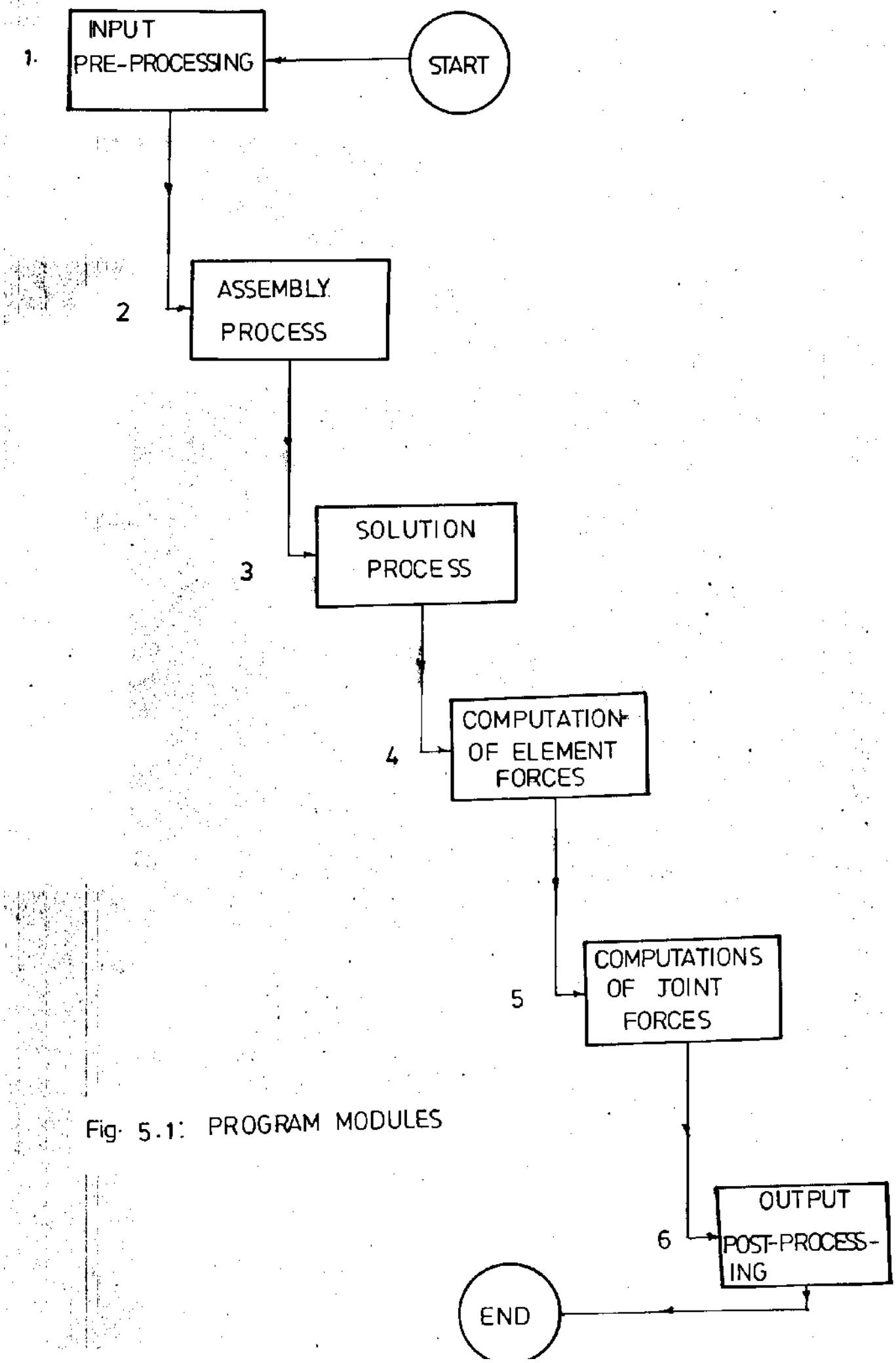


Fig. 5.1: PROGRAM MODULES

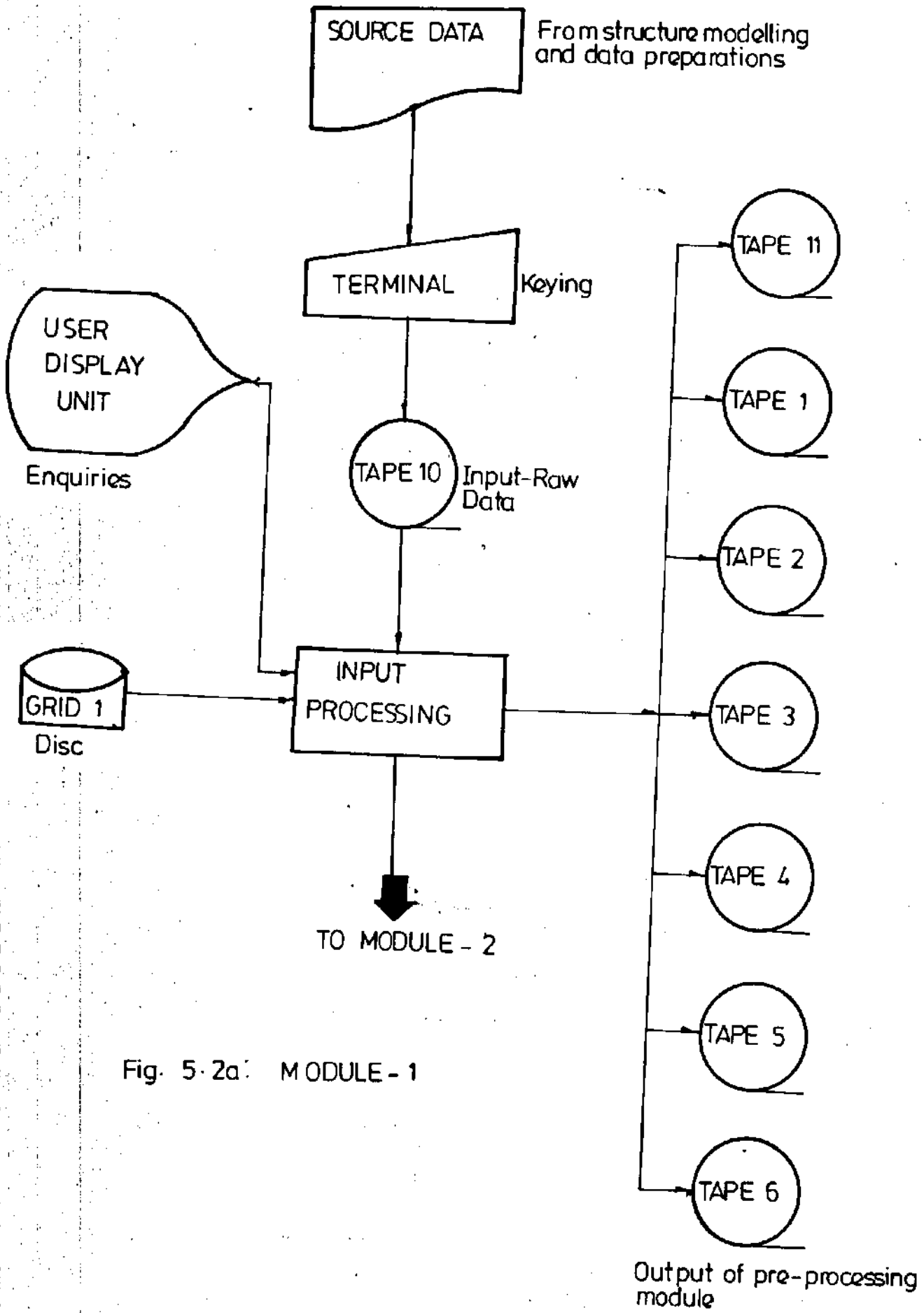


Fig. 5·2a: MODULE - 1

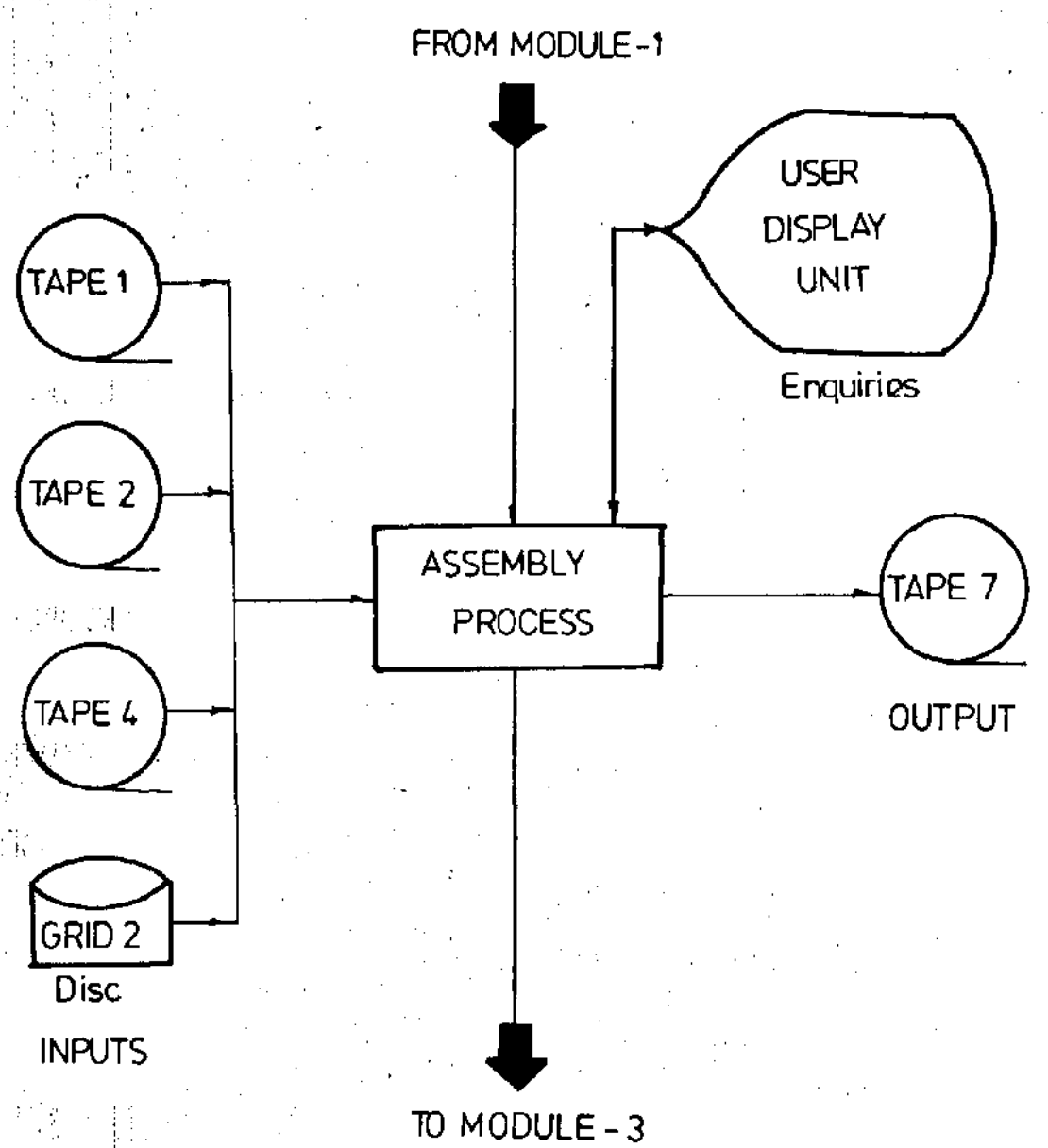


Fig. 5.2b MODULE - 2

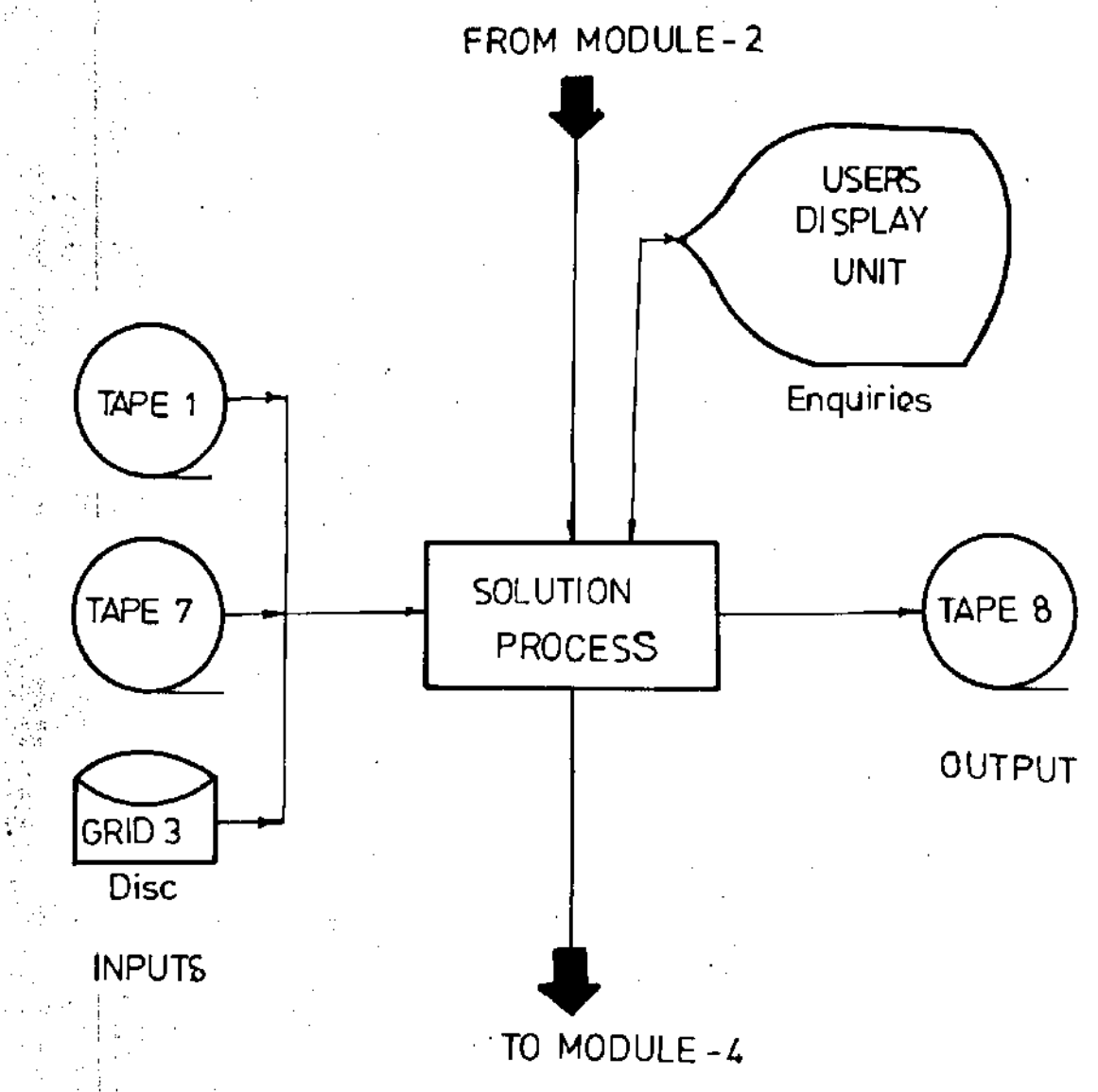


Fig. 5·2c: MODULE - 3

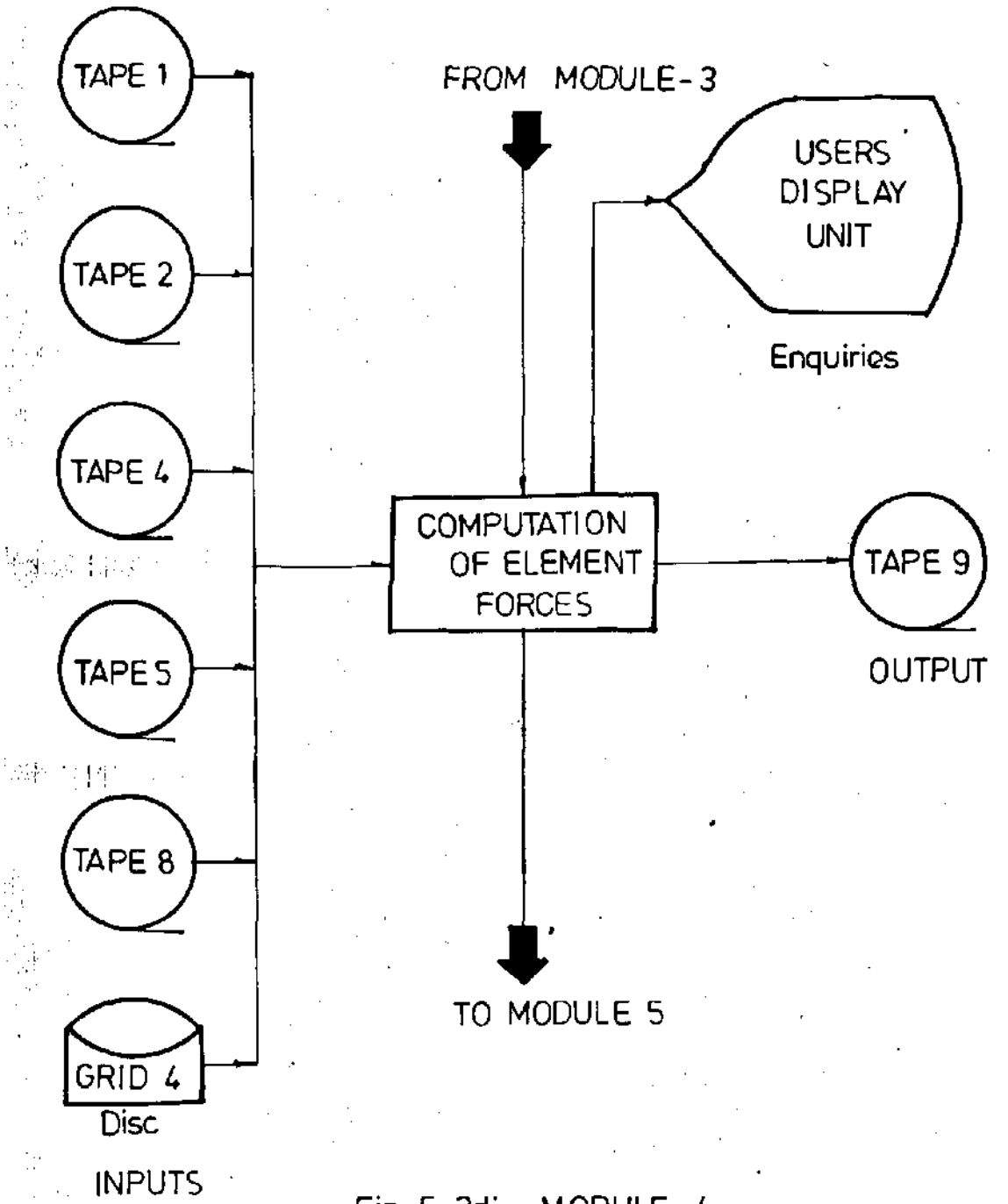


Fig. 5.2d: MODULE-4

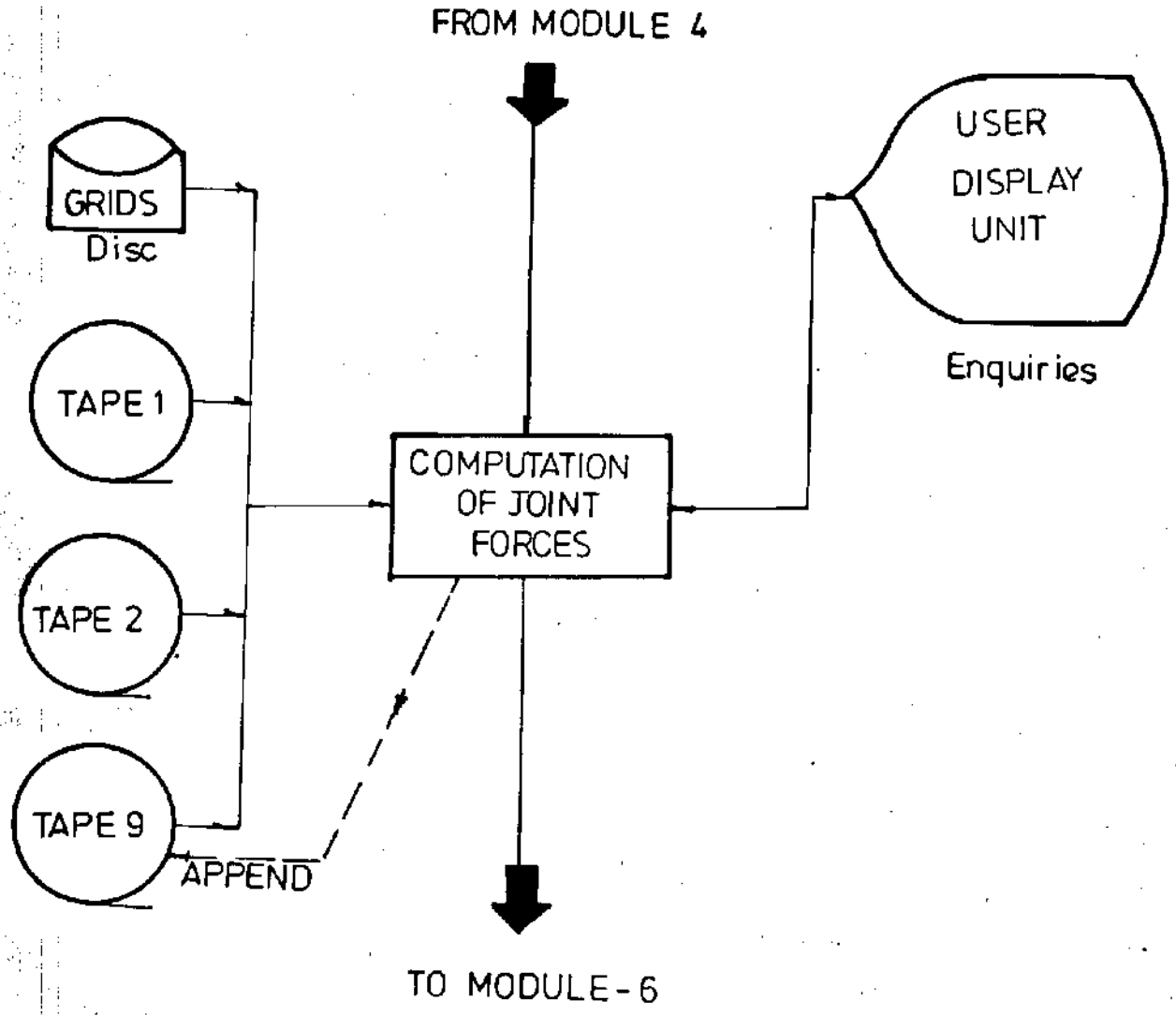


Fig. 5.2e: MODULE-5

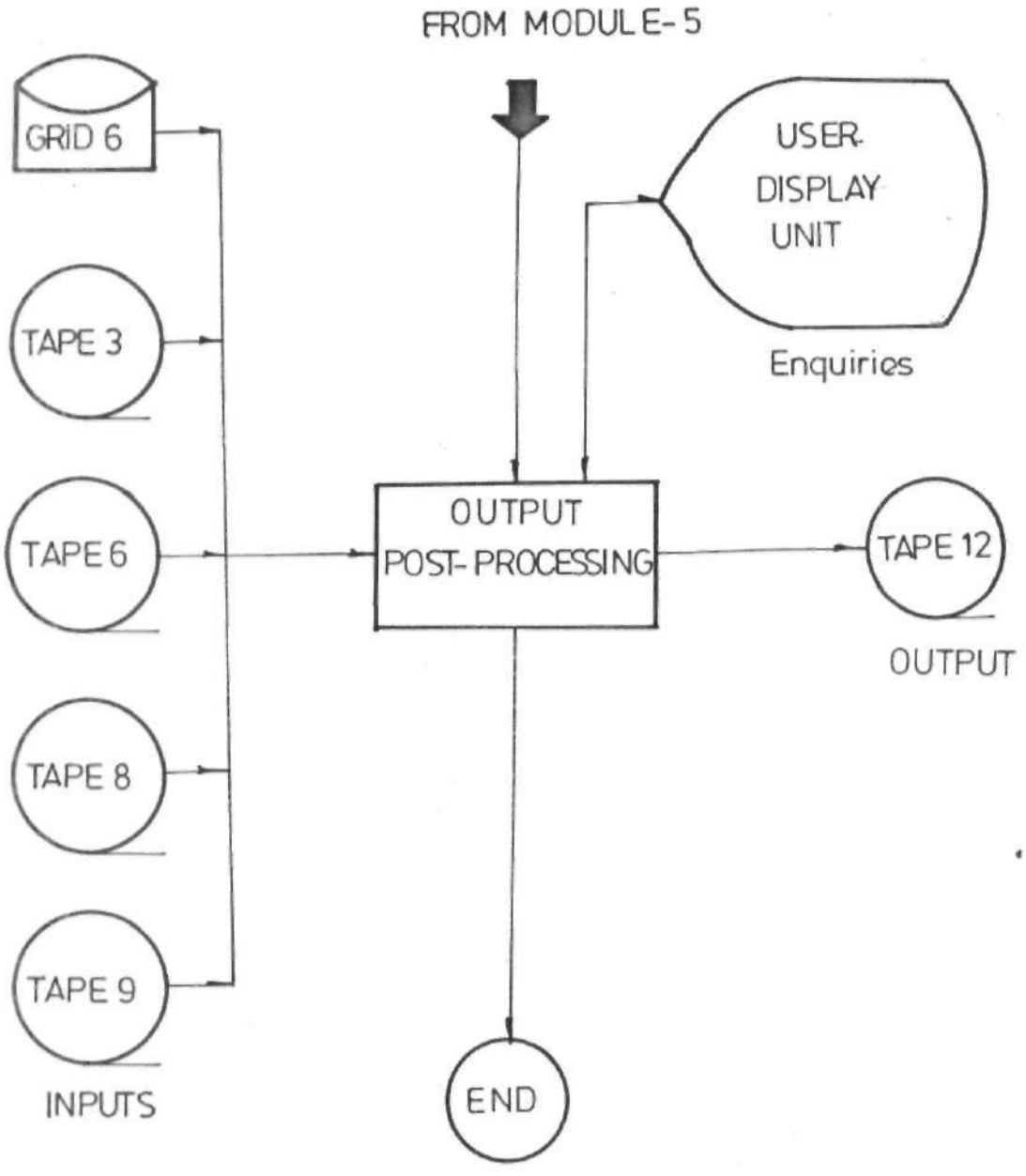


Fig. 5.2f: MODULE-6

5. COMPUTATION OF JOINT FORCES (figure 5.2e) - Reads required data from tapes, computes the joint forces and appends the results to tape 9

6. OUTPUT PROCESSING (figure 5.2f) - This post-processing module reads displacements, element-end forces, joint forces and output information from tape 12.

These modules are stored as separate programs (GRID 1 - 6) on the hard disc (see Table 5.1 for details) and the low-speed storage

TABLE 5.1 - DESCRIPTION OF PROGRAM MODULES

MODULE	DESCRIPTION
GRID 1	Pre-processing module. Accepts all input data, generates other information necessary to complete the analysis, and finally stores data into appropriate tapes for further processes.
GRID 2	Assembly processing module. Performs the system stiffness matrix transformation.
GRID 3	Solution Processing module. Solves the equilibrium equations using triple matrix decomposition technique.
GRID 4	Computation of element-end forces module. Performs the transformation of assemblage displacements into local axes and computes the element-end forces.
GRID 5	Computation of joint forces module. Computes applied and reactive joint forces.
GRID 6	Post-processing module. Performs load combinations and output the desired results.

allocations used during the analysis process, named TAPE 1 - 12 are shown on Table 5.2.

TABLE 5.2 - DESCRIPTION OF LOW-SPEED STORAGE ALLOCATIONS

TAPE	CONTENT
TAPE 1	Parameters such as number of elements, joints, load cases and load combinations. System degree of freedom, half-bandwidth and equivalent joint loads for all load cases.
TAPE 2	Element connectivity data, joint coordinates and member-code-matrix.
TAPE 3	Parameters such as number of elements, joints, load cases and load combinations. System degree of freedom, member-code-matrix and element connectivity data.
TAPE 4	Material properties: Elasticity and shear modulus, torsion constants and moment of inertias of all elements.
TAPE 5	Fixed-end forces for all load cases.
TAPE 6	Post-processing information: load combinations factors and particular joints and elements of which results are required.
TAPE 7	System stiffness matrix.
TAPE 8	Joint displacements for all load cases.
TAPE 9	Element-end forces and joint forces for all load cases.
TAPE 10	Raw - input data
TAPE 11	Raw - input and generated data
TAPE 12	Results for all load cases - joint displacements, element-end forces, and joint forces of all required load combinations.

5.3 Program Information Flow

The first module reads and/or generates all data required for the complete grillage analysis. The input data consists of the following categories:

Problem Title

Control Information

Joint Coordinates

Elements Connectivity

Joint Releases

Element Properties

Load Data

Output Information

The full description of each category is presented in the user's guide (Appendix I). With all the data known, the program goes on to generate other information necessary to complete the analysis.

Consider first the data that correspond to the joints. The program is set up to allow a maximum of three degrees of freedom at each joint-one translational and two rotational degrees of freedom. Corresponding to each joint, it must then be identified which of these degrees of freedom shall actually be used in the analysis, that is, which of the three possible joint degrees of freedom correspond to degrees of freedom of the assemblage. This is achieved by defining an identification array, or joint releases array, JR, of dimension NJ times 3, where NJ is the number of joints in the system.

Element (i,j) in the JR matrix corresponds to the jth degree of freedom at that joint i. If JR (I,J) = 0, the corresponding degree of freedom is defined in the element system, and if JR (I,J) = 1, the degree of freedom is not defined.

Once all active degrees of freedom have been defined by zeros in the JR array, the equation numbers corresponding to these degrees of freedom are assigned. The procedure is to simply scan row after row through the JR array and replace each zero by an equation number, which increases successively from 1 to the total number of equations, that is, the total system degree of freedom. At the same time the entries corresponding to the non-active degrees of freedom are set to zero.

At this stage, with element connectivity and joint releases data known, the program generates the member - code - matrix, M (see section 4.4.1). This matrix relates to each element degree of freedom the corresponding assemblage degree of freedom. It is conveniently a connectivity array M(I,J), in which entry (i,j) gives the equation number that corresponds to the ith element's degree of freedom j. The procedure of establishing the connectivity array M(I,J) is achieved by using the element connectivity joint pairs to extract the element's assemblage degrees of freedom from the JR array, that is, the connectivity array of each element is determined from the joints to which the element is connected and the equation numbers that have been assigned to these joints.

Once the array M has been defined, the corresponding element stiffness matrix can be added in compact form to the system stiffness

matrix, but the process must take due account of the specific storage scheme used. As explained in Harrison (1980), an effective storage scheme for the system stiffness matrix is to store only the elements on the leading diagonal and up to the half-bandwidth.

The triple matrix decomposition technique described in Harrison (1980), is then applied to solve the resulting equilibrium equations. Next, for each element, its assemblage degrees of freedom are transformed to local axes (section 4.6) and its end forces computed (Eq. 4.27). Finally, the applied and reactive joint forces for each joint are computed (Eq. 4.5) to complete the analysis process.

Once the analysis is completed, GRID provides the results in an output-file. Joint displacements (deflections and rotations), element-end forces (torsion, shear and bending moments) and joint forces (applied and reactive) may be displayed numerically on the screen or printer. The numerical results output is formatted to allow a quick comparison of all displacements and forces created by each load combination, so that the most severe load combination on an element can quickly be obtained. In addition, output of results concerning particular joints or elements can be obtained easily.

Chapter 6

BRIDGE DECK LOADING TO BS5400

6.1 Introduction

Bridge deck loadings in this study are in accordance with the British Standard 5400, hereafter, referred to as the Code, BS5400 (1978). Nominal loads are specified in part 2 of the Code, together with values of the partial safety factors, which are applied to the nominal loads to obtain the design loads. Only loads condidered in this study are discussed. These are the permanent and primary vertical live loads. It should be noted that this study does not cover secondary highway loadings such as centrigugal, braking, skidding and collision loads. If desired, they could be analysed separately and added to the results of permanent and primary loads.

The general philosophy governing the application of the loads is that the worst effects of the loads should be sought. In practice, this implies that the arrangement of the loads on the bridge is dependent upon the load effect being considered, and the critical section being considered.

In the following, carriageways and lanes used in deciding how live load is applied to a bridge deck are discussed. Next, various load modelling schemes permissible by program GRID are presented. After that, permanent and primary loadings together with their descretisation on a bridge deck are discussed. Finally, load cases and combinations necessary to aid design at both ultimate and serviceability limit states are presented.

6.2 Highway Carriageways and Lanes

The carriageway is defined as the traffic lanes plus hard shoulders plus hard strips plus marker strips [BS5400 (1978)]. if raised kerbs are present, the carriageway width is the distance between the raised kerbs. In the absence of raised kerbs, the carriageway width is the distance between the safety fences less the set-back for the fences: the set-back must be in the range 0.6 to 1.0m.

6.22 Traffic Lane

The lanes marked on the running surface of the bridge are referred to as traffic lanes. However, the traffic lanes in the Code have no significance in deciding how live load is applied to the bridge.

6.2.3 Notional Lanes

These are notional parts of the carriageway which are used solely for applying the highway loading. They are determined according to Clause 3.2.9.3.1 of part 2 of the Code.

6.3 Load Modelling

There are a number of modelling schemes that one can use to get around most bridge loadings. The program GRID permits three types of loadings. Two element loads and one set of joint loads.

6.3.1 Element Loads

There are two permissible types of element loads:

(a) Uniformly distributed load acting perpendicular to the element regardless of its orientation relative to the global coordinates. This load may act from the lower to the greater element joint numbers or partially along the element. As demonstrated in figure 6.1, this load acts parallel to the global Z-axis. To be consistent positive loads are in the positive direction of gravity and therefore are given positive value downwards.

(b) The second type of element load is discrete point loads. The load must act vertically and is positive in the gravity sense. No restrictions on the maximum number of point loads allowed per element. Element point loads are located from the lower joint number relative to the local coordinate axes. An illustration of element point loads is seen in figure 6.2.

Note that element loads always act perpendicular to the element and thus follows the local axis sign convention. The positive element x-axis is drawn from the lower to the greater joint number. The positive element y-axis is drawn 90 degrees counter clockwise to the positive element x-axis.

6.3.2 Joint Loads

There are three permissible types of joint loads. They are:

(1) Moment about X-global coordinate axis.

(2) Force in the Z-global coordinate axis.

(3) Moment about Y-global coordinate axis.

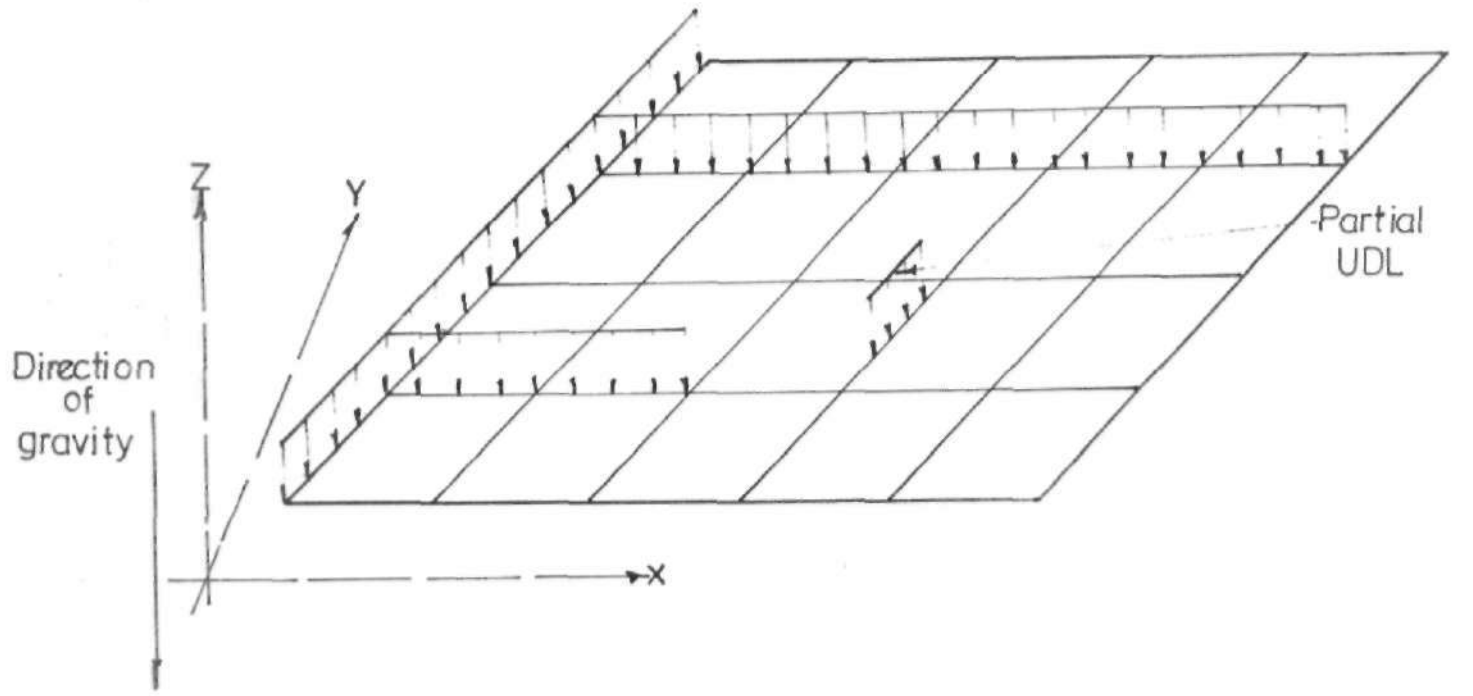


Fig. 6.1: Element Uniformly Distributed Load - UDL on 20°-Skewed Deck

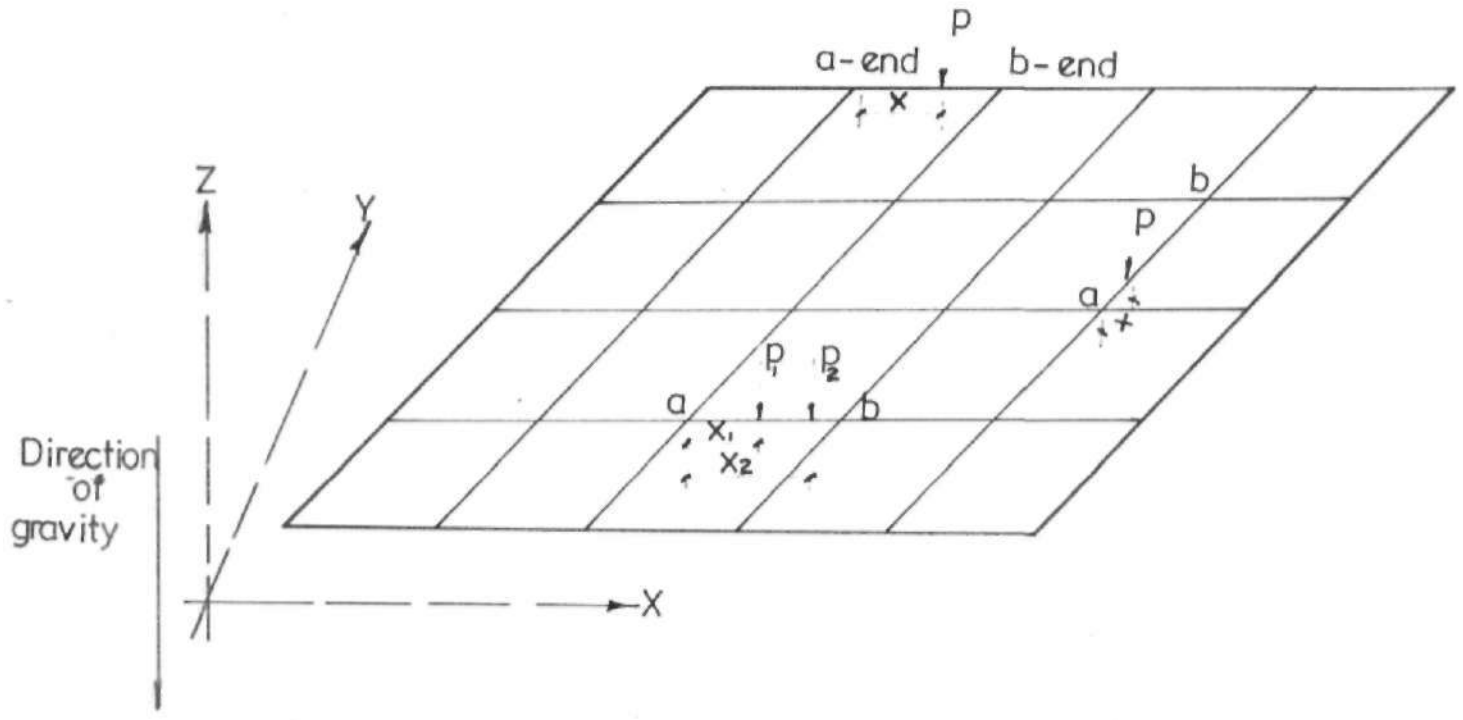


Fig. 6.2. Element point loads on a 20°-Skewed Deck

These three forces comprise one loaded joint. This concept is important when inputing data for joint loads. Specifically, the program asks for loaded joint number and these three forces. Joint loads are input with respect to the global coordinate system. The global coordinate system was initially used to generate joint coordinates (section 4.2.2). Relative to this system, the positive sign convention for joint loads is described in figure 6.3

6.3.3 Other Loads Modelling

If GRID does not contain provisions for the element load required, then it is possible to calculate fixed-end forces by hand and use the principle of superposition. It merely requires that the user solves the equivalent fixed-end forces. These forces "R" are then input as joint loads. The problem is then executed. Finally, the solution is complete when negative values of forces "R" are added to the computer results for the element with the particular element load. This is illustrated diagrammatically in figure 6.4.

6.3.4 Load Modelling Limitations

There are a number of load modelling limitations for GRID. One obvious limitation on member point loads is that they have to be parallel to the gravity. This is illustrated in figure 6.5. This limitation is inherent in the modelling of grillages. However, non-gravity parallel loads are hardly encountered and therefore are not considered in this study.

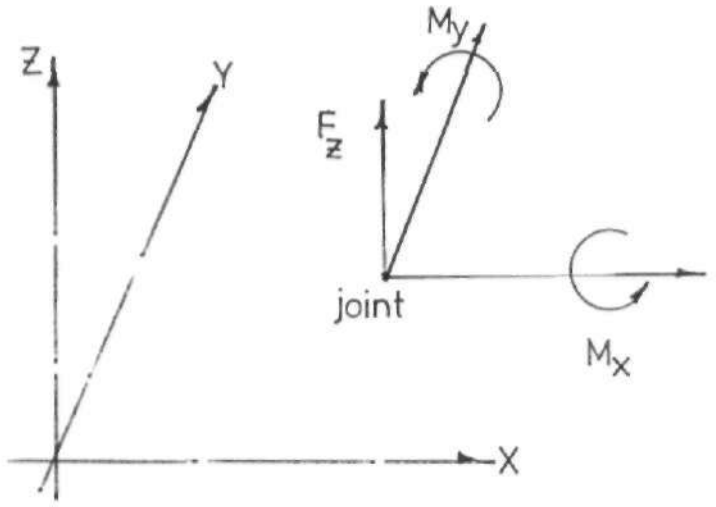
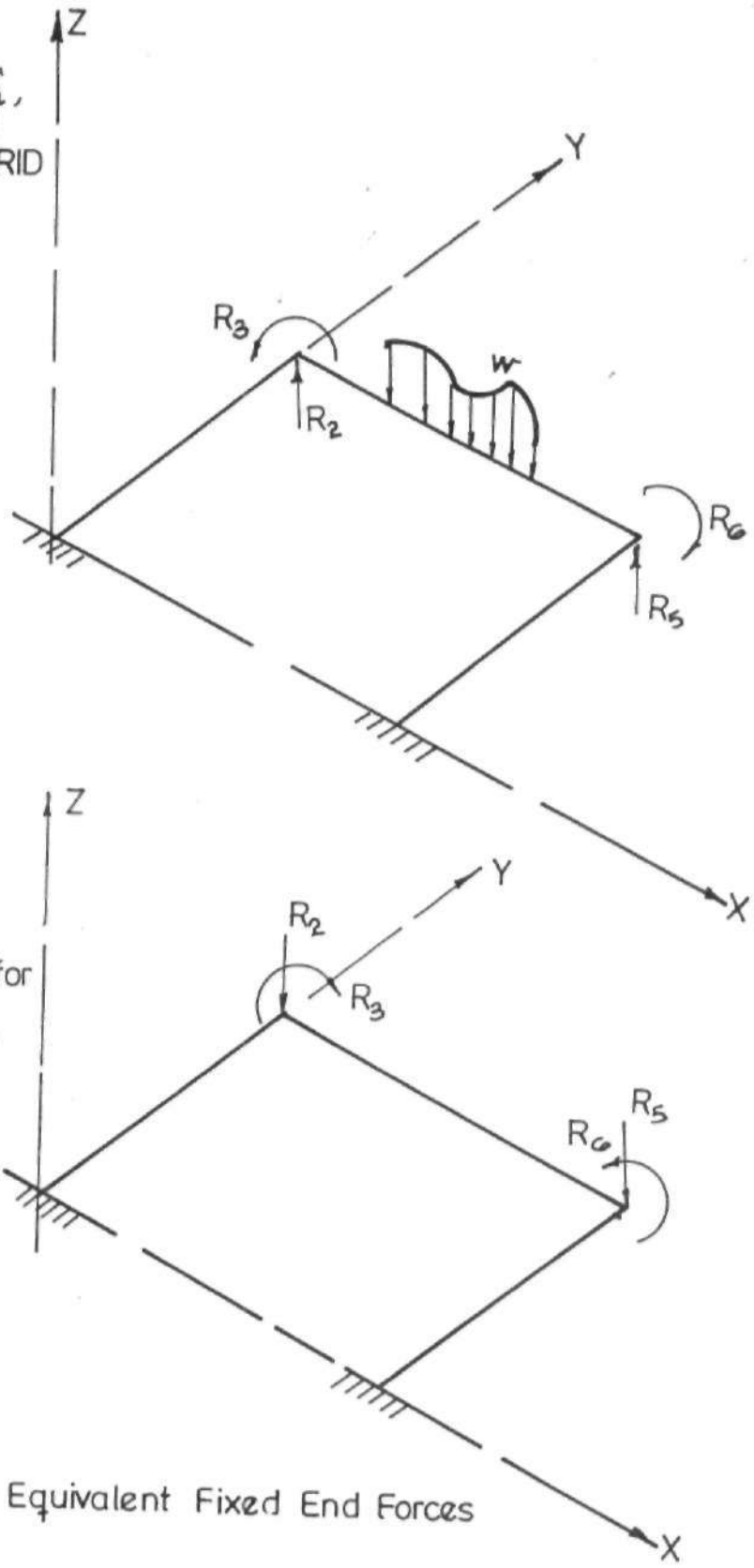


Fig. 6.3: Joint Load Sign Convention

a. Resolve "w" into components of "R_i^*", input as joint load data and execute GRID



b. Add "-w" to the calculated results for the element-end actions for correct results

Fig. 6.4: Solving Equivalent Fixed End Forces

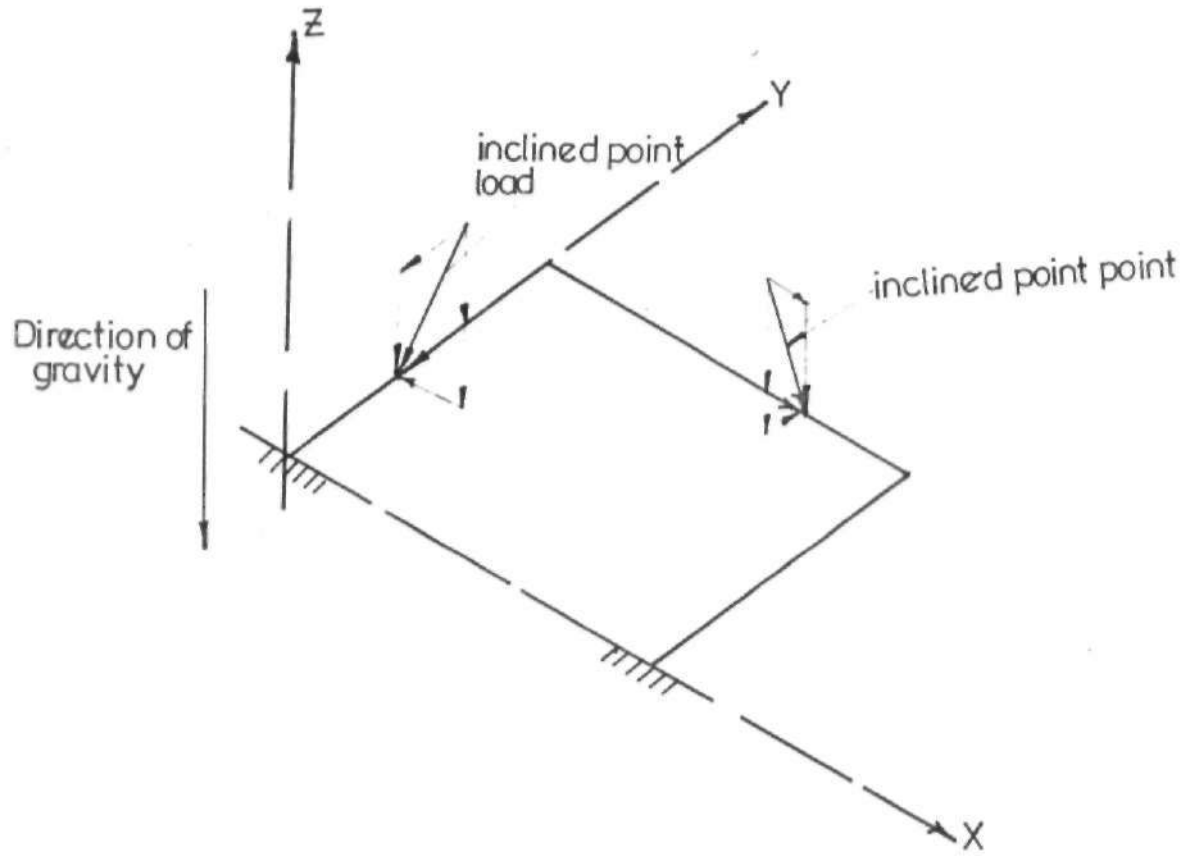


Fig. 6.5: Load Modelling Limitation - Non-gravity parallel loads

6.4 Permanent Loads

6.4.1 Dead Load

The nominal dead loads will generally be calculated from the usual assumed values for the specific weights of the materials, for example 24 KN/m3 for concrete. When such assumed values are used it is necessary, at the ultimate limit state, to adopt a partial safety factor of 1.2 for concrete, Clark (1983) , rather than the value of 1.15 given in Table 1 of the Code. The later value is only used when the nominal dead loads have been accurately assessed from the final structure. Such an assessment would require the material densities to be confirmed and the weight of, for example, reinforcement to be ascertained.

Modelling Dead Load

Dead Load is considered to act as a uniformly distributed load on the whole bridge deck. However, the descretisation of this load is considered to act on only elements along the main girders, since finally the load is going to be converted into equivalent joint loads for the whole deck. For the transverse elements, only the elements along the edges, which carry the diaphragms are assumed to be loaded. Dead Load discretisation is illustrated in figure 6.6.

6.4.2 Superimposed Dead Load

This load consist of mainly the surfacing on all the lanes. The partial safety factor of 1.75 given in Table 1 of the Code for superimposed dead load appears to be rather large. The reason for

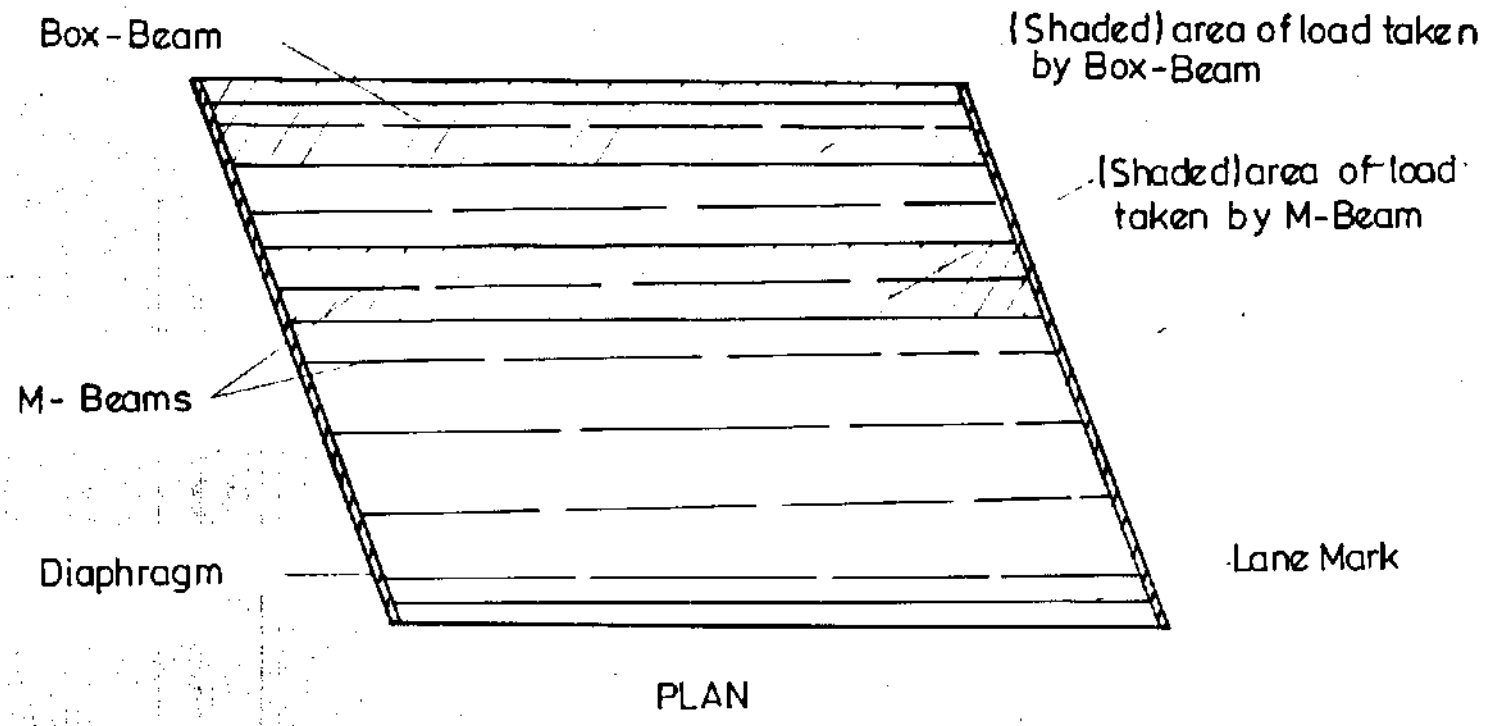


Fig. 6.6: Dead Load Modelling

this is to allow for the fact that bridge decks are often resurfaced, with the result that the actual superimposed dead load can be much greater than that assumed at the design stage, Clark (1983).

Modelling Superimposed Dead Load

Superimposed dead load acts as a uniformly distributed load on all traffic lanes, therefore, care must be taken to load only elements that falls within these lanes. This is illustrated diagrammatically in figure 6.7.

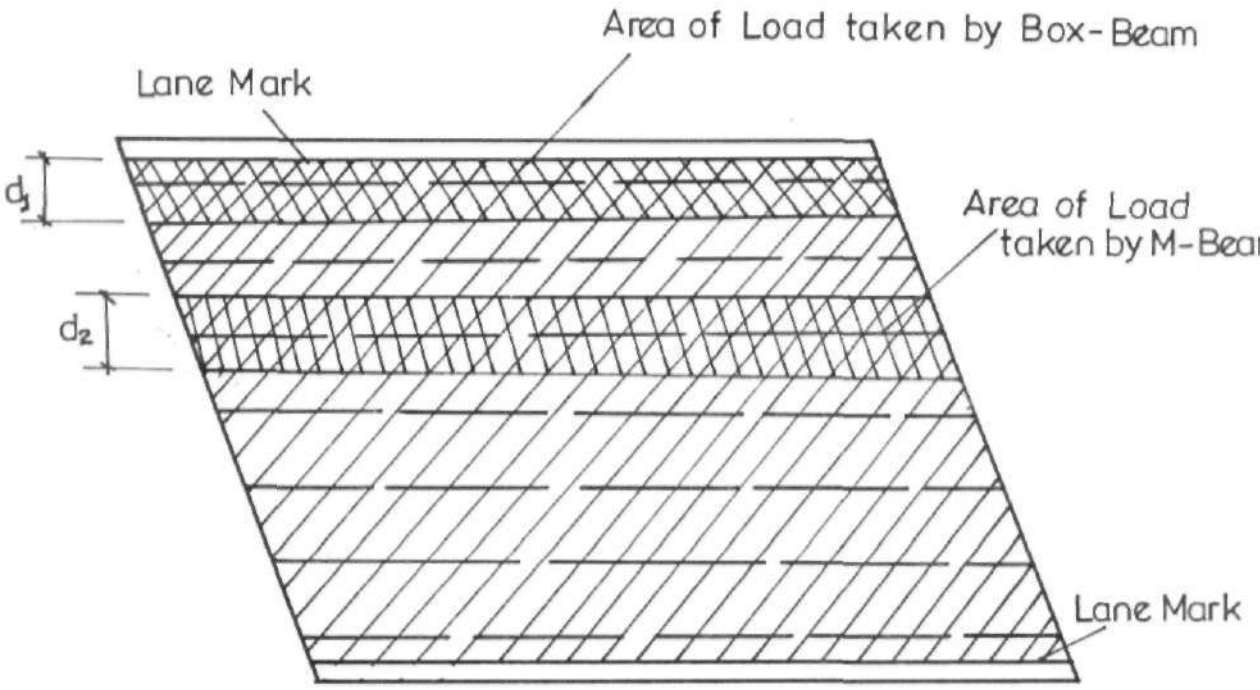
6.5 Primary Highway Loading

The primary effects of highway loading are the vertical loads due to the mass of the traffic, and are considered as static loads. Footway or Pedestrian loading on sidewalks is also discussed in this section.

The standard highway loading consists of normal (HA) loading and abnormal (HB) loading. Both of these loadings are deemed to include an allowance for impact. The partial safety factors of 1.2 and 1.1 are given in Table 1 of the Code for HA and HB loadings, respectively.

6.5.1 HA Loading

HA loading is a formula loading which is intended to represent normal actual vehicle loading. The HA loading consists of either a uniformly distributed load plus a knife edge load or a single wheel load. Only the former option has been considered in this study.



Uniformly Distributed load on each element along:

(a) Box - Beam = Material unit weight (KN/m^2) $\times d_1$ (KN/m)

(b) M - Beam = Material unit weight (KN/m^2) $\times d_2$ (KN/m)

Fig. 6.7: Superimposed Dead load Modelling

Uniformly Distributed Load

The uniformly distributed component of HA loading is 30KN per linear metre of notional lane for loaded length (L) up to 30m and is given by 151(1/L) 0.475 KN per linear metre of notional lane for longer lengths, but not less than 9KN per linear metre.

It should be noted that the loaded length referred to above is the length of the base of the positive or negative portion of the influence line for a particular effect at the design point under consideration.

Knife-Edge Load (KEL)

It is emphasised that the knife edge part of HA loading is not intended to represent a heavy axle, Clerk (1983) , but is merely a device to enable the same uniformly distributed loading to be used to simulate the shearing and bending effects of actual vehicle loading. The Code value of this is 120 KN per notional lane. The load per metre is always obtained by dividing, by the notional lane width, as is thus in the range 31.6 to 52.2 KN/m.

The knife edge load is generally positioned perpendicular to the notional lane except when considering supporting members in which case it is positioned in-line with the bearings, and when considering skew decks, in which case it can be positioned parallel to the supporting members or perpendicular to the free edges.

Application of HA Loading

The full uniformly distributed and knife edge loads are applied to two notional lanes and one-third of these loads to all other notional lanes.

Modelling HA Loading

It must be emphasised that in matrix displacement method of analysis, all loadings are converted to equivalent joint loads by the program. Hence, the uniformly distributed load component of HA loading is considered to act as uniformly distributed load on only elements along the main girders that fall within the notional lane concerned. The KEL component is positioned parallel to the supporting members to facilitate data preparations. Figure 6.8 illustrates the descretisation of HA loading on a bridge deck.

6.5.2 HB Loading

HB loading is intended to represent an abnormally heavy vehicle. The nominal loading consists of a single vehicle with 16 wheels arranged on four axles. Refer to figure 11 of the Code, reproduced here as figure 6.9. It can be seen that the transverse spacing of the wheels on an axle has been rounded-off to 2.0m, and that the overall width of the vehicle is given as 3.5m. The latter point means that it is not necessary to specify a minimum distance of the vehicle from a kerb, as is necessary in previous codes. However, the most significant difference is that the longitudinal spacing of

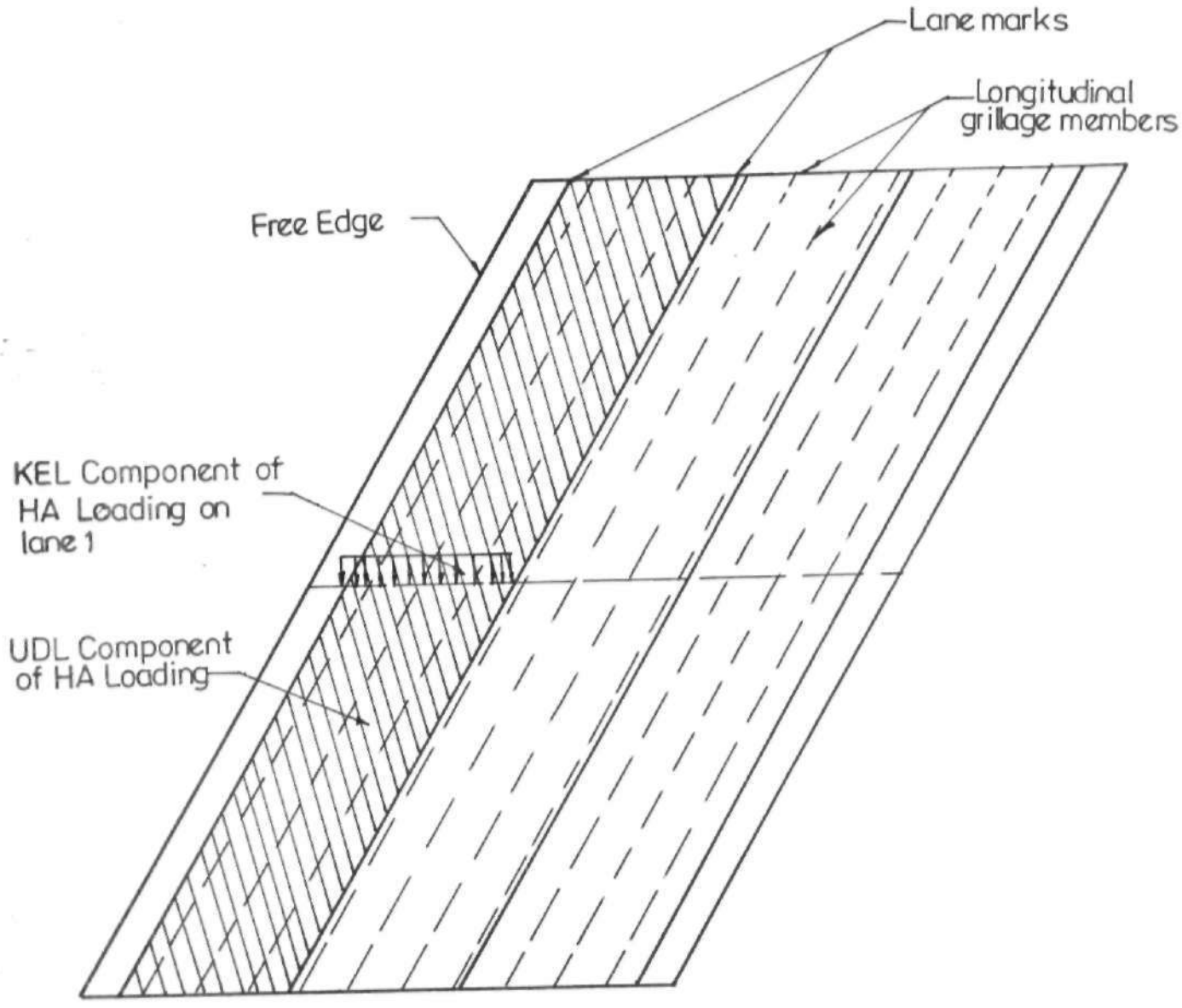


Fig. 6.8: HA Loading Model

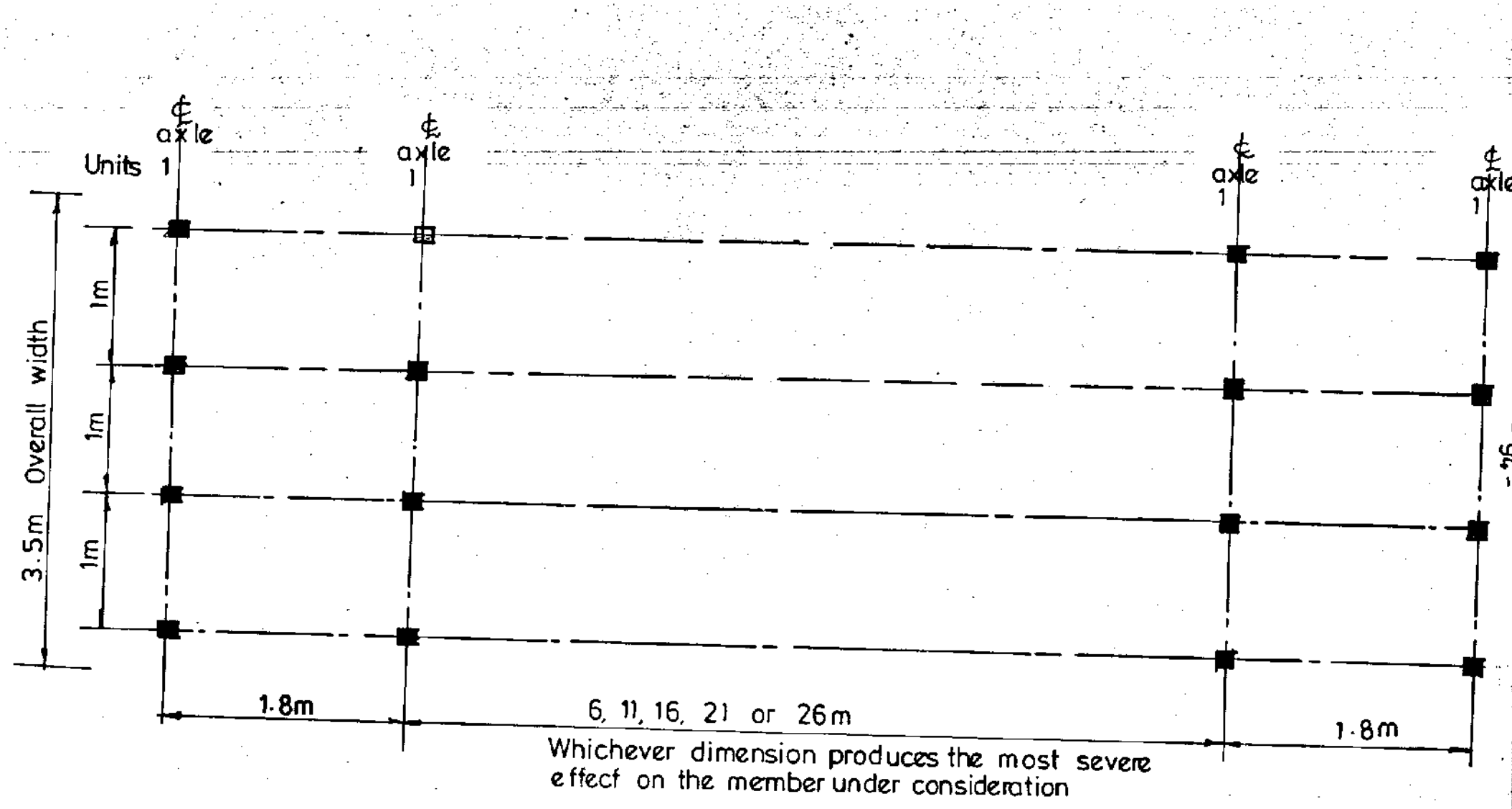


Fig. 6.9: Dimensions of HB Vehicle [BS5400(1978)]

the centre pair of axles is no longer constant at 6.1m, but can be any of the five values between 6 and 26m inclusive. The reason for this is that the BE 1/77 vehicle originated in BS 153, which was intended for simply supported bridges (although, in practice, it was also applied to continuous bridges) and the worst effects in a simply supported bridge occur with axles as close together as possible. However, since the code is intended to be applied to any span configuration, available spacing has been specified, in order to calculate the worst effects at all design points. As an example, the worst effects at an interior support of a continuous bridge could occur with a wide axle spacing.

The nominal HB loading is specified, in terms of units of loading, with one unit being equivalent to a total vehicle weight of 40KN. The number of units for all roads can vary from 25 to 45.

Application of HB Loading

Only one HB vehicle is, in general, required to be considered on any one superstructure, or any substructure supporting two or more superstructures. The vehicle can be either wholly in a notional lane, or can straddle two notional lanes. If it is wholly in a notional lane, the knife edge component of HA loading for that lane is completely removed, and the uniformly distributed component is removed for 25m in front to 25m behind the vehicle; the remainder of the lane is loaded with the uniformly distributed loading component of HA having an intensity appropriate to a loaded length which includes the displaced length. The vehicle is thus considered to displace part of

the HA loading in one lane, but the adjacent lane is still assumed to carry full HA loading. This is more severe than the BE1/77 loading, where the adjacent lane carries only one-third HA loading.

If the vehicle straddles two lanes, then it is considered to straddle either the two lanes loaded with full HA, or one lane with full and one with one-third HA; in each case the rules of omitting parts of the HA loading are applied.

The reason for the more severe arrangement of the accompanying - HA loading is that, in practice, queues of heavy vehicles accumulate behind abnormal loads and when they overtake, they do so in a platoon, Clark (1983).

It should be noted that, when HA loading is applied with HB loading, the partial safety factor for HA is the same as that of HB.

Modelling HB Loading

Discretisation of HB loading is achieved by placing the vehicle on a notional lane, with its centre of gravity at the midspan of a main girder, whose maximum bending moment is being sought for. As shown in figure 6.10, the wheels may not necessarily fall on the main girders as concentrated loads. Hence the principle of superposition must be used to distribute these loadings on the main girders as concentrated loads.

6.5.3 Footway Loading

Footway loading consists of mainly the pedestrian live load, applied only on the sidewalks. The nominal value for loaded lengths

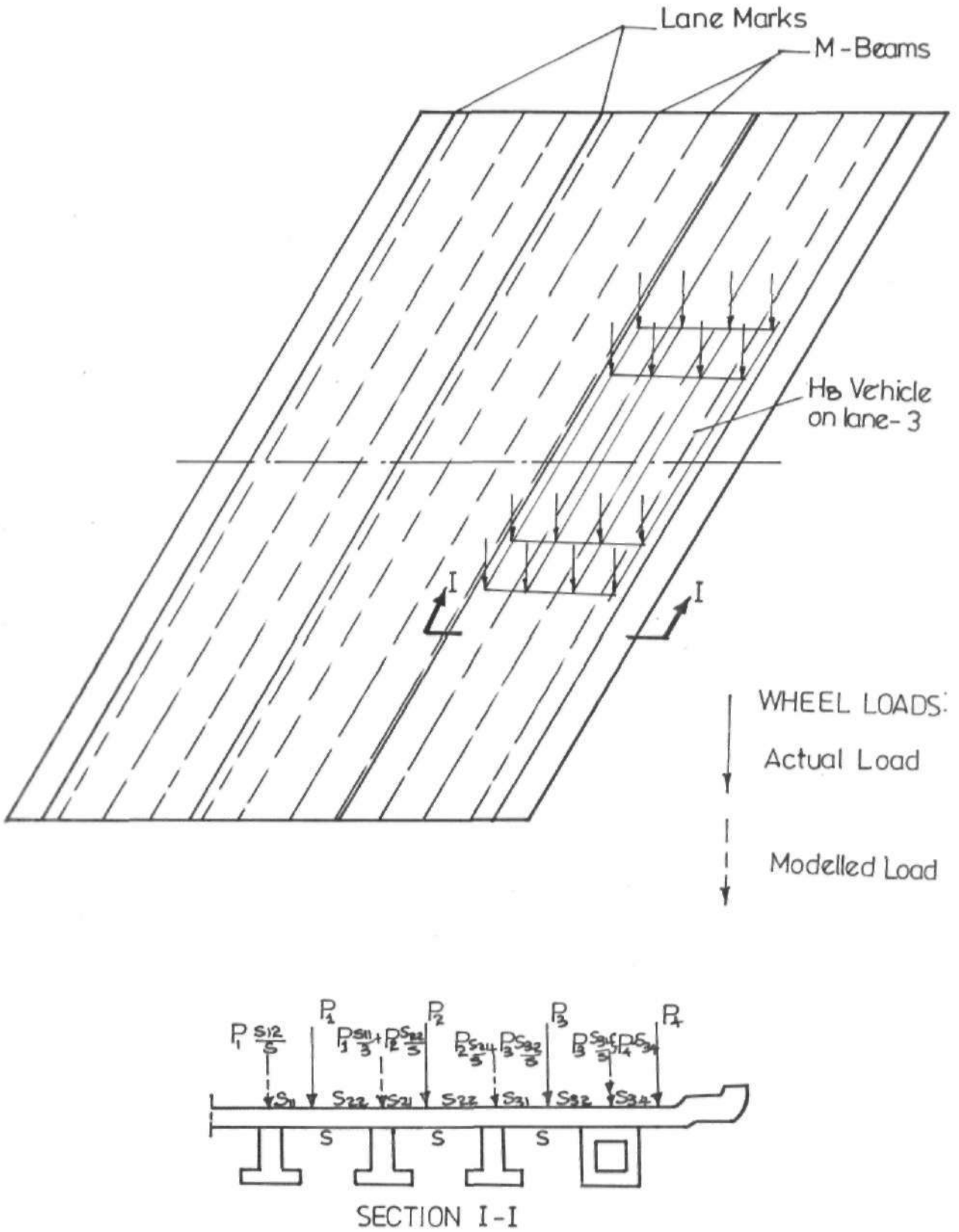


Fig. 6.10: HB Vehicle Modelling

of 30m and under, is a uniformly distributed live load of 5.0 KN/m2. For loaded lengths in excess of 30m, it is given by K* 5.0 KN/m2, where K is the

$$\frac{\text{Nominal HA UDL for Appropriate Load Length (in KN/m)}}{\text{30 KN/m}}$$

The descritisation of this load takes the form of applied joint loads (Mx), since the loading is outside the grillage layout and may be considered as cantilevered. See figure 6.11 for more details.

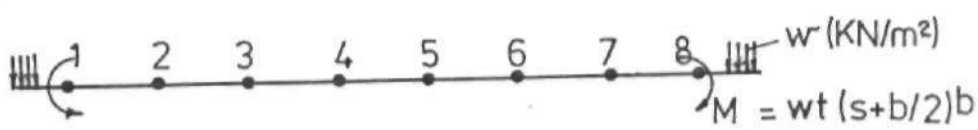
6.6 Load Cases and Combinations

With reference to the example given in Appendix II, and the design loading given in part 4 of the code, load cases considered in this study are as follows:-

Load Case	Description
1	Seft weight only
2	Superimposed dead load
3	Pedestrian
4	HA + KEL on lane 1
5	HA + KEL on lane 2
6	HA + KEL on lane 3
7	HB on lane 3.

Load combinations and their partial safety factors are chosen so as to aid checking the strength of members at the ultimate limit state and to satisfy the requirement to check stresses and crack widths at the serviceability limt state.





SECTION I-I

Fig. 6.11: Footway Load Modelling

The load combinations to be considered at the ultimate limit state may be taken as follows:

	Load Combination	Safety Factor
1.	Self weight only	1.2
2.	Superimposed dead load	1.75
3.	Pedestrian	1.5
4.	HA + KEL on lane 1	1.5
5.	HA + KEL on lane 2	1.5
6.	HA + KEL on lane 3	1.5
7.	HA + KEL on lane 3	1.3
8.	(4) + (5) + 1/3 (6)	1.0
9.	(7) + (5) + 1/3(4)	1.3
10.	(1) + (2) + (3) + (8) + (9)	1.0

At the serviceability limit state, the widths of cracks are controlled primarily for durability purpose, Clark (1983), therefore, it is logical to define the design loading as that which can be considered to be virtually permanent rather than that of occasional but more severe loads. This is because, after the passage of occasional severe loads, the crack widths return to their values under permanent loading provided that the reinforcement remained elastic during the application of the occasional load. Since the limiting reinforcement stress is 0.8fy, Clark (1983), the reinforcement will remain elastic.

The code considered that crack widths should be checked under full HA loading together with pedestrian loading, dead load and

superimposed dead load. When the appropriate partial safety factors are applied, the resulting design load is:

Dead load + 1.2 * (Superimposed dead load) + 1.0 * (HA) + 1.0 * (Pedestrian Loading).

Hence, load combinations to be considered at serviceability limit state are as follows:

	Load Combination	Safety Factor
1.	Self weight only	1.0
2.	Superimposed dead load	1.2
3.	Pedestrian	1.0
4.	HA on lane 1 + HA on lane 2 + 1/3 HA on lane 3	1.2
5.	HB on lane 3 + HA on lane 2 + 1/3 HA on lane 1	1.1
6.	(1) + (2) + (3) + (4)	1.0

Chapter 7

SIMPLIFIED ANALYSIS OF SKEWED-BRIDGE DECKS

7.1 Introduction

The analysis and design of skewed-bridge decks is of considerable importance and practical interest. Greater speeds on highways with their more exacting safety requirements, demand better alignment. In order to achieve this, skew-bridges are frequently built. In view of the considerable interest expressed by designers in skew bridges, it is considered essential to have a better understanding of the stress distribution in such structures, and if possible to have a simplified method of analysis. This study, therefore intended to make an investigation in such structures of various configurations (angle of skew, spans, materials properties) and their behaviour under various loading conditions.

Before the advent of the electronic computer, bridge elements were analysed by the force method. However, when torsion resistance is present as is the case in skew decks, and should be included in the analysis, then the degree of indeterminacy becomes very high and the compatibility conditions are more cumbersome to establish. Thus the common assumption is to neglect torsion, a practice which yields reasonable answers for bending and deflection but gives no indication as to the amount of torsion. In such cases, a nominal amount of torsional moment is usually provided for in the design process.

With the convenience in the application of the matrix displacement method on the computer, analysis of bridge elements with

or without torsion, becomes rather a simple matter so far as making up the input is concerned.

This study is concerned with the customary situations in which the arrangement and proportions of the structural elements and the support conditions are known. In practice, however, first the designer uses a preselected bridge deck with preliminary member sizes, which is then analysed under various loading conditions. From the analysis, member forces and displacements are obtained. The second step involves selecting new member sizes that are designed using the results of the first analysis. The analysis is repeated, using the new member sizes to check final member forces and displacements. This process is repeated until the designer is satisfied of the adequacy of the design.

The proposed simplified method follows the same pattern, but no calculation need to be performed in the analysis phase. Instead, the designer can identify a particular chart and read directly the value of the structural response concerned without performing any rigorous analysis. Freed from time consuming calculations, a number of different schemes of proposals can be processed in a short time, thus allowing the designer to devote himself to planning, evaluating results and decision making.

To achieve all the stated objectives, a careful planning and development of a computer program is necessary. A program GRID has been developed (chapter 5) and presented in Appendix III. The computer code is such that corresponding to each type of skewed-bridge geometry, and each type of material properties, the design be obtained

with minimal effort by the designer. Furthermore, it allows reinforcement to be proportioned for longitudinal and transverse flexure as well as stirrups to be proportioned for longitudinal shear and torsion.

The research procedure and methods of determining bridge responses are discussed in the following sections.

7.2 Research Procedure

Different standard configurations were selected for a detailed computer analysis. Many other types are, of course, possible; some could be more sophisticated in their layout, but unfortunately also more complex in their construction and therefore of less interest to practising engineers.

Much work has been done in the manufacture of standard prestressed beams for bridge construction. The most popular ones have been those developed by the British Ministry of Transport in cooperation with Cement and Concrete Association. See Somerville (1970) and Dow-Mac (1981). Two of these standard beams (M- and Box-Beams) have been utilised in this study to cover the range of spans 15 to 30m. The beams are placed at 1.0m centres with the Box-beams as external girders, while internal girders are made-up of M-beams. In-situ concrete top-slab is then used to cover these beams, so as to achieve a T-beam form of construction, Allen (1978).

There is a little doubt that for spans up to approximately 16m some form of slab construction offers the greatest economy, Somerville (1970). However, when the angle of skew is heavy and/or the span is

longer than 15m, standard prestressed beams and in-situ slab provide a very efficient form of construction. In-situ construction is possible, but more flexible methods of using post-tensioning are preferable, Allen (1978).

The solid slab bridge provides the maximum moment of resistance for given depth but at the cost of using a large part of its material inefficiently, while in standard prestressed beam-slab bridges, where although the overall depth will be greater than that of a solid slab, the material is used much more efficiently and less prestressing force is required, Allen (1978).

This study assumes the usual iterative design procedure, Abatan and Abubakar (1985). This procedure is illustrated in figure 7.1. However, here we are concerned with situations in which the geometry of the skewed-bridge that is in better alignment with the highway has been chosen. Next the arrangement and proportions of the structural members have been chosen in accordance with Cement and Concrete Association's requirements (see Somerville (1970) for more details). The standard support conditions are known to be simply supported. Usually the total span of the bridge is divided into simply supported spans within the range of 15 to 30 m. Hence, the geometrical properties of materials could be obtained from the standard specifications [Somerville (1970)] for the corresponding range of spans. The standard spans used in this study are 15 - 30m at step of 3m and that of skew angle increments at 5° from 0° to 45° maximum in order to minimize the cost of skew ended beam (see Dow-Mac (1981)). In addition, the material properties (Young's modulus and shear

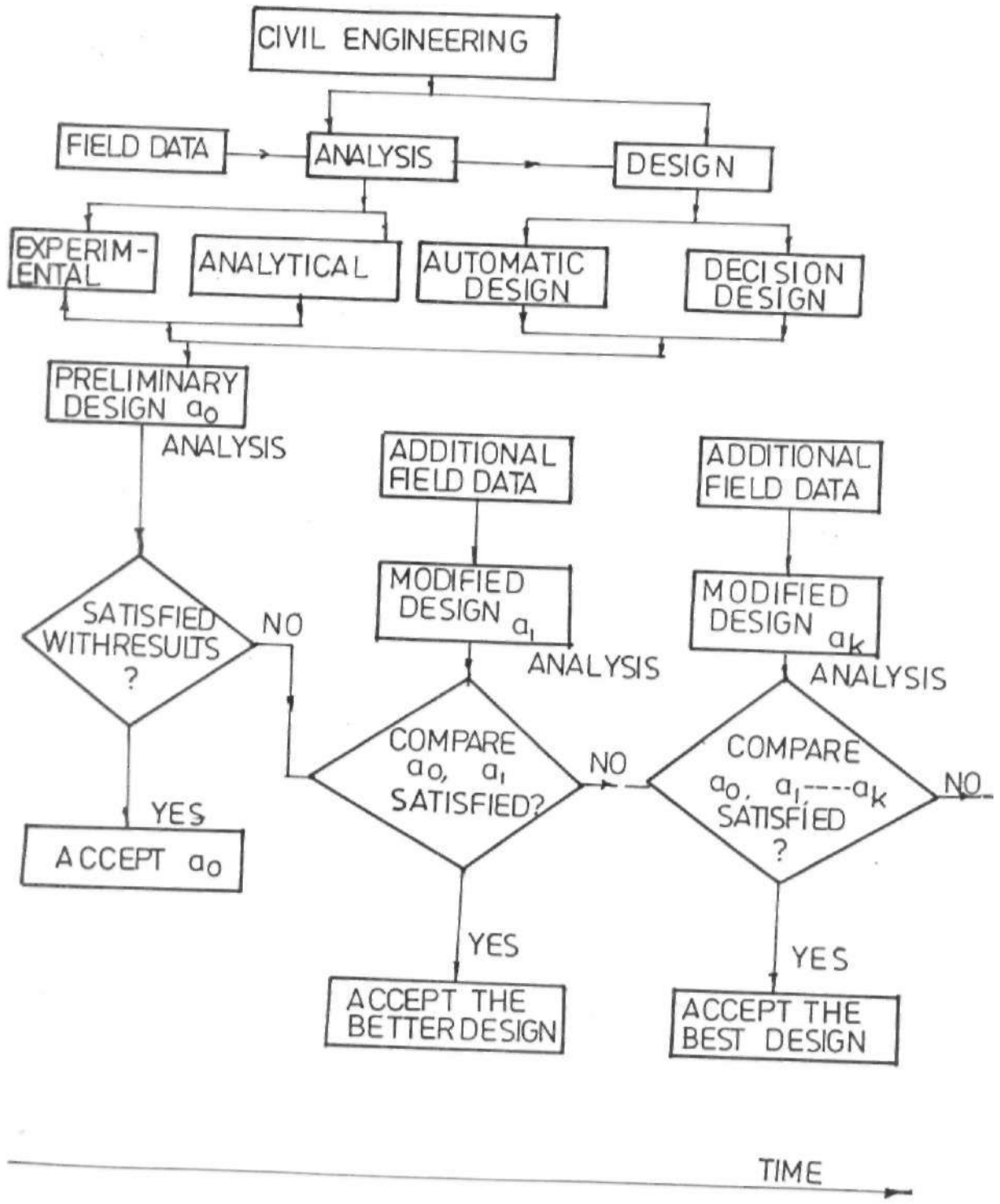


Fig. 7.1: ITERATIVE DESIGN/ANALYSIS PROCESS IN CIVIL ENGINEERING

modulus) are assumed to be those at 28-day cube strength of 50 N/mm2.

Knowing the geometry, the geometrical properties, support conditions and loadings (chapter 6), all the necessary input data needed to execute the program GRID are now completed. These data are then inputed into the program and executed. Finally, the responses (displacements, bending moments, shear forces and twisting moments) are obtained and tabulated into the appropriate charts (to be presented and discussed in the later sections).

7.3 Methodology of Determining Responses

Bridge responses need to be determined are such quantities as displacements, longitudinal bending moments, shears, twisting moments and their transverse counterparts. Bending moments which cause flexure in a longitudinal vertical plane are referred to as longitudinal moments. It is to be noted that the longitudinal direction corresponds to the direction of traffic flow on the bridge. The term longitudinal shears refers to the vertical shear in a longitudinal strip of the bridge. The support reactions refers to longitudinal shears at the supports. Bending moments in the direction perpendicular to the flow of traffic are referred to as transverse moments.

These quantities are given for one repetition of a pattern. That is, considering one girder together with that part of the slab which belongs with that girder (the portion of slab up to the midpoint between the girder and its neighbours on either side), and the responses are considered in terms of this portion of the total bridge.

An advantage of using the simplified method is that it gives the designer a direct insight into the physical behaviour of the structure. The physical significance of the various responses, and methods of obtaining them now follows.

The simplified method differentiate between external and internal portions of the cross section of the bridge. The external portions refer to the outer girders, and the internal portions to the inner ones. The method given herein has been developed for three-lanes highway bridges of various load combinations (section 6.6). The girder which produces the maximum span and quarter span responses is the governing one. Governing load combinations in skewed bridges for different spans are given in Appendix IV).

The various steps in determining bridge responses are illustrated in figure 7.2 They are as follows:-

1. Obtain the angle of skew from the alignment of the highway with the proposed bridge.
2. Divide the total bridge span into simply supported spans within the range of 15 - 30 metres.
3. Choose the main girders from standard configurations, Dow-Mac (1981) and obtain their geometrical properties.
4. Use Appendix IV to determine the various responses.
5. If these responses are not within the allowables, then GOTO step 3.
6. ELSE design the structural elements.
7. If the design is alright, THEN STOP.
8. ELSE GOTO step 2.

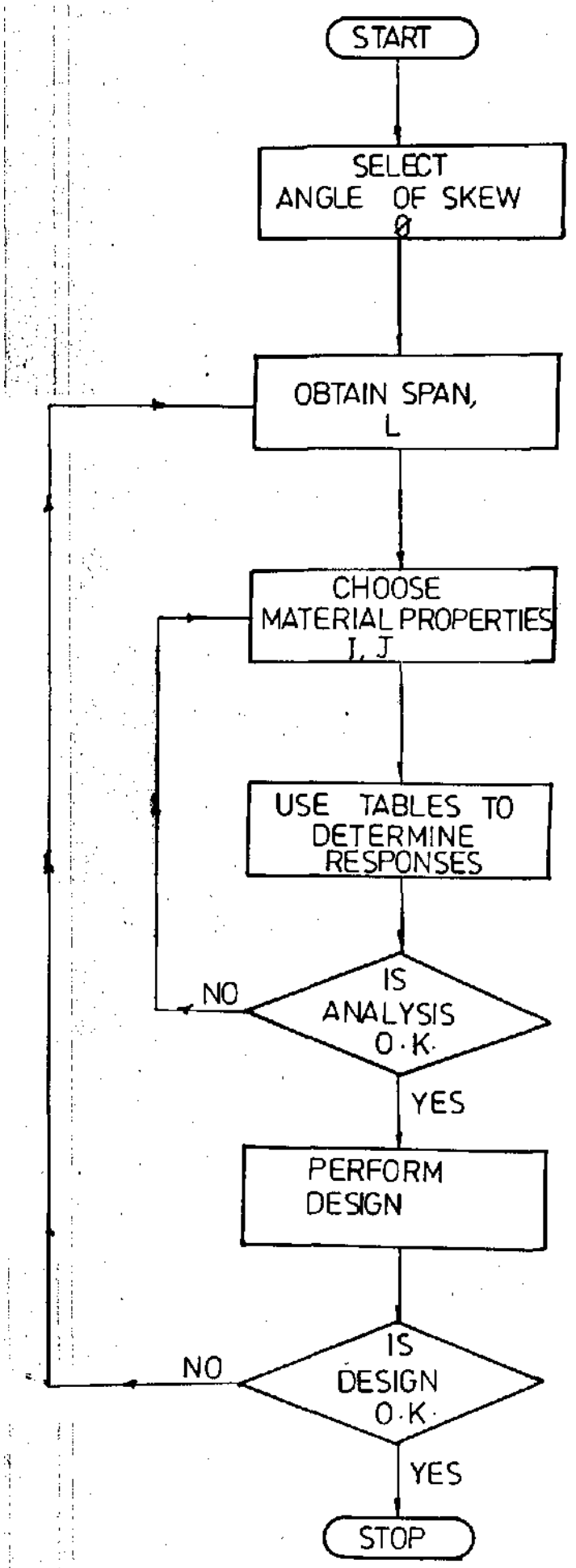


Fig. 7.2: Steps in Determining Bridge Responses Using Simplified Approach

Chapter 8

CONCLUSION

The study presents the fundamentals of matrix displacement method which could be easily extended to a more general technique of Finite Element Method (FEM). It offers efficient and practical tool for the analysis of skewed bridge decks, which poses specific difficulties in their response to torsional motions when the skew angle is greater than 20°. All the salient characteristics of such structures and their responses have been preserved in the modelling technique. The technique has been used to assess the adequacy of a proposed design with respect to strength and stiffness by methods which are more economical than the obvious way of constructing and testing a prototype.

All the three distinct components of a model: the conditions of compatibility, the conditions of equilibrium and the constitutive laws, that represent significant features of a stracture have been incorporated into the idealisation. A skew system of grillage beams have been used to idealise skewed-bridge decks, so as to correspond with reinforcement layout and ease automatic data preparations. The skew system also reduces the cost of computing time.

The matrix displacement method has been presented in a form which makes it suitable for the automatic computer analysis of any bridge deck that is represented as an assemblage of discrete interconnected elements. An efficient procedure has been formulated and automated for the assembly of element models into the system

models.

In addition, efficient programming methods have been used to effectively utilise the available hardware in the program development and implementation phases. The code shows all important features of more general codes, such as FEM programs.

The general philosophy governing the application of loading to BS5400, its modelling and discretisation on bridge decks have been fully presented. Moreover, load cases and combinations necessary to aid the design at both ultimate and serviceability limit states are discussed.

After the presentation of the general theories of matrix displacement method, its implementation on the computer and general bridge loadings, a simplified approach to the use of these tools is then provided and made available to the designer, without the need for performing complicated analysis in the design office.

The simplified approach follows the customary iterative design procedure. However, here no calculations need to be performed in the analysis phase. Suitable charts are used to substitute this phase. Having preselected a skew-bridge structure, the designer can then identify a particular chart and read directly the value of the structural response concerned without performing any rigorous analysis.

Clearly a great economy of time and effort is achieved, if for structures such as heavy skewed-bridges, which could not be analysed by classical methods, much detailed computer analysis can be replaced by the use of suitable charts.

It has been shown that the simplified approach can be used as an effective tool for systematic evaluation of alternative concepts and designs of a particular bridge deck in a relatively short time. Hence, it can guide the designer in selecting an economic structure from alternative designs.

It should be understood that most of the ideas presented are applicable to other structural systems. They could be used as a research tool that provides insight into structural behaviour and formulation of problems in a systematic manner.

Finally, it is hoped that engineers engaged in highway bridge design would find the information contained in this study much valuable.

Chapter 9

RECOMMENDATIONS

The simplified approach appears to be an especially useful tool for bridge designers. The difficult problem of the response to skewness is analysed simply and efficiently. Infact, one happy feature with all numerical procedures in structural analysis is that once the element model has been made to incorporate all the significant parameters, then it is easy to obtain a simplified method of analysis based on the chosen parameters to cover the whole range of structural types concerned. For example, if for skewed bridges, the span, skew angle and material properties are all inherent in the element model, then a more general simplified method is possible.

The concept of characterising parameters, discussed by Bakht and Jeager (1985), could be conveniently used to achieve this objective. For instance, the concept might be used to formulate the relationships that must exist between structural properties of two structures (i.e., such properties as the flexural and torsional stiffnesses of individual members) in order that they may have the same pattern of response (deformations) when subjected to the same pattern of action (load).

Consider a situation in which the element stiffnesses are modified on account of changes in cross-sectional properties or material properties. If the grillage is subjected to a given external loading, the problem of finding the responses may be expressed by the local element model as

$$\{ f \} = [k]\{ d \} \qquad (9.1)$$

Where [k] is the stiffness matrix, {d} is the displacement vector, and {f} is the force vector.

or

$$[k] = \begin{bmatrix} kaa & kab \\ kba & kbb \end{bmatrix}$$

$$= \alpha \begin{bmatrix} \beta & 0 & 0 & \beta & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ \beta & 0 & 0 & \beta & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix}$$

and

$$\alpha = EI/L^3 \quad , \quad \beta = GJ/EI*L^2 \quad , \quad \gamma = \alpha\beta = GJ/L$$

If the changes to the original stiffness matrix [k] are denoted as $[\delta k]$, the new stiffness equation can be written in the form:

$$\{f\} = [\,[k] + [\delta k]\,]\{d\} \qquad (9.2)$$

Note that in this development the load vector, {f} is assumed to be unaltered by the changes in dead load due to changes in member sizes represented in $[\delta k]$.

Also observe that in the light of the material properties, the stiffness matrix is a function of α and β. Therefore, if in a grillage number 1, the two parameters are identified as α_1 and β_1, and in a corresponding grillage number 2, the corresponding parameters are identified as α_2 and β_2 respectively, then the stiffness matrix could be made to be a function of one set of these parameters, say α_1 and β_1, and the ratios between this set and that of the other grillage, say $\alpha_r = \alpha_1/\alpha_2$ and $\beta_r = \beta_1/\beta_2$.

Hence from equations (9.1) and (9.2), it can be readily shown that the modified parameters on account of modified stiffness could be written as:

$$\alpha = \alpha_2 - \alpha_1 \quad ; \quad \alpha_2 \neq \alpha_1 \tag{9.3a}$$

and

$$\beta = (\alpha_2\beta_2 - \alpha_1\beta_1)/\alpha \quad ; \quad \alpha_2\beta_2 \neq \alpha_1\beta_1 \tag{9.3b}$$

letting $\alpha_r = \alpha_1/\alpha_2 \quad ; \quad \alpha_2 \neq 0$

and $\beta_r = \beta_1/\beta_2 \quad ; \quad \beta_2 \neq 0$

Equations (9.3) become:

$$\alpha = \alpha_1/\alpha_r*(1 - \alpha_r) \quad ; \quad \alpha_r \neq 1 \tag{9.4a}$$

and

$$\beta = \alpha_1\beta_1/\alpha_r\beta_r*(1 - \alpha_r\beta_r)/ \quad ; \alpha_r\beta_r \neq 1 \tag{9.4b}$$

These two parameters (Equations (9.4) are the characterising parameters for grillage behaviour, on account of modified stiffnesses, i.e. if two different grillages have the same values of α_r and β_r, then the two grillages will have the same patterns of distribution of deflections, shear forces, and bending and twisting moments when

subjected to the same pattern of load.

Similarly, once the span, width, and angle of skew have been characterised into the element model, then a more general simplified method could be achieved.

Furthermore, with the help of known practical ranges of these characterising parameters, it is easy to ensure that a simplified method of analysis is achieved. In other words, one intends to recommend the characterisation of all parameters involved in the analysis of a structural type concerned in order to achieve the objectives of simplified approach.

In addition, it may be worthwhile developing finite element models for the calculations of the nonlinear response of bridges subjected to static and dynamic loads. Finally, geometric as well as material nonlinearities of elastoplastic type should be considered in order to accomplish the desired objectives.

REFERENCES

Abatan A.O. and Abubakar A. (1985) "Computer-Assisted Civil Engineering Education at Ahmadu Bello University", Proceedings; First National Conference on Computer Applications, Lagos - Nigeria, Feb. 1985, pp. 46-53

Allen, A.H. (1978); An Introduction to Prestressed Concrete, Cement and Concrete Association, Publication 47.002.

Bakht, B., and Jeager, L.G. (1985), Bridge Analysis Simplified, McGraw - Hill, New York.

Bathe, K.J. (1975): "ADINA - A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis", Report 82448-1, Acostics and Vibration Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass, (rev. Dec. 1978).

Bathe, K.J, Wilson, E.L. and Peterson, F.E. (1974): "SapIV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems", Report EERC73 - 11, College of Engineering, University of California, Berkeley.

BS5400 (1978): British Standards Institution; Steel Concrete and Composite Bridges.

Clark, L.A. (1983): Concrete Bridge Design to BS5400, Construction Press, London.

Crandall, S.H., Dahl, N.C., and Landner, T.J. (1978): An Introduction to the Mechanics of Solids, 2nd ed., McGraw-Hill, New York.

Cusen, A.R., and Pama, R.P. (1975): Bridge Deck Analysis, Wiley, London.

Dow-Mac Concrete Limited (1981), Prestressed Concrete Bridge Beams, MCMLXXXI, U.K.

Hall, A., and Kabaila, A.P.: Basic Concepts of Structural Analysis, Pitman Publishing Limited, London.

Harrison, H.B. (1980), Structural Analysis and Design, Some minicomputer applications, Part I & II, Pergamon Press, Oxford.

Holzer, S.M. (1985): Computer Analysis of Structures, Brooks/Cole, Montreney.

Livesley, R.K. (1975): Matrix Methods of Structural Analysis, 2nd ed., Pergamon Press, Oxford.

Martin, H.C., (1966): Introduction to Matrix Methods of Structural Analysis, McGraw-Hill, New York.

Somerville, G. (1970): Standard Bridge Beams for spans from 7m-36m, Cement and Concrete Association, Publication 32.005

Tezcan, S.S. (1963), "Simplified Formulation of Stiffness Matrices", Journal of Structural Division, ASCE, Vol. 89, No. ST6, December 1963, pp. 445 - 449.

Wang, C.K. (1983): Intermediate Structural Analysis McGraw-Hill, New York.

West, R. (1973), "C. & CA/CIRIA Recommendations on the use of Grillage Analysis for Slab and Pseudo - Slab Bridge Decks", Cement and Concrete Assocation, Publication 46.017.

APPENDIX I

USER'S GUIDE TO PROGRAM GRID

I.1 Introduction

Program GRID is an engineering structural analysis program developed specifically for IBM PC microcomputer applications. Another version of the program runs on CDC Cyber 72 mainframe computer. The program is designed to analyse planar (two dimensional) grillages. It is intended to be used for routine day-to-day design. Several load cases and combinations may be specified. A load case includes element uniformly distributed loads, element point loads and joint loads.

The program utilizes the matrix displacement method of structural analysis. The computer formulates all necessary equations, solves them and stores the results. All data required by GRID to generate and analyse a structure is user-input via an input-data-file, created using either EDLIN text editor or any suitable word processor, such as Word Star. Categories of input data are given in Section 5.3.

Once the analysis is completed, GRID provides the results in an output-file. Joint displacements (deflections and rotations), Element-End forces (torsional, shear and bending moments) and Joint forces (applied and reactive) may be displayed numerically on the screen or printer. The numerical results output is formatted to allow a quick comparison of all displacements and forces created by each load combination, so that the most severe load combination on an element can quickly be obtained. In addition, output of results concerning particular joints or elements can be obtained easily.

I.2 Program Capacity

GRID has been desinged to handle large structural grillages through the efficient use of Random Access Memory (RAM). Using IBM PC with a minimum 256K RAM, GRID will successfully execute problems with the following parameters:

Maximum No. of Elements	=	360
Maximum No. of Joints	=	200
Maximum No. of supported Joints	=	60
Maximum No. of material Sections	=	50
Maximum No. of Load cases	=	10
Maximum No. of Load combinations	=	10
Maximum No. of point loads/element	=	3
Maximum half-band width * System degree-of-freedom	=	5500

I.3 GRID

To use GRID for grillage analysis the engineer must begin by modeling the grillage into data which can be recognised by the program. Structural modeling is covered in Section 4.2. Operation of the program involves (a). Creating a data file with a name DATA.Gnn, where nn represents any two characters - Structure Number - used for identification, (b). keying in data into the file, in accordance to the formats (to be presented in INPUT DATA, Section I.5) , and (c). Loading the program into the computer and executing the grillage analysis.

To load the program and execute, insert the GRID system disk and type

gr RETURN

The program will reply with :

Enter Data Disk Drive [A:, B:, C:]

Then type the appropriate data disk drive and RETURN. Note that the program reads input data and writes ouput files in this drive.

Next, the program displays:

Enter Structure Number [2 digits]

Now type the characters 'nn' used in creating the data file. Lastly, the program asks for the analysis disk drive [A:, B:].

Note that only floppy disk drives are allowed for the analysis, since the program utilizes Random Access files.

I.4 UNITS

Any consistent units may be used. However, it's worthwhile to note that the program automatically multiplies the sectional properties by 1.0E+06. Therefore, multiply sectional properties by 1.0E-06 before inputting. Note also that the output headings are in KN, m and radians, hence it is recommended to use KN, m and radians as consistent units.

I.5 INPUT DATA

All data-input are entered via either EDLIN (described in DOS Reference Manual) or any suitable word processor. The following sequence of data numerically defines the problem.

A. PROBLEM TITLE (A) - One line

Columns 1-50: Problem title to be printed with output.

B. JOINT COORDINATES

Refer to Section 4.2.2-3 for detailed discussion on joint coordinates and numbering.

(i) Columns 1-5: Option to generate joint coordinates automatically. Enter 1 for automatic generation, else 0

(ii) CONTROL INFORMATION FOR AUTOMATIC GENERATION - (2I5,3E10.0)

If 1 is entered in (i) above, then enter the followings:

Columns 1- 5: Number of longitudinal girders

6-10: Number of transverse members (beams)

11-20: Span of the bridge

21-30: Angle of skew (in degrees)

31-40: Spacing of longitudinal girders

(iii) MANUAL JOINT COORDINATES DATA

If 0 is entered in (i), then enter:

(a) - Number of Joints - (I5)

Columns 1 - 5: Number of joints

(b) - Joint Data - (I5,5X,2E10.0,I5)

Columns 1- 5: Joint number

11-20: X-coordinate

21-30: Y-coordinate

31-35: STEP (see Note 1)

(c) - EXIT - (see Note 2)

C. ELEMENT CONNECTIVITY AND SECTION PROPERTY NUMBER

Refer to Section 4.2.4-5, for detailed discussion on element connectivity and numbering.

(i) Columns 1 - 5: Option to generate element connectivity data automatically. Enter 1 for automatic generation, else 0.

(ii) If 1 is entered in (i), then enter

(a) Section property number for each element as follows (3I5):

Columns 1- 5: Element number

6-10: Section property number

11-15: STEP (see Note 3), and

(b) EXIT (see Note 2)

(iii) Else if 0 is entered in (i), then enter

(a) Element connectivity data together with section property number as follows (5I5):

Columns 1- 5: Element number

6-10: A-END joint number

11-15: B-END joint number

16-20: Section property number

21-25: STEP (see Note 3), and

(b) EXIT (see Note 2)

D. JOINT RELEASES

Refer to Note 4 for detailed discussion on 'Joint Coding'. All joints degrees of freedom have been automatically set to code '0,0,0'. Hence, input data is required for only supported joints - (5I5):

Columns 1- 5: Joint number

6-10: X-Rotation

11-15: Z-Movement

16-20: Y-Rotation

21-25: STEP (see Note 1)

EXIT (see Note 2)

CAUTION: Remember to input the structure support joint degrees of freedom to '1' before running the program. This is to avoid rigid body translation, that is, System stiffness matrix singularity.

E. MATERIAL PROPERTIES

(i) Control Information - (I5,5X,2E10.0)

Columns 1- 5: Number of sections. This refers to the total number of different element sections used in the grillage.

11-20: Elasticity Modulus

21-30: Shear Modulus

(ii) Element Property Data - (2E10.0)

Columns 1-10: Torsion constant * 1.0E-06

11-20: Moment of Inertia * 1.0E-06

Repeat (ii) as many times as there are number of sections specified in (i) above.

F. LOADINGS

Refer to Chapter 6 for detailed discussions on bridge deck loadings and modeling.

(a) Loading Information - (2I5)

Columns 1- 5: Number of load cases

6-10: Number of load combinations

Enter the following sets of data for each load case.

(b) Load Case Title - (A)

Columns 1 - 50: Load case title

(c) Uniformly Distributed Load Data - (I5,3E10.0,I5)

Refer to Section 6.3.1 for detailed discussion on element uniform loading.

Columns 1- 5: Element identification number, on which this load is applied.

6-15: Value of applied load per unit length.

16-25: Starting distance of applied load from 'a-end' of the element.

26-35: Distance of the finishing point of applied load with respect to 'a-end'. Enter 0 to assume the whole length of the element.

36-40: STEP (see Note 3)
EXIT (see Note 2)

(d) Element Point Loads Data - (I5,6E10.0,I5)

Refer to Section 6.3.1 for detailed discussion on element point loads. A maximum of three point loads are permissible per element. Element point loads are located from the lower joint number (a-end) relative to the local coordinate axis.

Columns 1- 5: Element number on which this load is applied

6-15: Value of applied concentrated Load 1

16-25: Distance of applied Load 1 from 'a-end'

26-35: Value of applied concentrated Load 2

36-45: Distance of applied Load 2 from 'a-end'

46-55: Value of applied concentrated Load 3

56-65: Distance of applied Load 3 from 'a-end'

66-70: STEP (see Note 3)

EXIT (see Note 2)

(e) Joint Load Data - (I5,3E10.0,I5)

Refer to Section 6.3.2 for a discussion of joint load coding.

Columns 1- 5: Joint number at which this set of load is applied

6-15: Applied moment about global X-axis

16-25: Applied force in global Z-axis

26-35: Applied moment about global Y-axis

36-40: STEP (see Note 1)

EXIT (see Note 2)

G. OUTPUT INFORMATION

Output information consist of the load combination data and particular joints and elements of which results are desired.

(a) Load Combination Data

(i) Load Combination Title - (A)

Columns 1-50: Load combination title

(ii) Load Combination Factors - for each required load case (I5,E10.0):

Columns 1- 5: Load case number

6-15: Load factor for this load case

Repeat (ii) for all load cases required in this load combination. Data is required for only the combined load cases.

To EXIT to the next load combination, either enter 0 as a response to load case number or leave a blank line.

Repeat the above procedure from (i) as many times as there are number of load combinations.

(b) To output results concerning particular joints or elements, enter the information as follows:

(i) Title - (A)

Columns 1-50: Title of response to be printed with output. See next page.

(ii) Concerned Joints/Elements Data - (3I5)

Columns 1- 5: Start joint/element number

6-10: Finish joint/element number

11-15: STEP

That is, to output results of Start-joint or element number through Finish-joint or element number at STEP specified, for all load combinations. To EXIT to the next response either enter zero on column 5 or leave a blank line.

Title response refers to one of the followings:

- Global Joint Displacements
- Element-End Local Displacements
- Element-End Forces
- Support Reactions, and
- Element-End Forces Comparison

Repeat the above procedure from (i) for each of the above titles.

NOTES

(1) Usually one line is needed for each joint. This can be achieved by setting STEP less than or equal to zero. However, if some joints fall on a straight line and are equidistant, then data for only the first and the last joint of this group are needed. Intermediate joint coordinates are automatically generated by linear interpolation. STEP gives the constant increment from a joint to its neighbouring joint number. A second line is needed for the last joint. FORMAT of this line is (I5,5x,2E10.0):

Columns 1- 5: Joint number
11-20: X-coordinate
21-30: Y-coordinate

In the case of JOINT RELEASES and Joint Load Data - If some joints are on a line in such a way that the difference between

'0' indicates the joint is 'free' to move in that direction.

'1' indicates the joint is 'fixed' and is not allowed to move in that direction.

For example fixed and free - bearing supports may be coded as '1 1 0'.

APPENDIX II

II.1 VERIFICATION PROBLEM

Type: Closed Grid Frame

Reference: 'Intermediate Structural Analysis' by C.K. Wang, page 714, example 19.4.2

Problem: Analyze the closed grid frame shown in Figure II.1a, which is supported on the three columns and subjected to a uniform load on top of 0.6kN/m.

Given: Constant EI = 600 kN.m2, GJ = 480 kN.m2
(For 4-in. std pipe approx.)

Let: E = 200E+06 kN/m2 and G = 160E+06 kN/m2

Therefore, I = 3E-06 m4 and J = 3E-06 m4

Solution Comparison:

GLOBAL DISPLACEMENTS. Note the difference in sign convention!

	JOINT NO.	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad.
WANG	1	-26.466	.000	58.875
GRID	1	26.4661	.0000	-58.8752
WANG	2	-102.066	.000	-41.989
GRID	2	102.0669	.0000	41.9890
WANG	3	-33.826	496.535	107.301
GRID	3	33.8263	-496.5369	-107.3018
WANG	4	7.407	.000	127.064
GRID	4	-7.4066	.0000	-127.0648

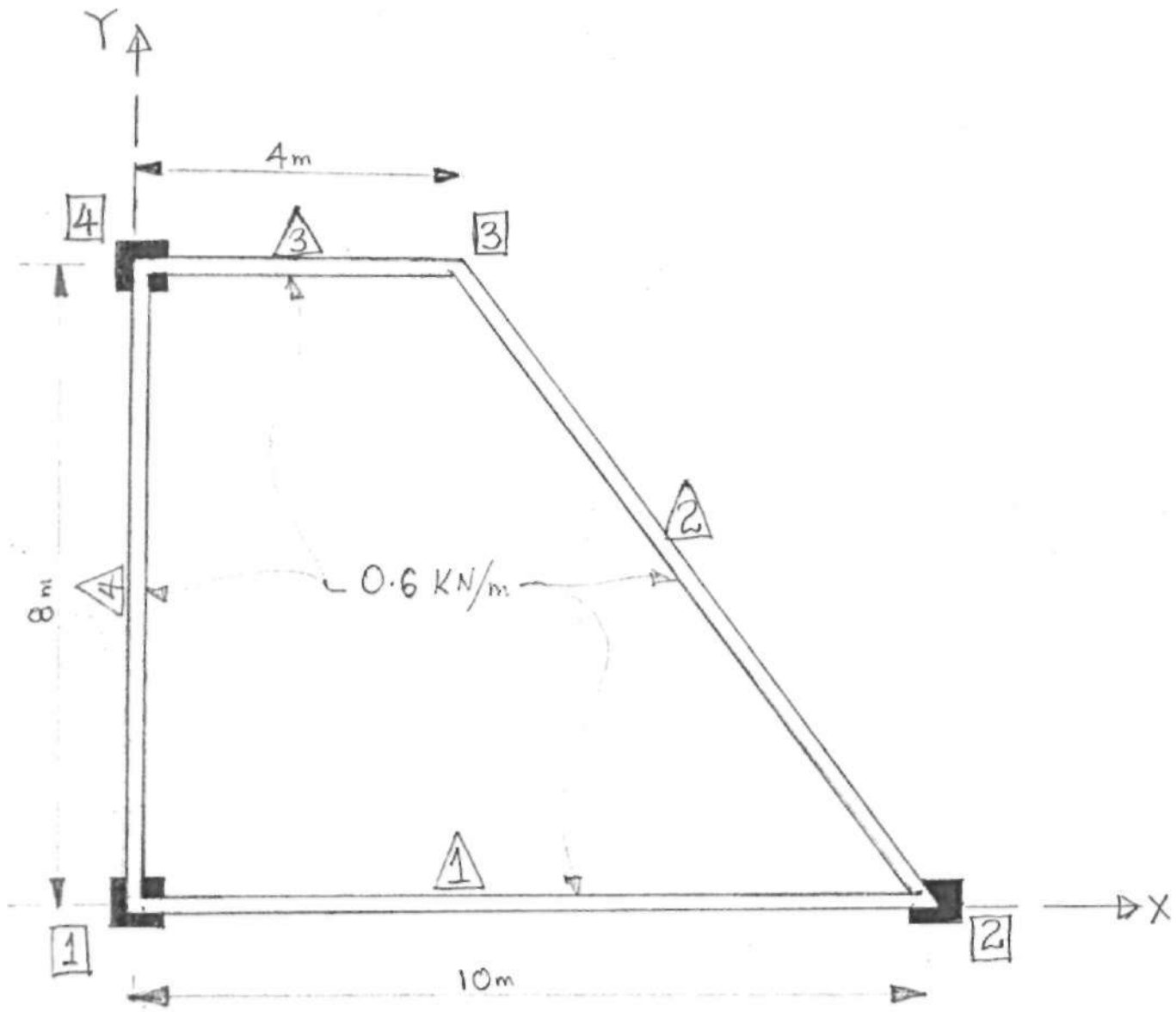


Figure II·1a , Closed Grid Frame

II.2 LISTING OF SOURCE INPUT DATA FOR VERIFICATION PROBLEM

```
Example 19.4.2  C.K. WANG - Inter. Str. Analysis
    0
    4
    1      0.0          0.0
    2      10.0          0.0
    3      4.0          8.0
    4      0.0          8.0
    0
    0
    4
    1     1     2     1
    2     2     3     1
    3     3     4     1
    4     1     4     1
    0
    1     0     1     0     1
    2
    4     0     1     0
    0
    1      200000000.160000000.
 3.0       3.0
    1     1
Uniform Load on top of 0.6 KN/m
    1  0.6       0.0          0.0          1
    4
    0
    0
    0
Load Case 1 only
    1  1.0
    0
Global Displacements
    1     4     1
    0
Element-End Displacements
    1     4     1
    0
Element-End Forces
    1     4     1
    0
Support Reactions
    1     1     1
    2     2     2
    4     4     4
    0
Element Actions Comparisons
    1     4     1
    0
```

II.3 LISTING OF INPUT DATA FROM PROGRAM GRID

STRUCTURAL ANALYSIS OF PLANE GRILLAGES

STRUCTURE NO. 01 Example 19.4.2 C.K. WANG - Inter. Str. Analysis

CONTROL INFORMATION

NO. OF ELEMENTS	=	4
NO. OF JOINTS	=	4
NO. OF LOAD CASES	=	1
NO. OF LOAD COMBINATIONS	=	1

GENERAL DATA

ELASTICITY MODULUS	=	.2000E+09
SHEAR MODULUS	=	.1600E+09
ANGLE OF SKEW (Degrees)	=	.0000E+00

JOINT DATA

JOINT NO.	X-FREEDOM	Z-FREEDOM	Y-FREEDOM	X-COORDINATE (METRES)	Y-COORDINATE (METRES)
1 S	0	1	0	.0000	.0000
2 S	0	1	0	10.0000	.0000
3	0	0	0	4.0000	8.0000
4 S	0	1	0	.0000	8.0000

ELEMENT DATA

Section Property Data :

SECTION NUMBER	TORS. CONST. 1.0E-06 (M4)	MOM. INERTIA 1.0E-06 (M4)
1	3.0000	3.0000

Element Connectivity Data :

ELEMENT NUMBER	LOWER JOINT	GREATER JOINT	SECTION NUMBER	ELEMENT LENGTH
1	1	2	1	10.0000
2	2	3	1	10.0000
3	3	4	1	4.0000
4	1	4	1	8.0000

LOAD DATA

LOAD CASE 1 Uniform Load on top of 0.6 KN/m

Element Uniform Load :

ELEMENT NUMBER	UNIFORM LOAD (KN/m)	DISTANCE FROM A-END START (m)	END (m)
1	.6000	.00	10.00
2	.6000	.00	10.00
3	.6000	.00	4.00
4	.6000	.00	8.00

Element Point Loads

ELEMENT NUMBER	PT. LOAD 1 (KN)	DIST. (M)	PT. LOAD 2 (KN)	DIST. (M)	PT. LOAD 3 (KN)	DIST. (M)

Joint Loads

LOADED JOINT	EXTERNAL MOM.-X (KN-m)	VERTICAL LOAD-Z (KN)	EXTERNAL MOM.-Y (KN-m)

LOAD COMBINATION DATA

	LOAD COMBINATION NO./FACTORS
LC	1
1	1.00

LOAD COMBINATION 1 Load Case 1 only

OUTPUT INFORMATION

Global Displacements
1 4 1
Element-End Displacements
1 4 1
Element-End Forces
1 4 1
Support Reactions
1 1 1
2 2 2
4 4 4
Element Actions Comparisons
1 4 1

SYSTEM DEGREES-OF-FREEDOM = 9
BAND-WIDTH = 12
NO. OF SUPPORTED JOINTS = 3

II.4 LISTING OF OUTPUT FROM PROGRAM GRID

GLOBAL DISPLACEMENTS

JOINT NO.	LOAD COMBINATION	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad.
1	1	26.4661	.0000	-58.8752
2	1	102.0669	.0000	41.9890
3	1	33.8263	-496.5369	-107.3018
4	1	-7.4066	.0000	-127.0648

ELEMENT - END DISPLACEMENTS

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad
1	1	1	26.4661	.0000	-58.8752
		2	102.0669	.0000	41.9890
2	1	2	-27.6490	.0000	-106.8469
		3	-106.1373	-496.5369	37.3201
3	1	3	-33.8263	-496.5369	107.3018
		4	7.4066	.0000	127.0648
4	1	1	-58.8752	.0000	-26.4661
		4	-127.0648	.0000	7.4066

ELEMENT - END FORCES

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	TORSION - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
1	1	1	-3.6288	2.3921	-4.0914
		2	3.6288	3.6079	-1.9877
2	1	2	3.7674	4.0721	1.7105
		3	-3.7674	1.9279	9.0105
3	1	3	-4.9479	-1.9279	-8.4203
		4	4.9479	4.3279	-4.0914
4	1	1	4.0914	1.3279	-3.6288
		4	-4.0914	3.4721	-4.9479

SUPPORT REACTIONS

JOINT NO.	LOAD COMBINATION	MOMENT - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
1	1	.0000	3.7200	.000

JOINT NO.	LOAD COMBINATION	MOMENT - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
2	1	.0000	7.6800	.0000

JOINT NO.	LOAD COMBINATION	MOMENT - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
4	1	.0000	7.8000	.0000

COMPARISON OF ELEMENT-END FORCES

COMPARISON OF FORCES ALONG ELEMENTS 1 THRU 4 AT STEP 1

LOAD COMB	ELEM END	Max/Min TORSION - X	On EL.	Max/Min SHEAR - Z	On EL.	Max/Min MOMENT - Y	On EL.
1	A-End	4.09	4	4.07	2	1.71	2
		-4.95	3	-1.93	3	-8.42	3
	B-End	4.95	3	4.33	3	9.01	2
		-4.09	4	1.93	2	-4.95	4

II.5 SAMPLE BRIDGE DECK ANALYSIS

Type: 33.5 degree Skewed Bridge deck over river Jadna, in Federal Capital territory, Abuja.

Reference: Samaila Omale and Partners, Federal Capital Development Authority, Abuja, Project No. 171/81ED/CONS. 51, CONTRACT No 1, Vol. II: BRIDGEWORKS, Oct. 1983.

Problem: Analyze the skewed bridge deck shown in Figure II.2 (inside the file jacket).

Discretisation: Refer to Figure II.3 (also inside the file jacket) for detailed joint numbering and element numbering schemes.

DISCUSSIONS:

The listing of the source input data shows clearly how program GRID allows automatic generation of joint coordinates and element connectivity data. The listing could be read in conjunction with the user's guide and the discretisation of the deck (Figure II.3). Furthermore, the listing of the input data generated from the program could be use to check all automatically generated data.

Figure II.3 illustrates the deck descretised into 120 joints, which are interconnected into 218 elements. These give 312 system degrees of freedom with a half-bandwidth of 33. Therefore the largest array storage requirements = 312*33, that

is 10296 locations, about 41,184 Kilobytes!

The output of joint data shows an 's' infront of supported joints to diffrentiate them from unsupported ones. In addition, element data section gives also the lengths of indivisual elements. This could be use to check with actual lengths.

Load cases & combinations

Four load cases have been chosen to cover all the loadings discussed in chapter 6. They are as follows:

1. Dead Load
2. Superimposed Dead Load
3. HA & Associates
4. HB & Associates

These are combined to give eight load combinations. Each load case is divided into its ultimate and serviceability states component.

Boundary Conditions

Boundary conditions have been specified through the joint releases data. Refer to NOTE(4) in Appendix I for more details.

Timing

With the IBM PC running at 8 Hertz, it takes about 80 minutes to completely execute the problem.

Results

Observe that the output is given for only the joints and elements on which results are desired.

The maximum vertical displacement of the whole structure is

given as 2.3078 mm (downwards) i.e. about (1/7800) of the span. This occurs at joint number 25, on the third girder and it is given by the HB & its associates load combination at the ultimate limit state. The remaining results give the element-end displacements of selected elements, element-end forces comparisons and support reactions.

II.6_LISTING_OF_SOURCE_INPUT_DATA

```
Bridge Deck - B27 Over River Jadna FCDA, Abuja
  1
 12    10  18.          33.5        1.0
  1
109     1     1
119
208     1     1
218
  1     2     1
  9
100     2     1
108
 10     3     1
 99
120     4     1
207
  0
  1     1     1     0    10
111
 10     1     1     0    10
120
  0
  4      32940000. 14330000.
 33570.     72173.
 5722.1515 90495.379
 4780.6505148791.026
 2593.0     682.667
    4    8
Self Weigth Only
 109   13.08    0.          0.            1
 119
 208   13.08    0.          0.            1
 218
   1   19.855   0.          0.            1
   9
 100   19.855   0.          0.            1
 108
  10   12.25     0.          0.           1
  99
   0
   0
   0
Superimposed Dead Load
    1    1.056  0.          0.            1
    9
  100    1.056  0.          0.            1
  108
```

```
 10   1.92   0.          0.            1
 99
  0
109   1.1539 0.2         0.          0.          0.          0.          1
119
208   1.1539 0.2         0.          0.          0.          0.          1
218
  0
  1   10.    0.          0.            1
 10
111  -10.    0.          0.            1
120
  0
Full HA + KEL on Lanes 1 & 2 + 1/3 on Lane 3
100    5.5   0.          0.            1
108
 82   10.    0.          0.            1
 99
 73   11.5   0.          0.            1
 81
 64    8.5   0.0         0.0           1
 72
 46   10.0   0.0         0.0           1
 63
 37    8.5   0.0         0.0           1
 45
  1    1.83    0.0       0.0           1
  9
 10    3.33    0.0       0.0           1
 27
 28    3.83    0.0       0.0           1
 36
  0
117    4.3767  0.1167
118    3.3094  0.1667      0.0         0.0         0.0         0.0         1
119
216    4.3767  0.1167
217    3.3039  0.1667      0.0         0.0         0.0         0.0         1
218
 77   37.2973  1.0
 86   32.4324  1.0
 95   32.4324  1.0
104   17.8378  1.0
113    2.391   .2167
114    3.3094  .1667       0.0         0.0         0.0         0.0         1
115
116    2.391   .2167
 41   27.5675   1.0
 50   32.4324   1.0
 59   32.4324   1.0
 68   27.5675   1.0
109    0.3337   0.3167
```

```
110   1.1031   0.1667    0.0         0.0       0.0       0.0          1
111
112   1.4589   0.1167
208   0.3337   0.3167
209   1.1031   0.1667
210   1.1031   0.1667
211   1.4589   0.1167
  5   5.9459   1.0
 14  10.8108   1.0
 23  10.8108   1.0
 32  12.4324   1.0
  0
111   0.0      0.0        0.1214
120   0.0      0.0       -0.1214
  0
HB on Lane 1 + Full HA & KEL on 2 + 1/3 on 3
 64   8.5      0.0        0.0          1
 72
 46  10.0      0.0        0.0          1
 63
 37   8.5      0.0        0.0          1
 45
  1   1.83     0.0        0.0          1
  9
 10   3.33     0.0        0.0          1
 27
 28   3.83     0.0        0.0          1
 36
  0
  3  81.5625   0.2
 12 112.5      0.86
 21 112.5      1.52
 31 112.5      0.19
 40  30.9375   0.85
 13 112.5      0.66
 22 112.5      1.32
 31 112.5      1.99
 41  30.9375   0.65
 16 112.5      0.66
 25 112.5      1.32
 34 112.5      1.99
 44  30.9375   0.65
  7  81.5625   1.8
 17 112.5      0.46
 26 112.5      1.12
 35 112.5      1.79
 45  30.9375   0.45
113   2.391    .2167
114   3.3094   .1667     0.0       0.0       0.0       0.0          1
115
116   2.391    .2167
 41  27.5675   1.0
```

```
Element-End Forces
    1     9     1
   10    18     1
  109   117     1
  208   216     1
    0
Support Reactions
    1   111    10
   10   120    10
    0
Comparison of Element-End Forces
    1     9     1
  100   108     1
   10    99     1
  200   207     1
    0
```

II.7 LISTING OF INPUT DATA FROM PROGRAM GRID

STRUCTURAL ANALYSIS OF PLANE GRILLAGES

STRUCTURE NO. 33 Bridge Deck - B27 Over River Jadna FCDA, Abuja

CONTROL INFORMATION

NO. OF ELEMENTS	=	218
NO. OF JOINTS	=	120
NO. OF LOAD CASES	=	4
NO. OF LOAD COMBINATIONS	=	8

GENERAL DATA

ELASTICITY MODULUS	=	.3294E+08
SHEAR MODULUS	=	.1433E+08
ANGLE OF SKEW (Degrees)	=	.3350E+02

JOINT DATA

JOINT NO.		X-FREEDOM	Z-FREEDOM	Y-FREEDOM	X-COORDINATE (METRES)	Y-COORDINATE (METRES)
1	S	1	1	0	.0000	.0000
2		0	0	0	2.0000	.0000
3		0	0	0	4.0000	.0000
4		0	0	0	6.0000	.0000
5		0	0	0	8.0000	.0000
6		0	0	0	10.0000	.0000
7		0	0	0	12.0000	.0000
8		0	0	0	14.0000	.0000
9		0	0	0	16.0000	.0000
10	S	1	1	0	18.0000	.0000
11	S	1	1	0	1.7741	1.0000
12		0	0	0	3.7741	1.0000
13		0	0	0	5.7741	1.0000
14		0	0	0	7.7741	1.0000
15		0	0	0	9.7741	1.0000

16		0	0	0	11.7741	1.0000
17		0	0	0	13.7741	1.0000
18		0	0	0	15.7741	1.0000
19		0	0	0	17.7741	1.0000
20	S	1	1	0	19.7741	1.0000
21	S	1	1	0	3.5482	2.0000
22		0	0	0	5.5482	2.0000
23		0	0	0	7.5482	2.0000
24		0	0	0	9.5482	2.0000
25		0	0	0	11.5482	2.0000
26		0	0	0	13.5482	2.0000
27		0	0	0	15.5482	2.0000
28		0	0	0	17.5482	2.0000
29		0	0	0	19.5482	2.0000
30	S	1	1	0	21.5482	2.0000
31	S	1	1	0	5.3223	3.0000
32		0	0	0	7.3223	3.0000
33		0	0	0	9.3223	3.0000
34		0	0	0	11.3223	3.0000
35		0	0	0	13.3223	3.0000
36		0	0	0	15.3223	3.0000
37		0	0	0	17.3223	3.0000
38		0	0	0	19.3223	3.0000
39		0	0	0	21.3223	3.0000
40	S	1	1	0	23.3223	3.0000
41	S	1	1	0	7.0964	4.0000
42		0	0	0	9.0964	4.0000
43		0	0	0	11.0964	4.0000
44		0	0	0	13.0964	4.0000
45		0	0	0	15.0964	4.0000
46		0	0	0	17.0964	4.0000
47		0	0	0	19.0964	4.0000
48		0	0	0	21.0964	4.0000
49		0	0	0	23.0964	4.0000
50	S	1	1	0	25.0964	4.0000
51	S	1	1	0	8.8705	5.0000
52		0	0	0	10.8705	5.0000
53		0	0	0	12.8705	5.0000
54		0	0	0	14.8705	5.0000
55		0	0	0	16.8705	5.0000
56		0	0	0	18.8705	5.0000
57		0	0	0	20.8705	5.0000
58		0	0	0	22.8705	5.0000
59		0	0	0	24.8705	5.0000
60	S	1	1	0	26.8705	5.0000
61	S	1	1	0	10.6445	6.0000
62		0	0	0	12.6445	6.0000
63		0	0	0	14.6445	6.0000
64		0	0	0	16.6445	6.0000
65		0	0	0	18.6445	6.0000
66		0	0	0	20.6445	6.0000
67		0	0	0	22.6445	6.0000

68	0	0	0	24.6445	6.0000
69	0	0	0	26.6445	6.0000
70 S	1	1	0	28.6445	6.0000
71 S	1	1	0	12.4186	7.0000
72	0	0	0	14.4186	7.0000
73	0	0	0	16.4186	7.0000
74	0	0	0	18.4186	7.0000
75	0	0	0	20.4186	7.0000
76	0	0	0	22.4186	7.0000
77	0	0	0	24.4186	7.0000
78	0	0	0	26.4186	7.0000
79	0	0	0	28.4186	7.0000
80 S	1	1	0	30.4186	7.0000
81 S	1	1	0	14.1927	8.0000
82	0	0	0	16.1927	8.0000
83	0	0	0	18.1927	8.0000
84	0	0	0	20.1927	8.0000
85	0	0	0	22.1927	8.0000
86	0	0	0	24.1927	8.0000
87	0	0	0	26.1927	8.0000
88	0	0	0	28.1927	8.0000
89	0	0	0	30.1927	8.0000
90 S	1	1	0	32.1927	8.0000
91 S	1	1	0	15.9668	9.0000
92	0	0	0	17.9668	9.0000
93	0	0	0	19.9668	9.0000
94	0	0	0	21.9668	9.0000
95	0	0	0	23.9668	9.0000
96	0	0	0	25.9668	9.0000
97	0	0	0	27.9668	9.0000
98	0	0	0	29.9668	9.0000
99	0	0	0	31.9668	9.0000
100 S	1	1	0	33.9668	9.0000
101 S	1	1	0	17.7409	10.0000
102	0	0	0	19.7409	10.0000
103	0	0	0	21.7409	10.0000
104	0	0	0	23.7409	10.0000
105	0	0	0	25.7409	10.0000
106	0	0	0	27.7409	10.0000
107	0	0	0	29.7409	10.0000
108	0	0	0	31.7409	10.0000
109	0	0	0	33.7409	10.0000
110 S	1	1	0	35.7409	10.0000
111 S	1	1	0	19.5150	11.0000
112	0	0	0	21.5150	11.0000
113	0	0	0	23.5150	11.0000
114	0	0	0	25.5150	11.0000
115	0	0	0	27.5150	11.0000
116	0	0	0	29.5150	11.0000
117	0	0	0	31.5150	11.0000
118	0	0	0	33.5150	11.0000

119	0	0	0	35.5150	11.0000
120 S	1	1	0	37.5150	11.0000

ELEMENT DATA

Section Property Data :

SECTION NUMBER	TORS. CONST. 1.0E-06 (M4)	MOM. INERTIA 1.0E-06 (M4)
1	33570.0000	72173.0000
2	5722.1510	90495.3800
3	4780.6500	148791.0000
4	2593.0000	682.6670

Element Connectivity Data :

ELEMENT NUMBER	LOWER JOINT	GREATER JOINT	SECTION NUMBER	ELEMENT LENGTH
1	1	2	2	2.0000
2	2	3	2	2.0000
3	3	4	2	2.0000
4	4	5	2	2.0000
5	5	6	2	2.0000
6	6	7	2	2.0000
7	7	8	2	2.0000
8	8	9	2	2.0000
9	9	10	2	2.0000
10	11	12	3	2.0000
11	12	13	3	2.0000
12	13	14	3	2.0000
13	14	15	3	2.0000
14	15	16	3	2.0000
15	16	17	3	2.0000
16	17	18	3	2.0000
17	18	19	3	2.0000
18	19	20	3	2.0000
19	21	22	3	2.0000
20	22	23	3	2.0000
21	23	24	3	2.0000
22	24	25	3	2.0000
23	25	26	3	2.0000
24	26	27	3	2.0000
25	27	28	3	2.0000
26	28	29	3	2.0000
27	29	30	3	2.0000
28	31	32	3	2.0000

29	32	33	3	2.0000
30	33	34	3	2.0000
31	34	35	3	2.0000
32	35	36	3	2.0000
33	36	37	3	2.0000
34	37	38	3	2.0000
35	38	39	3	2.0000
36	39	40	3	2.0000
37	41	42	3	2.0000
38	42	43	3	2.0000
39	43	44	3	2.0000
40	44	45	3	2.0000
41	45	46	3	2.0000
42	46	47	3	2.0000
43	47	48	3	2.0000
44	48	49	3	2.0000
45	49	50	3	2.0000
46	51	52	3	2.0000
47	52	53	3	2.0000
48	53	54	3	2.0000
49	54	55	3	2.0000
50	55	56	3	2.0000
51	56	57	3	2.0000
52	57	58	3	2.0000
53	58	59	3	2.0000
54	59	60	3	2.0000
55	61	62	3	2.0000
56	62	63	3	2.0000
57	63	64	3	2.0000
58	64	65	3	2.0000
59	65	66	3	2.0000
60	66	67	3	2.0000
61	67	68	3	2.0000
62	68	69	3	2.0000
63	69	70	3	2.0000
64	71	72	3	2.0000
65	72	73	3	2.0000
66	73	74	3	2.0000
67	74	75	3	2.0000
68	75	76	3	2.0000
69	76	77	3	2.0000
70	77	78	3	2.0000
71	78	79	3	2.0000
72	79	80	3	2.0000
73	81	82	3	2.0000
74	82	83	3	2.0000
75	83	84	3	2.0000
76	84	85	3	2.0000
77	85	86	3	2.0000
78	86	87	3	2.0000
79	87	88	3	2.0000
80	88	89	3	2.0000

81	89	90	3	2.0000
82	91	92	3	2.0000
83	92	93	3	2.0000
84	93	94	3	2.0000
85	94	95	3	2.0000
86	95	96	3	2.0000
87	96	97	3	2.0000
88	97	98	3	2.0000
89	98	99	3	2.0000
90	99	100	3	2.0000
91	101	102	3	2.0000
92	102	103	3	2.0000
93	103	104	3	2.0000
94	104	105	3	2.0000
95	105	106	3	2.0000
96	106	107	3	2.0000
97	107	108	3	2.0000
98	108	109	3	2.0000
99	109	110	3	2.0000
100	111	112	2	2.0000
101	112	113	2	2.0000
102	113	114	2	2.0000
103	114	115	2	2.0000
104	115	116	2	2.0000
105	116	117	2	2.0000
106	117	118	2	2.0000
107	118	119	2	2.0000
108	119	120	2	2.0000
109	1	11	1	2.0365
110	11	21	1	2.0365
111	21	31	1	2.0365
112	31	41	1	2.0365
113	41	51	1	2.0365
114	51	61	1	2.0365
115	61	71	1	2.0365
116	71	81	1	2.0365
117	81	91	1	2.0365
118	91	101	1	2.0365
119	101	111	1	2.0365
120	2	12	4	2.0365
121	12	22	4	2.0365
122	22	32	4	2.0365
123	32	42	4	2.0365
124	42	52	4	2.0365
125	52	62	4	2.0365
126	62	72	4	2.0365
127	72	82	4	2.0365
128	82	92	4	2.0365
129	92	102	4	2.0365
130	102	112	4	2.0365
131	3	13	4	2.0365
132	13	23	4	2.0365

133	23	33	4	2.0365
134	33	43	4	2.0365
135	43	53	4	2.0365
136	53	63	4	2.0365
137	63	73	4	2.0365
138	73	83	4	2.0365
139	83	93	4	2.0365
140	93	103	4	2.0365
141	103	113	4	2.0365
142	4	14	4	2.0365
143	14	24	4	2.0365
144	24	34	4	2.0365
145	34	44	4	2.0365
146	44	54	4	2.0365
147	54	64	4	2.0365
148	64	74	4	2.0365
149	74	84	4	2.0365
150	84	94	4	2.0365
151	94	104	4	2.0365
152	104	114	4	2.0365
153	5	15	4	2.0365
154	15	25	4	2.0365
155	25	35	4	2.0365
156	35	45	4	2.0365
157	45	55	4	2.0365
158	55	65	4	2.0365
159	65	75	4	2.0365
160	75	85	4	2.0365
161	85	95	4	2.0365
162	95	105	4	2.0365
163	105	115	4	2.0365
164	6	16	4	2.0365
165	16	26	4	2.0365
166	26	36	4	2.0365
167	36	46	4	2.0365
168	46	56	4	2.0365
169	56	66	4	2.0365
170	66	76	4	2.0365
171	76	86	4	2.0365
172	86	96	4	2.0365
173	96	106	4	2.0365
174	106	116	4	2.0365
175	7	17	4	2.0365
176	17	27	4	2.0365
177	27	37	4	2.0365
178	37	47	4	2.0365
179	47	57	4	2.0365
180	57	67	4	2.0365
181	67	77	4	2.0365
182	77	87	4	2.0365
183	87	97	4	2.0365
184	97	107	4	2.0365

185	107	117	4	2.0365
186	8	18	4	2.0365
187	18	28	4	2.0365
188	28	38	4	2.0365
189	38	48	4	2.0365
190	48	58	4	2.0365
191	58	68	4	2.0365
192	68	78	4	2.0365
193	78	88	4	2.0365
194	88	98	4	2.0365
195	98	108	4	2.0365
196	108	118	4	2.0365
197	9	19	4	2.0365
198	19	29	4	2.0365
199	29	39	4	2.0365
200	39	49	4	2.0365
201	49	59	4	2.0365
202	59	69	4	2.0365
203	69	79	4	2.0365
204	79	89	4	2.0365
205	89	99	4	2.0365
206	99	109	4	2.0365
207	109	119	4	2.0365
208	10	20	1	2.0365
209	20	30	1	2.0365
210	30	40	1	2.0365
211	40	50	1	2.0365
212	50	60	1	2.0365
213	60	70	1	2.0365
214	70	80	1	2.0365
215	80	90	1	2.0365
216	90	100	1	2.0365
217	100	110	1	2.0365
218	110	120	1	2.0365

LOAD DATA

LOAD CASE 1 Self Weigth Only

Element Uniform Load :

ELEMENT NUMBER	UNIFORM LOAD (KN/m)	DISTANCE FROM A-END START (m)	END (m)
109	13.0800	.00	2.04
110	13.0800	.00	2.04
111	13.0800	.00	2.04
112	13.0800	.00	2.04
113	13.0800	.00	2.04

114	13.0800	.00	2.04
115	13.0800	.00	2.04
116	13.0800	.00	2.04
117	13.0800	.00	2.04
118	13.0800	.00	2.04
119	13.0800	.00	2.04
208	13.0800	.00	2.04
209	13.0800	.00	2.04
210	13.0800	.00	2.04
211	13.0800	.00	2.04
212	13.0800	.00	2.04
213	13.0800	.00	2.04
214	13.0800	.00	2.04
215	13.0800	.00	2.04
216	13.0800	.00	2.04
217	13.0800	.00	2.04
218	13.0800	.00	2.04
1	19.8550	.00	2.00
2	19.8550	.00	2.00
3	19.8550	.00	2.00
4	19.8550	.00	2.00
5	19.8550	.00	2.00
6	19.8550	.00	2.00
7	19.8550	.00	2.00
8	19.8550	.00	2.00
9	19.8550	.00	2.00
100	19.8550	.00	2.00
101	19.8550	.00	2.00
102	19.8550	.00	2.00
103	19.8550	.00	2.00
104	19.8550	.00	2.00
105	19.8550	.00	2.00
106	19.8550	.00	2.00
107	19.8550	.00	2.00
108	19.8550	.00	2.00
10	12.2500	.00	2.00
11	12.2500	.00	2.00
12	12.2500	.00	2.00
13	12.2500	.00	2.00
14	12.2500	.00	2.00
15	12.2500	.00	2.00
16	12.2500	.00	2.00
17	12.2500	.00	2.00
18	12.2500	.00	2.00
19	12.2500	.00	2.00
20	12.2500	.00	2.00
21	12.2500	.00	2.00
22	12.2500	.00	2.00
23	12.2500	.00	2.00
24	12.2500	.00	2.00
25	12.2500	.00	2.00
26	12.2500	.00	2.00

27	12.2500	.00	2.00
28	12.2500	.00	2.00
29	12.2500	.00	2.00
30	12.2500	.00	2.00
31	12.2500	.00	2.00
32	12.2500	.00	2.00
33	12.2500	.00	2.00
34	12.2500	.00	2.00
35	12.2500	.00	2.00
36	12.2500	.00	2.00
37	12.2500	.00	2.00
38	12.2500	.00	2.00
39	12.2500	.00	2.00
40	12.2500	.00	2.00
41	12.2500	.00	2.00
42	12.2500	.00	2.00
43	12.2500	.00	2.00
44	12.2500	.00	2.00
45	12.2500	.00	2.00
46	12.2500	.00	2.00
47	12.2500	.00	2.00
48	12.2500	.00	2.00
49	12.2500	.00	2.00
50	12.2500	.00	2.00
51	12.2500	.00	2.00
52	12.2500	.00	2.00
53	12.2500	.00	2.00
54	12.2500	.00	2.00
55	12.2500	.00	2.00
56	12.2500	.00	2.00
57	12.2500	.00	2.00
58	12.2500	.00	2.00
59	12.2500	.00	2.00
60	12.2500	.00	2.00
61	12.2500	.00	2.00
62	12.2500	.00	2.00
63	12.2500	.00	2.00
64	12.2500	.00	2.00
65	12.2500	.00	2.00
66	12.2500	.00	2.00
67	12.2500	.00	2.00
68	12.2500	.00	2.00
69	12.2500	.00	2.00
70	12.2500	.00	2.00
71	12.2500	.00	2.00
72	12.2500	.00	2.00
73	12.2500	.00	2.00
74	12.2500	.00	2.00
75	12.2500	.00	2.00
76	12.2500	.00	2.00
77	12.2500	.00	2.00
78	12.2500	.00	2.00

79	12.2500	.00	2.00
80	12.2500	.00	2.00
81	12.2500	.00	2.00
82	12.2500	.00	2.00
83	12.2500	.00	2.00
84	12.2500	.00	2.00
85	12.2500	.00	2.00
86	12.2500	.00	2.00
87	12.2500	.00	2.00
88	12.2500	.00	2.00
89	12.2500	.00	2.00
90	12.2500	.00	2.00
91	12.2500	.00	2.00
92	12.2500	.00	2.00
93	12.2500	.00	2.00
94	12.2500	.00	2.00
95	12.2500	.00	2.00
96	12.2500	.00	2.00
97	12.2500	.00	2.00
98	12.2500	.00	2.00
99	12.2500	.00	2.00

Element Point Loads

ELEMENT NUMBER	PT. LOAD 1 (KN)	DIST. (M)	PT. LOAD 2 (KN)	DIST. (M)	PT. LOAD 3 (KN)	DIST. (M)

Joint Loads

LOADED JOINT	EXTERNAL MOM.-X (KN-m)	VERTICAL LOAD-Z (KN)	EXTERNAL MOM.-Y (KN-m)

LOAD CASE 2 Superimposed Dead Load

Element Uniform Load :

ELEMENT NUMBER	UNIFORM LOAD (KN/m)	DISTANCE FROM A-END START (m)	END (m)
1	1.0560	.00	2.00
2	1.0560	.00	2.00
3	1.0560	.00	2.00
4	1.0560	.00	2.00

5	1.0560	.00	2.00
6	1.0560	.00	2.00
7	1.0560	.00	2.00
8	1.0560	.00	2.00
9	1.0560	.00	2.00
100	1.0560	.00	2.00
101	1.0560	.00	2.00
102	1.0560	.00	2.00
103	1.0560	.00	2.00
104	1.0560	.00	2.00
105	1.0560	.00	2.00
106	1.0560	.00	2.00
107	1.0560	.00	2.00
108	1.0560	.00	2.00
10	1.9200	.00	2.00
11	1.9200	.00	2.00
12	1.9200	.00	2.00
13	1.9200	.00	2.00
14	1.9200	.00	2.00
15	1.9200	.00	2.00
16	1.9200	.00	2.00
17	1.9200	.00	2.00
18	1.9200	.00	2.00
19	1.9200	.00	2.00
20	1.9200	.00	2.00
21	1.9200	.00	2.00
22	1.9200	.00	2.00
23	1.9200	.00	2.00
24	1.9200	.00	2.00
25	1.9200	.00	2.00
26	1.9200	.00	2.00
27	1.9200	.00	2.00
28	1.9200	.00	2.00
29	1.9200	.00	2.00
30	1.9200	.00	2.00
31	1.9200	.00	2.00
32	1.9200	.00	2.00
33	1.9200	.00	2.00
34	1.9200	.00	2.00
35	1.9200	.00	2.00
36	1.9200	.00	2.00
37	1.9200	.00	2.00
38	1.9200	.00	2.00
39	1.9200	.00	2.00
40	1.9200	.00	2.00
41	1.9200	.00	2.00
42	1.9200	.00	2.00
43	1.9200	.00	2.00
44	1.9200	.00	2.00
45	1.9200	.00	2.00
46	1.9200	.00	2.00
47	1.9200	.00	2.00

48	1.9200	.00	2.00
49	1.9200	.00	2.00
50	1.9200	.00	2.00
51	1.9200	.00	2.00
52	1.9200	.00	2.00
53	1.9200	.00	2.00
54	1.9200	.00	2.00
55	1.9200	.00	2.00
56	1.9200	.00	2.00
57	1.9200	.00	2.00
58	1.9200	.00	2.00
59	1.9200	.00	2.00
60	1.9200	.00	2.00
61	1.9200	.00	2.00
62	1.9200	.00	2.00
63	1.9200	.00	2.00
64	1.9200	.00	2.00
65	1.9200	.00	2.00
66	1.9200	.00	2.00
67	1.9200	.00	2.00
68	1.9200	.00	2.00
69	1.9200	.00	2.00
70	1.9200	.00	2.00
71	1.9200	.00	2.00
72	1.9200	.00	2.00
73	1.9200	.00	2.00
74	1.9200	.00	2.00
75	1.9200	.00	2.00
76	1.9200	.00	2.00
77	1.9200	.00	2.00
78	1.9200	.00	2.00
79	1.9200	.00	2.00
80	1.9200	.00	2.00
81	1.9200	.00	2.00
82	1.9200	.00	2.00
83	1.9200	.00	2.00
84	1.9200	.00	2.00
85	1.9200	.00	2.00
86	1.9200	.00	2.00
87	1.9200	.00	2.00
88	1.9200	.00	2.00
89	1.9200	.00	2.00
90	1.9200	.00	2.00
91	1.9200	.00	2.00
92	1.9200	.00	2.00
93	1.9200	.00	2.00
94	1.9200	.00	2.00
95	1.9200	.00	2.00
96	1.9200	.00	2.00
97	1.9200	.00	2.00
98	1.9200	.00	2.00
99	1.9200	.00	2.00

Element Point Loads

ELEMENT NUMBER	PT. LOAD 1 (KN)	DIST. (M)	PT. LOAD 2 (KN)	DIST. (M)	PT. LOAD 3 (KN)	DIST. (M)
109	1.154	.200	.000	.000	.000	.000
110	1.154	.200	.000	.000	.000	.000
111	1.154	.200	.000	.000	.000	.000
112	1.154	.200	.000	.000	.000	.000
113	1.154	.200	.000	.000	.000	.000
114	1.154	.200	.000	.000	.000	.000
115	1.154	.200	.000	.000	.000	.000
116	1.154	.200	.000	.000	.000	.000
117	1.154	.200	.000	.000	.000	.000
118	1.154	.200	.000	.000	.000	.000
119	1.154	.200	.000	.000	.000	.000
208	1.154	.200	.000	.000	.000	.000
209	1.154	.200	.000	.000	.000	.000
210	1.154	.200	.000	.000	.000	.000
211	1.154	.200	.000	.000	.000	.000
212	1.154	.200	.000	.000	.000	.000
213	1.154	.200	.000	.000	.000	.000
214	1.154	.200	.000	.000	.000	.000
215	1.154	.200	.000	.000	.000	.000
216	1.154	.200	.000	.000	.000	.000
217	1.154	.200	.000	.000	.000	.000
218	1.154	.200	.000	.000	.000	.000

Joint Loads

LOADED JOINT	EXTERNAL MOM.-X (KN-m)	VERTICAL LOAD-Z (KN)	EXTERNAL MOM.-Y (KN-m)
1	10.0000	.0000	.0000
2	10.0000	.0000	.0000
3	10.0000	.0000	.0000
4	10.0000	.0000	.0000
5	10.0000	.0000	.0000
6	10.0000	.0000	.0000
7	10.0000	.0000	.0000
8	10.0000	.0000	.0000
9	10.0000	.0000	.0000
10	10.0000	.0000	.0000
111	-10.0000	.0000	.0000
112	-10.0000	.0000	.0000
113	-10.0000	.0000	.0000
114	-10.0000	.0000	.0000
115	-10.0000	.0000	.0000
116	-10.0000	.0000	.0000
117	-10.0000	.0000	.0000

118	-10.0000	.0000	.0000
119	-10.0000	.0000	.0000
120	-10.0000	.0000	.0000

LOAD CASE 3 Full HA + KEL on Lanes 1 & 2 + 1/3 on Lane 3

Element Uniform Load :

ELEMENT NUMBER	UNIFORM LOAD (KN/m)	DISTANCE FROM A-END START (m)	END (m)
100	5.5000	.00	2.00
101	5.5000	.00	2.00
102	5.5000	.00	2.00
103	5.5000	.00	2.00
104	5.5000	.00	2.00
105	5.5000	.00	2.00
106	5.5000	.00	2.00
107	5.5000	.00	2.00
108	5.5000	.00	2.00
82	10.0000	.00	2.00
83	10.0000	.00	2.00
84	10.0000	.00	2.00
85	10.0000	.00	2.00
86	10.0000	.00	2.00
87	10.0000	.00	2.00
88	10.0000	.00	2.00
89	10.0000	.00	2.00
90	10.0000	.00	2.00
91	10.0000	.00	2.00
92	10.0000	.00	2.00
93	10.0000	.00	2.00
94	10.0000	.00	2.00
95	10.0000	.00	2.00
96	10.0000	.00	2.00
97	10.0000	.00	2.00
98	10.0000	.00	2.00
99	10.0000	.00	2.00
73	11.5000	.00	2.00
74	11.5000	.00	2.00
75	11.5000	.00	2.00
76	11.5000	.00	2.00
77	11.5000	.00	2.00
78	11.5000	.00	2.00
79	11.5000	.00	2.00
80	11.5000	.00	2.00
81	11.5000	.00	2.00
64	8.5000	.00	2.00
65	8.5000	.00	2.00

66	8.5000	.00	2.00
67	8.5000	.00	2.00
68	8.5000	.00	2.00
69	8.5000	.00	2.00
70	8.5000	.00	2.00
71	8.5000	.00	2.00
72	8.5000	.00	2.00
46	10.0000	.00	2.00
47	10.0000	.00	2.00
48	10.0000	.00	2.00
49	10.0000	.00	2.00
50	10.0000	.00	2.00
51	10.0000	.00	2.00
52	10.0000	.00	2.00
53	10.0000	.00	2.00
54	10.0000	.00	2.00
55	10.0000	.00	2.00
56	10.0000	.00	2.00
57	10.0000	.00	2.00
58	10.0000	.00	2.00
59	10.0000	.00	2.00
60	10.0000	.00	2.00
61	10.0000	.00	2.00
62	10.0000	.00	2.00
63	10.0000	.00	2.00
37	8.5000	.00	2.00
38	8.5000	.00	2.00
39	8.5000	.00	2.00
40	8.5000	.00	2.00
41	8.5000	.00	2.00
42	8.5000	.00	2.00
43	8.5000	.00	2.00
44	8.5000	.00	2.00
45	8.5000	.00	2.00
1	1.8300	.00	2.00
2	1.8300	.00	2.00
3	1.8300	.00	2.00
4	1.8300	.00	2.00
5	1.8300	.00	2.00
6	1.8300	.00	2.00
7	1.8300	.00	2.00
8	1.8300	.00	2.00
9	1.8300	.00	2.00
10	3.3300	.00	2.00
11	3.3300	.00	2.00
12	3.3300	.00	2.00
13	3.3300	.00	2.00
14	3.3300	.00	2.00
15	3.3300	.00	2.00
16	3.3300	.00	2.00
17	3.3300	.00	2.00
18	3.3300	.00	2.00

19	3.3300	.00	2.00
20	3.3300	.00	2.00
21	3.3300	.00	2.00
22	3.3300	.00	2.00
23	3.3300	.00	2.00
24	3.3300	.00	2.00
25	3.3300	.00	2.00
26	3.3300	.00	2.00
27	3.3300	.00	2.00
28	3.8300	.00	2.00
29	3.8300	.00	2.00
30	3.8300	.00	2.00
31	3.8300	.00	2.00
32	3.8300	.00	2.00
33	3.8300	.00	2.00
34	3.8300	.00	2.00
35	3.8300	.00	2.00
36	3.8300	.00	2.00

Element Point Loads

ELEMENT NUMBER	PT. LOAD 1 (KN)	DIST. (M)	PT. LOAD 2 (KN)	DIST. (M)	PT. LOAD 3 (KN)	DIST. (M)
117	4.377	.117	.000	.000	.000	.000
118	3.309	.167	.000	.000	.000	.000
119	3.309	.167	.000	.000	.000	.000
216	4.377	.117	.000	.000	.000	.000
217	3.304	.167	.000	.000	.000	.000
218	3.304	.167	.000	.000	.000	.000
77	37.297	1.000	.000	.000	.000	.000
86	32.432	1.000	.000	.000	.000	.000
95	32.432	1.000	.000	.000	.000	.000
104	17.838	1.000	.000	.000	.000	.000
113	2.391	.217	.000	.000	.000	.000
114	3.309	.167	.000	.000	.000	.000
115	3.309	.167	.000	.000	.000	.000
116	2.391	.217	.000	.000	.000	.000
41	27.567	1.000	.000	.000	.000	.000
50	32.432	1.000	.000	.000	.000	.000
59	32.432	1.000	.000	.000	.000	.000
68	27.567	1.000	.000	.000	.000	.000
109	.334	.317	.000	.000	.000	.000
110	1.103	.167	.000	.000	.000	.000
111	1.103	.167	.000	.000	.000	.000
112	1.459	.117	.000	.000	.000	.000
208	.334	.317	.000	.000	.000	.000
209	1.103	.167	.000	.000	.000	.000
210	1.103	.167	.000	.000	.000	.000
211	1.459	.117	.000	.000	.000	.000

5	5.946	1.000	.000	.000	.000	.000
14	10.811	1.000	.000	.000	.000	.000
23	10.811	1.000	.000	.000	.000	.000
32	12.432	1.000	.000	.000	.000	.000

Joint Loads

LOADED JOINT	EXTERNAL MOM.-X (KN-m)	VERTICAL LOAD-Z (KN)	EXTERNAL MOM.-Y (KN-m)
111	.0000	.0000	.1214
120	.0000	.0000	-.1214

LOAD CASE 4 HB on Lane 1 + Full HA & KEL on 2 + 1/3 on 3

Element Uniform Load :

ELEMENT NUMBER	UNIFORM LOAD (KN/m)	DISTANCE FROM A-END START (m)	END (m)
64	8.5000	.00	2.00
65	8.5000	.00	2.00
66	8.5000	.00	2.00
67	8.5000	.00	2.00
68	8.5000	.00	2.00
69	8.5000	.00	2.00
70	8.5000	.00	2.00
71	8.5000	.00	2.00
72	8.5000	.00	2.00
46	10.0000	.00	2.00
47	10.0000	.00	2.00
48	10.0000	.00	2.00
49	10.0000	.00	2.00
50	10.0000	.00	2.00
51	10.0000	.00	2.00
52	10.0000	.00	2.00
53	10.0000	.00	2.00
54	10.0000	.00	2.00
55	10.0000	.00	2.00
56	10.0000	.00	2.00
57	10.0000	.00	2.00
58	10.0000	.00	2.00
59	10.0000	.00	2.00
60	10.0000	.00	2.00
61	10.0000	.00	2.00
62	10.0000	.00	2.00
63	10.0000	.00	2.00

37	8.5000	.00	2.00
38	8.5000	.00	2.00
39	8.5000	.00	2.00
40	8.5000	.00	2.00
41	8.5000	.00	2.00
42	8.5000	.00	2.00
43	8.5000	.00	2.00
44	8.5000	.00	2.00
45	8.5000	.00	2.00
1	1.8300	.00	2.00
2	1.8300	.00	2.00
3	1.8300	.00	2.00
4	1.8300	.00	2.00
5	1.8300	.00	2.00
6	1.8300	.00	2.00
7	1.8300	.00	2.00
8	1.8300	.00	2.00
9	1.8300	.00	2.00
10	3.3300	.00	2.00
11	3.3300	.00	2.00
12	3.3300	.00	2.00
13	3.3300	.00	2.00
14	3.3300	.00	2.00
15	3.3300	.00	2.00
16	3.3300	.00	2.00
17	3.3300	.00	2.00
18	3.3300	.00	2.00
19	3.3300	.00	2.00
20	3.3300	.00	2.00
21	3.3300	.00	2.00
22	3.3300	.00	2.00
23	3.3300	.00	2.00
24	3.3300	.00	2.00
25	3.3300	.00	2.00
26	3.3300	.00	2.00
27	3.3300	.00	2.00
28	3.8300	.00	2.00
29	3.8300	.00	2.00
30	3.8300	.00	2.00
31	3.8300	.00	2.00
32	3.8300	.00	2.00
33	3.8300	.00	2.00
34	3.8300	.00	2.00
35	3.8300	.00	2.00
36	3.8300	.00	2.00

Element Point Loads

ELEMENT NUMBER	PT. LOAD 1 (KN)	DIST. (M)	PT. LOAD 2 (KN)	DIST. (M)	PT. LOAD 3 (KN)	DIST. (M)
3	81.563	.200	.000	.000	.000	.000
12	112.500	.860	.000	.000	.000	.000
21	112.500	1.520	.000	.000	.000	.000
31	112.500	.190	.000	.000	.000	.000
40	30.938	.850	.000	.000	.000	.000
13	112.500	.660	.000	.000	.000	.000
22	112.500	1.320	.000	.000	.000	.000
31	112.500	1.990	.000	.000	.000	.000
41	30.938	.650	.000	.000	.000	.000
16	112.500	.660	.000	.000	.000	.000
25	112.500	1.320	.000	.000	.000	.000
34	112.500	1.990	.000	.000	.000	.000
44	30.938	.650	.000	.000	.000	.000
7	81.563	1.800	.000	.000	.000	.000
17	112.500	.460	.000	.000	.000	.000
26	112.500	1.120	.000	.000	.000	.000
35	112.500	1.790	.000	.000	.000	.000
45	30.938	.450	.000	.000	.000	.000
113	2.391	.217	.000	.000	.000	.000
114	3.309	.167	.000	.000	.000	.000
115	3.309	.167	.000	.000	.000	.000
116	2.391	.217	.000	.000	.000	.000
41	27.567	1.000	.000	.000	.000	.000
50	32.432	1.000	.000	.000	.000	.000
59	32.432	1.000	.000	.000	.000	.000
68	27.567	1.000	.000	.000	.000	.000
109	.334	.317	.000	.000	.000	.000
110	1.103	.167	.000	.000	.000	.000
111	1.103	.167	.000	.000	.000	.000
112	1.459	.117	.000	.000	.000	.000
208	.334	.317	.000	.000	.000	.000
209	1.103	.167	.000	.000	.000	.000
210	1.103	.167	.000	.000	.000	.000
211	1.459	.117	.000	.000	.000	.000
5	5.946	1.000	.000	.000	.000	.000
14	10.811	1.000	.000	.000	.000	.000
23	10.811	1.000	.000	.000	.000	.000
32	12.432	1.000	.000	.000	.000	.000

Joint Loads

LOADED JOINT	EXTERNAL MOM.-X (KN-m)	VERTICAL LOAD-Z (KN)	EXTERNAL MOM.-Y (KN-m)
4	.0000	-81.5625	.0000
7	.0000	-81.5625	.0000

LOAD COMBINATION DATA

	LOAD COMBINATION NO./FACTORS							
LC	1	2	3	4	5	6	7	8
1	1.20	1.00	.00	.00	.00	.00	.00	.00
2	.00	.00	1.75	1.20	.00	.00	.00	.00
3	.00	.00	.00	.00	1.50	1.20	.00	.00
4	.00	.00	.00	.00	.00	.00	1.30	1.10

LOAD COMBINATION 1 Dead Load at ULS

LOAD COMBINATION 2 Dead Load at SLS

LOAD COMBINATION 3 Superimposed Dead Load at ULS

LOAD COMBINATION 4 Superimposed Dead Load at SLS

LOAD COMBINATION 5 HA & Associates at ULS

LOAD COMBINATION 6 HA & Associates at SLS

LOAD COMBINATION 7 HB & Associates at ULS

LOAD COMBINATION 8 HB & Associates at SLS

OUTPUT INFORMATION

Global Displacements
5 115 10
6 116 10
Element-End Displacements
1 9 1
10 18 1
Element-End Forces
1 9 1
10 18 1
109 119 1
208 218 1
Support Reactions
1 111 10
10 120 10
Comparison of Element-End Forces
1 9 1
100 108 1
10 99 1
120 207 1

SYSTEM DEGREES-OF-FREEDOM = 312
BAND-WIDTH = 33
NO. OF SUPPORTED JOINTS = 24

GLOBAL DISPLACEMENTS

JOINT NO.	LOAD COMBINATION	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad.
5	1	-.5773	-1.7838	-.0859
	2	-.4811	-1.4865	-.0715
	3	-.0045	-.1682	-.0089
	4	-.0031	-.1153	-.0061
	5	.0015	-.3204	-.0182
	6	.0012	-.2563	-.0145
	7	.2780	-1.5789	-.0788
	8	.2352	-1.3360	-.0667
15	1	-.4681	-1.0250	-.0422
	2	-.3901	-.8542	-.0352
	3	-.0072	-.1747	-.0079
	4	-.0050	-.1198	-.0054
	5	.0086	-.3403	-.0167
	6	.0069	-.2723	-.0134
	7	.1466	-2.1636	-.0850
	8	.1240	-1.8307	-.0719
25	1	-.1990	-.7814	-.0354
	2	-.1658	-.6511	-.0295
	3	-.0092	-.1767	-.0080
	4	-.0063	-.1211	-.0055
	5	.0535	-.3732	-.0188
	6	.0428	-.2985	-.0151
	7	-.1441	-2.3078	-.0878
	8	-.1219	-1.9527	-.0743
35	1	-.0755	-.7490	-.0350
	2	-.0629	-.6241	-.0292
	3	-.0101	-.1772	-.0081
	4	-.0069	-.1215	-.0055
	5	.1374	-.5050	-.0277
	6	.1099	-.4040	-.0221
	7	-.4246	-2.1311	-.0830
	8	-.3593	-1.8032	-.0702
45	1	-.0439	-.7608	-.0352
	2	-.0366	-.6340	-.0293
	3	-.0105	-.1773	-.0081
	4	-.0072	-.1215	-.0055
	5	.1398	-.8258	-.0441
	6	.1119	-.6607	-.0352
	7	-.5001	-1.4739	-.0659
	8	-.4232	-1.2472	-.0558
55	1	-.0432	-.7699	-.0353
	2	-.0360	-.6416	-.0294
	3	-.0105	-.1772	-.0081
	4	-.0072	-.1215	-.0055
	5	.0360	-1.0107	-.0510
	6	.0288	-.8085	-.0408

	7	-.3411	-1.0386	-.0505
	8	-.2886	-.8788	-.0427
65	1	-.0478	-.7701	-.0351
	2	-.0399	-.6417	-.0292
	3	-.0106	-.1772	-.0081
	4	-.0072	-.1215	-.0055
	5	-.0437	-1.0415	-.0512
	6	-.0350	-.8332	-.0410
	7	-.2562	-.8677	-.0433
	8	-.2167	-.7342	-.0366
75	1	-.0468	-.7616	-.0344
	2	-.0390	-.6346	-.0286
	3	-.0106	-.1772	-.0081
	4	-.0073	-.1215	-.0056
	5	-.0346	-1.0101	-.0510
	6	-.0277	-.8081	-.0408
	7	-.3068	-.6300	-.0281
	8	-.2596	-.5331	-.0238
85	1	-.0179	-.7504	-.0335
	2	-.0149	-.6253	-.0279
	3	-.0109	-.1772	-.0081
	4	-.0075	-.1215	-.0056
	5	-.0435	-1.1239	-.0568
	6	-.0348	-.8991	-.0454
	7	-.2530	-.1683	-.0054
	8	-.2141	-.1424	-.0046
95	1	.0920	-.7804	-.0361
	2	.0767	-.6503	-.0301
	3	-.0116	-.1766	-.0081
	4	-.0079	-.1211	-.0055
	5	-.0881	-1.0854	-.0539
	6	-.0705	-.8683	-.0431
	7	-.0984	-.0132	-.0008
	8	-.0833	-.0112	-.0007
105	1	.3429	-1.0130	-.0543
	2	.2857	-.8441	-.0452
	3	-.0119	-.1746	-.0080
	4	-.0081	-.1197	-.0055
	5	-.0868	-1.0527	-.0528
	6	-.0694	-.8422	-.0423
	7	-.0261	.0146	.0002
	8	-.0220	.0123	.0002
115	1	.4745	-1.8023	-.0693
	2	.3954	-1.5019	-.0577
	3	-.0100	-.1709	-.0063
	4	-.0068	-.1172	-.0043
	5	-.0701	-1.0204	-.0418
	6	-.0561	-.8163	-.0334
	7	-.0091	.0185	.0004
	8	-.0077	.0157	.0003

JOINT NO.	LOAD COMBINATION	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad.
6	1	-.4746	-1.8023	.0693
	2	-.3955	-1.5019	.0577
	3	.0100	-.1709	.0063
	4	.0069	-.1172	.0043
	5	.0310	-.3252	.0136
	6	.0248	-.2601	.0109
	7	.4357	-1.6102	.0481
	8	.3687	-1.3625	.0407
16	1	-.3429	-1.0129	.0543
	2	-.2858	-.8441	.0452
	3	.0119	-.1746	.0080
	4	.0081	-.1197	.0055
	5	.0500	-.3397	.0175
	6	.0400	-.2717	.0140
	7	.3565	-2.1563	.0893
	8	.3016	-1.8245	.0756
26	1	-.0920	-.7804	.0361
	2	-.0767	-.6503	.0301
	3	.0116	-.1766	.0081
	4	.0080	-.1211	.0056
	5	.1070	-.3734	.0186
	6	.0856	-.2988	.0149
	7	.0961	-2.2811	.1088
	8	.0814	-1.9302	.0920
36	1	.0179	-.7504	.0335
	2	.0150	-.6253	.0279
	3	.0109	-.1772	.0081
	4	.0075	-.1215	.0056
	5	.2101	-.5094	.0232
	6	.1681	-.4075	.0186
	7	-.1944	-2.0945	.1114
	8	-.1645	-1.7723	.0942
46	1	.0468	-.7616	.0344
	2	.0390	-.6347	.0286
	3	.0106	-.1772	.0081
	4	.0073	-.1215	.0056
	5	.2360	-.8310	.0387
	6	.1888	-.6648	.0310
	7	-.3084	-1.4576	.0805
	8	-.2609	-1.2333	.0681
56	1	.0478	-.7701	.0351
	2	.0398	-.6417	.0292
	3	.0106	-.1772	.0081
	4	.0072	-.1215	.0056
	5	.1520	-1.0117	.0500
	6	.1216	-.8094	.0400
	7	-.1968	-1.0356	.0533
	8	-.1665	-.8763	.0451

66	1	.0432	-.7699	.0353
	2	.0360	-.6416	.0294
	3	.0106	-.1772	.0081
	4	.0072	-.1215	.0056
	5	.0826	-1.0399	.0528
	6	.0661	-.8320	.0422
	7	-.1514	-.8672	.0436
	8	-.1281	-.7338	.0369
76	1	.0439	-.7608	.0352
	2	.0366	-.6340	.0293
	3	.0105	-.1772	.0081
	4	.0072	-.1215	.0056
	5	.0969	-1.0109	.0501
	6	.0775	-.8087	.0401
	7	-.2382	-.6236	.0346
	8	-.2015	-.5277	.0293
86	1	.0755	-.7490	.0350
	2	.0629	-.6241	.0292
	3	.0101	-.1772	.0081
	4	.0070	-.1215	.0056
	5	.0898	-1.1251	.0556
	6	.0718	-.9000	.0445
	7	-.2170	-.1624	.0113
	8	-.1836	-.1374	.0096
96	1	.1990	-.7814	.0354
	2	.1659	-.6512	.0295
	3	.0092	-.1766	.0080
	4	.0063	-.1211	.0055
	5	.0449	-1.0848	.0546
	6	.0360	-.8679	.0437
	7	-.0870	-.0132	.0007
	8	-.0736	-.0112	.0006
106	1	.4681	-1.0250	.0422
	2	.3901	-.8542	.0352
	3	.0072	-.1747	.0080
	4	.0050	-.1198	.0055
	5	.0347	-1.0528	.0527
	6	.0277	-.8423	.0422
	7	-.0250	.0138	-.0011
	8	-.0211	.0116	-.0009
116	1	.5773	-1.7838	.0858
	2	.4811	-1.4865	.0715
	3	.0045	-.1682	.0089
	4	.0031	-.1153	.0061
	5	.0203	-1.0038	.0576
	6	.0162	-.8030	.0461
	7	-.0099	.0176	-.0013
	8	-.0084	.0149	-.0011

ELEMENT - END DISPLACEMENTS

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad
1	1	1	.0000	.0000	-.0925
		2	-.2922	-.3813	-.2609
	2	1	.0000	.0000	-.0771
		2	-.2435	-.3178	-.2174
	3	1	.0000	.0000	-.0071
		2	-.0169	-.0335	-.0238
	4	1	.0000	.0000	-.0049
		2	-.0116	-.0229	-.0163
	5	1	.0000	.0000	-.0128
		2	-.0294	-.0610	-.0439
	6	1	.0000	.0000	-.0102
		2	-.0235	-.0488	-.0351
	7	1	.0000	.0000	-.0647
		2	-.1072	-.3268	-.2375
	8	1	.0000	.0000	-.0547
		2	-.0907	-.2765	-.2009
2	1	2	-.2922	-.3813	-.2609
		3	-.4965	-.9517	-.2885
	2	2	-.2435	-.3178	-.2174
		3	-.4137	-.7931	-.2404
	3	2	-.0169	-.0335	-.0238
		3	-.0223	-.0868	-.0275
	4	2	-.0116	-.0229	-.0163
		3	-.0153	-.0595	-.0189
	5	2	-.0294	-.0610	-.0439
		3	-.0374	-.1608	-.0523
	6	2	-.0235	-.0488	-.0351
		3	-.0299	-.1286	-.0418
	7	2	-.1072	-.3268	-.2375
		3	-.0720	-.8531	-.2636
	8	2	-.0907	-.2765	-.2009
		3	-.0609	-.7219	-.2230
3	1	3	-.4965	-.9517	-.2885
		4	-.5912	-1.4722	-.2174
	2	3	-.4137	-.7931	-.2404
		4	-.4926	-1.2268	-.1812
	3	3	-.0223	-.0868	-.0275
		4	-.0169	-.1371	-.0214
	4	3	-.0153	-.0595	-.0189
		4	-.0116	-.0940	-.0147
	5	3	-.0374	-.1608	-.0523
		4	-.0247	-.2580	-.0422
	6	3	-.0299	-.1286	-.0418
		4	-.0198	-.2064	-.0337
	7	3	-.0720	-.8531	-.2636
		4	.0851	-1.3095	-.1868

	8	3	-.0609	-.7219	-.2230
		4	.0720	-1.1080	-.1581
4	1	4	-.5912	-1.4722	-.2174
		5	-.5773	-1.7838	-.0859
	2	4	-.4926	-1.2268	-.1812
		5	-.4811	-1.4865	-.0715
	3	4	-.0169	-.1371	-.0214
		5	-.0045	-.1682	-.0089
	4	4	-.0116	-.0940	-.0147
		5	-.0031	-.1153	-.0061
	5	4	-.0247	-.2580	-.0422
		5	.0015	-.3204	-.0182
	6	4	-.0198	-.2064	-.0337
		5	.0012	-.2563	-.0145
	7	4	.0851	-1.3095	-.1868
		5	.2780	-1.5789	-.0788
	8	4	.0720	-1.1080	-.1581
		5	.2352	-1.3360	-.0667
5	1	5	-.5773	-1.7838	-.0859
		6	-.4746	-1.8023	.0693
	2	5	-.4811	-1.4865	-.0715
		6	-.3955	-1.5019	.0577
	3	5	-.0045	-.1682	-.0089
		6	.0100	-.1709	.0063
	4	5	-.0031	-.1153	-.0061
		6	.0069	-.1172	.0043
	5	5	.0015	-.3204	-.0182
		6	.0310	-.3252	.0136
	6	5	.0012	-.2563	-.0145
		6	.0248	-.2601	.0109
	7	5	.2780	-1.5789	-.0788
		6	.4357	-1.6102	.0481
	8	5	.2352	-1.3360	-.0667
		6	.3687	-1.3625	.0407
6	1	6	-.4746	-1.8023	.0693
		7	-.3181	-1.5181	.2099
	2	6	-.3955	-1.5019	.0577
		7	-.2651	-1.2651	.1749
	3	6	.0100	-.1709	.0063
		7	.0214	-.1437	.0202
	4	6	.0069	-.1172	.0043
		7	.0147	-.0986	.0139
	5	6	.0310	-.3252	.0136
		7	.0520	-.2699	.0401
	6	6	.0248	-.2601	.0109
		7	.0416	-.2159	.0321
	7	6	.4357	-1.6102	.0481
		7	.5163	-1.3876	.1716
	8	6	.3687	-1.3625	.0407
		7	.4369	-1.1741	.1452
7	1	7	-.3181	-1.5181	.2099
		8	-.1555	-1.0008	.2945

	2	7	-.2651	-1.2651	.1749
		8	-.1296	-.8340	.2454
	3	7	.0214	-.1437	.0202
		8	.0252	-.0938	.0283
	4	7	.0147	-.0986	.0139
		8	.0173	-.0643	.0194
	5	7	.0520	-.2699	.0401
		8	.0559	-.1734	.0537
	6	7	.0416	-.2159	.0321
		8	.0447	-.1387	.0430
	7	7	.5163	-1.3876	.1716
		8	.4854	-.9366	.2728
	8	7	.4369	-1.1741	.1452
		8	.4107	-.7925	.2308
8	1	8	-.1555	-1.0008	.2945
		9	-.0386	-.4084	.2761
	2	8	-.1296	-.8340	.2454
		9	-.0321	-.3403	.2301
	3	8	.0252	-.0938	.0283
		9	.0181	-.0373	.0260
	4	8	.0173	-.0643	.0194
		9	.0124	-.0256	.0178
	5	8	.0559	-.1734	.0537
		9	.0382	-.0679	.0478
	6	8	.0447	-.1387	.0430
		9	.0306	-.0543	.0382
	7	8	.4854	-.9366	.2728
		9	.3108	-.3716	.2633
	8	8	.4107	-.7925	.2308
		9	.2630	-.3144	.2228
9	1	9	-.0386	-.4084	.2761
		10	.0000	.0000	.1006
	2	9	-.0321	-.3403	.2301
		10	.0000	.0000	.0838
	3	9	.0181	-.0373	.0260
		10	.0000	.0000	.0083
	4	9	.0124	-.0256	.0178
		10	.0000	.0000	.0057
	5	9	.0382	-.0679	.0478
		10	.0000	.0000	.0149
	6	9	.0306	-.0543	.0382
		10	.0000	.0000	.0119
	7	9	.3108	-.3716	.2633
		10	.0000	.0000	.0765
	8	9	.2630	-.3144	.2228
		10	.0000	.0000	.0647

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	X - ROTATION 1.0E-3 rad.	Z - MOVEMENT (mm)	Y - ROTATION 1.0E-3 rad
10	1	11	.0000	.0000	-.0313

		12	-.2801	-.2006	-.1506
	2	11	.0000	.0000	-.0261
		12	-.2334	-.1672	-.1255
	3	11	.0000	.0000	-.0065
		12	-.0239	-.0350	-.0255
	4	11	.0000	.0000	-.0044
		12	-.0164	-.0240	-.0175
	5	11	.0000	.0000	-.0119
		12	-.0414	-.0653	-.0481
	6	11	.0000	.0000	-.0095
		12	-.0331	-.0522	-.0385
	7	11	.0000	.0000	-.0791
		12	-.2327	-.4286	-.3177
	8	11	.0000	.0000	-.0669
		12	-.1969	-.3626	-.2688
11	1	12	-.2801	-.2006	-.1506
		13	-.4542	-.5391	-.1735
	2	12	-.2334	-.1672	-.1255
		13	-.3785	-.4493	-.1446
	3	12	-.0239	-.0350	-.0255
		13	-.0309	-.0918	-.0291
	4	12	-.0164	-.0240	-.0175
		13	-.0212	-.0630	-.0199
	5	12	-.0414	-.0653	-.0481
		13	-.0496	-.1741	-.0565
	6	12	-.0331	-.0522	-.0385
		13	-.0397	-.1393	-.0452
	7	12	-.2327	-.4286	-.3177
		13	-.2516	-1.1512	-.3739
	8	12	-.1969	-.3626	-.2688
		13	-.2129	-.9741	-.3163
12	1	13	-.4542	-.5391	-.1735
		14	-.5137	-.8502	-.1277
	2	13	-.3785	-.4493	-.1446
		14	-.4281	-.7085	-.1065
	3	13	-.0309	-.0918	-.0291
		14	-.0236	-.1442	-.0218
	4	13	-.0212	-.0630	-.0199
		14	-.0162	-.0989	-.0149
	5	13	-.0496	-.1741	-.0565
		14	-.0293	-.2776	-.0439
	6	13	-.0397	-.1393	-.0452
		14	-.0234	-.2221	-.0351
	7	13	-.2516	-1.1512	-.3739
		14	-.0880	-1.8112	-.2654
	8	13	-.2129	-.9741	-.3163
		14	-.0745	-1.5326	-.2246
13	1	14	-.5137	-.8502	-.1277
		15	-.4681	-1.0250	-.0422
	2	14	-.4281	-.7085	-.1065
		15	-.3901	-.8542	-.0352
	3	14	-.0236	-.1442	-.0218

		15	-.0072	-.1747	-.0079
	4	14	-.0162	-.0989	-.0149
		15	-.0050	-.1198	-.0054
	5	14	-.0293	-.2776	-.0439
		15	.0086	-.3403	-.0167
	6	14	-.0234	-.2221	-.0351
		15	.0069	-.2723	-.0134
	7	14	-.0880	-1.8112	-.2654
		15	.1466	-2.1636	-.0850
	8	14	-.0745	-1.5326	-.2246
		15	.1240	-1.8307	-.0719
14	1	15	-.4681	-1.0250	-.0422
		16	-.3429	-1.0129	.0543
	2	15	-.3901	-.8542	-.0352
		16	-.2858	-.8441	.0452
	3	15	-.0072	-.1747	-.0079
		16	.0119	-.1746	.0080
	4	15	-.0050	-.1198	-.0054
		16	.0081	-.1197	.0055
	5	15	.0086	-.3403	-.0167
		16	.0500	-.3397	.0175
	6	15	.0069	-.2723	-.0134
		16	.0400	-.2717	.0140
	7	15	.1466	-2.1636	-.0850
		16	.3565	-2.1563	.0893
	8	15	.1240	-1.8307	-.0719
		16	.3016	-1.8245	.0756
15	1	16	-.3429	-1.0129	.0543
		17	-.1789	-.8202	.1337
	2	16	-.2858	-.8441	.0452
		17	-.1491	-.6835	.1114
	3	16	.0119	-.1746	.0080
		17	.0275	-.1439	.0219
	4	16	.0081	-.1197	.0055
		17	.0188	-.0987	.0150
	5	16	.0500	-.3397	.0175
		17	.0786	-.2759	.0443
	6	16	.0400	-.2717	.0140
		17	.0628	-.2207	.0355
	7	16	.3565	-2.1563	.0893
		17	.4942	-1.8168	.2463
	8	16	.3016	-1.8245	.0756
		17	.4182	-1.5373	.2084
16	1	17	-.1789	-.8202	.1337
		18	-.0297	-.5070	.1702
	2	17	-.1491	-.6835	.1114
		18	-.0248	-.4225	.1418
	3	17	.0275	-.1439	.0219
		18	.0336	-.0914	.0291
	4	17	.0188	-.0987	.0150
		18	.0230	-.0627	.0200
	5	17	.0786	-.2759	.0443

		18	.0831	-.1721	.0564
	6	17	.0628	-.2207	.0355
		18	.0665	-.1377	.0452
	7	17	.4942	-1.8168	.2463
		18	.5196	-1.1916	.3623
	8	17	.4182	-1.5373	.2084
		18	.4397	-1.0083	.3066
17	1	18	-.0297	-.5070	.1702
		19	.0447	-.1828	.1409
	2	18	-.0248	-.4225	.1418
		19	.0373	-.1524	.1174
	3	18	.0336	-.0914	.0291
		19	.0252	-.0346	.0254
	4	18	.0230	-.0627	.0200
		19	.0173	-.0237	.0174
	5	18	.0831	-.1721	.0564
		19	.0572	-.0640	.0475
	6	18	.0665	-.1377	.0452
		19	.0458	-.0512	.0380
	7	18	.5196	-1.1916	.3623
		19	.3656	-.4588	.3346
	8	18	.4397	-1.0083	.3066
		19	.3094	-.3882	.2831
18	1	19	.0447	-.1828	.1409
		20	.0000	.0000	.0255
	2	19	.0373	-.1524	.1174
		20	.0000	.0000	.0213
	3	19	.0252	-.0346	.0254
		20	.0000	.0000	.0062
	4	19	.0173	-.0237	.0174
		20	.0000	.0000	.0042
	5	19	.0572	-.0640	.0475
		20	.0000	.0000	.0113
	6	19	.0458	-.0512	.0380
		20	.0000	.0000	.0090
	7	19	.3656	-.4588	.3346
		20	.0000	.0000	.0851
	8	19	.3094	-.3882	.2831
		20	.0000	.0000	.0720

ELEMENT - END FORCES

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	TORSION - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
1	1	1	14.3672	173.7945	458.9638
		2	-14.3672	-126.1425	-159.0270

	2	1	11.9726	144.8288	382.4698
		2	-11.9726	-105.1188	-132.5225
	3	1	.8296	15.2359	43.8212
		2	-.8296	-11.5399	-17.0453
	4	1	.5689	10.4475	30.0488
		2	-.5689	-7.9131	-11.6882
	5	1	1.4471	25.7151	79.5451
		2	-1.4471	-20.2251	-33.6050
	6	1	1.1576	20.5721	63.6361
		2	-1.1576	-16.1801	-26.8840
	7	1	5.2728	134.5144	441.7554
		2	-5.2728	-129.7564	-177.4847
	8	1	4.4616	113.8199	373.7931
		2	-4.4616	-109.7939	-150.1794
2	1	2	10.0422	136.0863	169.5831
		3	-10.0422	-88.4343	54.9371
	2	2	8.3685	113.4053	141.3193
		3	-8.3685	-73.6953	45.7809
	3	2	.2658	12.3755	17.7348
		3	-.2658	-8.6795	3.3203
	4	2	.1822	8.4861	12.1610
		3	-.1822	-5.9517	2.2768
	5	2	.3927	21.8292	34.9201
		3	-.3927	-16.3392	3.2482
	6	2	.3141	17.4633	27.9361
		3	-.3141	-13.0713	2.5986
	7	2	-1.7348	138.2104	183.2901
		3	1.7348	-133.4524	88.3724
	8	2	-1.4679	116.9473	155.0917
		3	1.4679	-112.9213	74.7767
3	1	3	4.6556	101.7325	-41.2217
		4	-4.6556	-54.0805	197.0345
	2	3	3.8797	84.7771	-34.3514
		4	-3.8797	-45.0671	164.1954
	3	3	-.2660	9.3890	-2.7471
		4	.2660	-5.6930	17.8290
	4	3	-.1824	6.4382	-1.8837
		4	.1824	-3.9038	12.2256
	5	3	-.6236	17.8566	-2.0122
		4	.6236	-12.3666	32.2353
	6	3	-.4989	14.2853	-1.6098
		4	.4989	-9.8933	25.7882
	7	3	-7.7213	137.4964	-87.1389
		4	7.7213	-26.7072	166.5180
	8	3	-6.5334	116.3431	-73.7329
		4	6.5334	-22.5984	140.8999
4	1	4	-.6790	68.4786	-182.6017
		5	.6790	-20.8266	271.9068
	2	4	-.5658	57.0655	-152.1681
		5	.5658	-17.3555	226.5890
	3	4	-.6099	6.1134	-17.4864
		5	.6099	-2.4174	26.0171

	4	4	-.4182	4.1920	-11.9907
		5	.4182	-1.6576	17.8403
	5	4	-1.2901	13.5060	-31.2680
		5	1.2901	-8.0160	52.7900
	6	4	-1.0321	10.8048	-25.0144
		5	1.0321	-6.4128	42.2320
	7	4	-9.4827	22.7950	-171.8315
		5	9.4827	-18.0370	212.6634
	8	4	-8.0239	19.2881	-145.3958
		5	8.0239	-15.2621	179.9460
5	1	5	-5.0530	34.2223	-258.9495
		6	5.0530	13.4297	279.7433
	2	5	-4.2108	28.5186	-215.7912
		6	4.2108	11.1914	233.1194
	3	5	-.7110	2.5174	-25.9241
		6	.7110	1.1786	27.2628
	4	5	-.4875	1.7262	-17.7765
		6	.4875	.8082	18.6945
	5	5	-1.4514	8.6310	-52.1966
		6	1.4514	5.7779	55.0497
	6	5	-1.1611	6.9048	-41.7573
		6	1.1611	4.6223	44.0398
	7	5	-7.7551	9.3339	-220.9627
		6	7.7551	3.1538	227.1428
	8	5	-6.5620	7.8979	-186.9685
		6	6.5620	2.6686	192.1978
6	1	6	-7.6946	-3.0442	-270.2743
		7	7.6946	50.6962	216.5335
	2	6	-6.4121	-2.5368	-225.2285
		7	6.4121	42.2468	180.4446
	3	6	-.5620	-1.3895	-27.4166
		7	.5620	5.0855	20.9417
	4	6	-.3854	-.9528	-18.8000
		7	.3854	3.4872	14.3600
	5	6	-1.0324	-5.8357	-54.9718
		7	1.0324	11.3257	37.8103
	6	6	-.8259	-4.6686	-43.9775
		7	.8259	9.0606	30.2482
	7	6	-3.9635	-13.5691	-236.0410
		7	3.9635	18.3272	204.1448
	8	6	-3.3538	-11.4816	-199.7270
		7	3.3538	15.5076	172.7379
7	1	7	-7.9926	-45.1546	-212.2703
		8	7.9926	92.8066	74.3092
	2	7	-6.6605	-37.6288	-176.8919
		8	6.6605	77.3388	61.9243
	3	7	-.1867	-5.5844	-21.3366
		8	.1867	9.2804	6.4718
	4	7	-.1281	-3.8293	-14.6308
		8	.1281	6.3637	4.4378
	5	7	-.1925	-11.9238	-38.1773
		8	.1925	17.4138	8.8398

	6	7	-.1540	-9.5391	-30.5419
		8	.1540	13.9311	7.0718
	7	7	1.5207	-29.6184	-213.0988
		8	-1.5207	140.4076	127.8981
	8	7	1.2867	-25.0617	-180.3144
		8	-1.2867	118.8064	108.2215
8	1	8	-5.7497	-93.2292	-76.1242
		9	5.7497	140.8811	-157.9859
	2	8	-4.7914	-77.6910	-63.4368
		9	4.7914	117.4010	-131.6549
	3	8	.3481	-10.0142	-7.0796
		9	-.3481	13.7102	-16.6448
	4	8	.2387	-6.8669	-4.8546
		9	-.2387	9.4013	-11.4136
	5	8	.8718	-18.4465	-9.6146
		9	-.8718	23.9365	-32.7686
	6	8	.6974	-14.7572	-7.6916
		9	-.6974	19.1492	-26.2148
	7	8	8.5814	-152.5114	-137.1369
		9	-8.5814	157.2694	-172.6434
	8	8	7.2612	-129.0481	-116.0389
		9	-7.2612	133.0741	-146.0829
9	1	9	-1.8961	-146.2909	151.4244
		10	1.8961	193.9429	-491.6581
	2	9	-1.5801	-121.9091	126.1870
		10	1.5801	161.6191	-409.7150
	3	9	.8921	-14.5247	15.9388
		10	-.8921	18.2207	-48.6842
	4	9	.6117	-9.9598	10.9295
		10	-.6117	12.4942	-33.3835
	5	9	1.8785	-25.1986	31.7154
		10	-1.8785	30.6886	-87.6026
	6	9	1.5028	-20.1589	25.3724
		10	-1.5028	24.5509	-70.0821
	7	9	15.2825	-167.9747	164.4409
		10	-15.2825	172.7327	-505.1481
	8	9	12.9313	-142.1324	139.1423
		10	-12.9313	146.1584	-427.4330

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	TORSION - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
10	1	11	11.5070	179.7903	520.3768
		12	-11.5070	-150.3903	-190.1967
	2	11	9.5892	149.8252	433.6473
		12	-9.5892	-123.3252	-158.4972
	3	11	.9833	30.1807	83.8860
		12	-.9833	-23.4607	-30.2447
	4	11	.6742	20.6953	57.5218
		12	-.6742	-16.0873	-20.7392

	5	11	1.7009	52.2053	155.2061
		12	-1.7009	-42.2153	-60.7857
	6	11	1.3607	41.7642	124.1649
		12	-1.3607	-33.7722	-48.6286
	7	11	9.5597	284.6891	983.0569
		12	-9.5597	-276.0311	-422.3373
	8	11	8.0890	240.8908	831.8174
		12	-8.0890	-233.5648	-357.3624
11	1	12	7.1491	142.4713	200.0352
		13	-7.1491	-113.0713	55.5074
	2	12	5.9576	118.7261	166.6960
		13	-5.9576	-94.2261	46.2562
	3	12	.2871	23.3932	31.7066
		13	-.2871	-16.6732	8.3598
	4	12	.1969	16.0410	21.7416
		13	-.1969	-11.4330	5.7324
	5	12	.3382	42.2400	63.6981
		13	-.3382	-32.2500	10.7918
	6	12	.2706	33.7920	50.9585
		13	-.2706	-25.8000	8.6335
	7	12	.7763	278.1719	440.3461
		13	-.7763	-269.5139	107.3393
	8	12	.6569	235.3762	372.6006
		13	-.6569	-228.0502	90.8255
12	1	13	2.4466	101.3162	-42.8920
		14	-2.4466	-71.9162	216.1244
	2	13	2.0388	84.4302	-35.7433
		14	-2.0388	-59.9302	180.1037
	3	13	-.3027	16.6619	-7.0721
		14	.3027	-9.9419	33.6757
	4	13	-.2076	11.4253	-4.8494
		14	.2076	-6.8173	23.0919
	5	13	-.8357	32.4625	-7.8463
		14	.8357	-22.4725	62.7813
	6	13	-.6686	25.9700	-6.2770
		14	.6686	-17.9780	50.2251
	7	13	-6.7193	276.1195	-93.0719
		14	6.7193	-121.2115	469.9291
	8	13	-5.6856	233.6396	-78.7531
		14	5.6856	-102.5636	397.6323
13	1	14	-1.8747	58.1126	-203.1052
		15	1.8747	-28.7126	289.9312
	2	14	-1.5622	48.4272	-169.2543
		15	1.5622	-23.9272	241.6093
	3	14	-.6709	9.9820	-32.8785
		15	.6709	-3.2620	46.1227
	4	14	-.4601	6.8448	-22.5453
		15	.4601	-2.2368	31.6270
	5	14	-1.5575	22.8793	-60.3250
		15	1.5575	-12.8893	96.0937
	6	14	-1.2460	18.3035	-48.2600
		15	1.2460	-10.3115	76.8749

	7	14	-9.6369	131.1632	-467.6154
		15	9.6369	23.7448	525.3107
	8	14	-8.1543	110.9842	-395.6746
		15	8.1543	20.0918	444.4937
14	1	15	-5.1419	14.5086	-278.7415
		16	5.1419	14.8914	278.3587
	2	15	-4.2849	12.0905	-232.2845
		16	4.2849	12.4095	231.9656
	3	15	-.7847	3.3144	-45.9111
		16	.7847	3.4056	45.8200
	4	15	-.5381	2.2727	-31.4819
		16	.5381	2.3353	31.4194
	5	15	-1.7001	13.4144	-94.4515
		16	1.7001	12.7918	95.0736
	6	15	-1.3601	10.7315	-75.5612
		16	1.3601	10.2335	76.0589
	7	15	-8.6224	-14.6527	-533.2252
		16	8.6224	37.3648	481.2065
	8	15	-7.2959	-12.3985	-451.1906
		16	7.2959	31.6163	407.1747
15	1	16	-6.7374	-27.7633	-270.9685
		17	6.7374	57.1633	186.0424
	2	16	-5.6145	-23.1361	-225.8071
		17	5.6145	47.6361	155.0353
	3	16	-.6404	-3.3688	-46.1953
		17	.6404	10.0888	32.7376
	4	16	-.4391	-2.3100	-31.6768
		17	.4391	6.9180	22.4487
	5	16	-1.1725	-12.2440	-94.5932
		17	1.1725	22.2340	60.1155
	6	16	-.9380	-9.7952	-75.6745
		17	.9380	17.7872	48.0924
	7	16	-5.6587	-29.7751	-493.9713
		17	5.6587	38.4331	425.7631
	8	16	-4.7881	-25.1944	-417.9757
		17	4.7881	32.5204	360.2611
16	1	17	-6.1285	-66.8385	-183.9659
		18	6.1285	96.2385	20.8896
	2	17	-5.1071	-55.6987	-153.3049
		18	5.1071	80.1987	17.4080
	3	17	-.2505	-10.0725	-33.6495
		18	.2505	16.7925	6.7846
	4	17	-.1717	-6.9069	-23.0739
		18	.1717	11.5149	4.6523
	5	17	-.1868	-21.7444	-60.6260
		18	.1868	31.7344	7.1474
	6	17	-.1494	-17.3955	-48.5008
		18	.1494	25.3875	5.7179
	7	17	-1.0432	-32.6594	-442.1769
		18	1.0432	187.5674	172.2267
	8	17	-.8827	-27.6348	-374.1497
		18	.8827	158.7109	145.7303

17	1	18	-3.0566	-101.0388	-24.6299
		19	3.0566	130.4388	-206.8473
	2	18	-2.5472	-84.1990	-20.5249
		19	2.5472	108.6990	-172.3727
	3	18	.3453	-16.7743	-8.1026
		19	-.3453	23.4943	-32.1660
	4	18	.2367	-11.5024	-5.5561
		19	-.2367	16.1104	-22.0567
	5	18	1.0630	-31.3251	-8.4948
		19	-1.0630	41.3151	-64.1452
	6	18	.8504	-25.0601	-6.7959
		19	-.8504	33.0521	-51.3162
	7	18	6.3257	-185.0496	-193.2337
		19	-6.3257	339.9576	-410.7481
	8	18	5.3525	-156.5804	-163.5054
		19	-5.3525	287.6564	-347.5561
18	1	19	1.8363	-130.0302	199.1292
		20	-1.8363	159.4302	-488.5894
	2	19	1.5303	-108.3585	165.9409
		20	-1.5303	132.8585	-407.1578
	3	19	1.0335	-23.4559	30.7485
		20	-1.0335	30.1759	-84.3803
	4	19	.7087	-16.0840	21.0847
		20	-.7087	20.6920	-57.8608
	5	19	2.3507	-41.0150	62.2814
		20	-2.3507	51.0050	-154.3014
	6	19	1.8805	-32.8120	49.8251
		20	-1.8805	40.8040	-123.4412
	7	19	15.0188	-340.4837	390.0470
		20	-15.0188	349.1416	-1079.6720
	8	19	12.7082	-288.1016	330.0398
		20	-12.7082	295.4276	-913.5687

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	TORSION - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
109	1	1	-8.5049	-428.8144	-522.0601
		11	8.5049	460.7796	-383.7760
	2	1	-7.0874	-357.3453	-435.0501
		11	7.0874	383.9830	-319.8133
	3	1	-.0953	-46.8860	-50.2495
		11	.0953	48.9053	-48.9430
	4	1	-.0653	-32.1504	-34.4568
		11	.0653	33.5351	-33.5609
	5	1	-.1249	-88.1724	-91.2411
		11	.1249	88.6729	-89.1842
	6	1	-.0999	-70.5379	-72.9929
		11	.0999	70.9383	-71.3474
	7	1	2.0036	-516.0589	-508.2296
		11	-2.0036	516.4927	-543.4786

	8	1	1.6953	-436.6652	-430.0405
		11	-1.6953	437.0323	-459.8665
110	1	11	-.3196	-200.8694	-218.1886
		21	.3196	232.8346	-223.4340
	2	11	-.2663	-167.3912	-181.8238
		21	.2663	194.0288	-186.1950
	3	11	.0293	-45.1814	-47.4216
		21	-.0293	47.2007	-48.2995
	4	11	.0201	-30.9815	-32.5177
		21	-.0201	32.3662	-33.1196
	5	11	.1361	-87.3064	-89.1272
		21	-.1361	88.9610	-91.7675
	6	11	.1089	-69.8451	-71.3018
		21	-.1089	71.1688	-73.4140
	7	11	.3223	-575.1383	-584.0440
		21	-.3223	576.5723	-589.9156
	8	11	.2727	-486.6555	-494.1911
		21	-.2727	487.8689	-499.1594
111	1	21	-.2026	-187.3805	-203.4276
		31	.2026	219.3457	-210.7245
	2	21	-.1688	-156.1504	-169.5230
		31	.1688	182.7881	-175.6038
	3	21	-.0032	-45.8542	-48.3920
		31	.0032	47.8735	-48.6993
	4	21	-.0022	-31.4429	-33.1831
		31	.0022	32.8275	-33.3938
	5	21	.4070	-101.3357	-101.0379
		31	-.4070	102.9903	-108.4277
	6	21	.3256	-81.0686	-80.8303
		31	-.3256	82.3923	-86.7422
	7	21	-.9741	-558.3027	-578.2675
		31	.9741	559.7368	-561.4063
	8	21	-.8242	-472.4100	-489.3033
		31	.8242	473.6234	-475.0361
112	1	31	.1238	-185.3450	-198.4932
		41	-.1238	217.3102	-211.5136
	2	31	.1032	-154.4542	-165.4110
		41	-.1032	181.0918	-176.2613
	3	31	.0005	-45.7842	-48.2876
		41	-.0005	47.8035	-48.6611
	4	31	.0004	-31.3949	-33.1115
		41	-.0004	32.7795	-33.3676
	5	31	1.9339	-161.2578	-149.2271
		41	-1.9339	163.4461	-183.3782
	6	31	1.5471	-129.0062	-119.3816
		41	-1.5471	130.7569	-146.7025
	7	31	-3.4071	-444.6610	-484.3675
		41	3.4071	446.5576	-424.8326
	8	31	-2.8829	-376.2516	-409.8494
		41	2.8829	377.8564	-359.4738
113	1	41	.0510	-189.8601	-203.7291
		51	-.0510	221.8253	-215.4729

	2	41	.0425	-158.2168	-169.7742
		51	-.0425	184.8544	-179.5607
	3	41	-.0004	-45.7878	-48.2994
		51	.0004	47.8071	-48.6567
	4	41	-.0003	-31.3973	-33.1196
		51	.0003	32.7820	-33.3646
	5	41	.9483	-234.4006	-233.2823
		51	-.9483	237.9871	-250.6049
	6	41	.7586	-187.5205	-186.6259
		51	-.7586	190.3897	-200.4840
	7	41	-2.0025	-303.7950	-329.4258
		51	2.0025	306.9033	-294.9140
	8	41	-1.6944	-257.0573	-278.7449
		51	1.6944	259.6874	-249.5427
114	1	51	.0051	-191.3084	-205.6064
		61	-.0051	223.2735	-216.5450
	2	51	.0042	-159.4236	-171.3387
		61	-.0042	186.0613	-180.4541
	3	51	-.0001	-45.7754	-48.2841
		61	.0001	47.7948	-48.6468
	4	51	-.0001	-31.3889	-33.1091
		61	.0001	32.7735	-33.3578
	5	51	.1645	-261.7484	-269.3462
		61	-.1645	266.7125	-272.9906
	6	51	.1316	-209.3987	-215.4770
		61	-.1316	213.3700	-218.3925
	7	51	-.6328	-234.5137	-248.0362
		61	.6328	238.8159	-237.5991
	8	51	-.5354	-198.4347	-209.8768
		61	.5354	202.0750	-201.0454
115	1	61	-.0280	-190.7172	-205.2941
		71	.0280	222.6824	-215.6532
	2	61	-.0233	-158.9310	-171.0784
		71	.0233	185.5686	-179.7110
	3	61	.0004	-45.7829	-48.2877
		71	-.0004	47.8023	-48.6584
	4	61	.0003	-31.3940	-33.1116
		71	-.0003	32.7787	-33.3658
	5	61	-.4893	-253.3595	-266.5361
		71	.4893	258.3236	-258.7163
	6	61	-.3914	-202.6876	-213.2289
		71	.3914	206.6589	-206.9730
	7	61	-.8016	-197.4630	-211.7891
		71	.8016	201.7652	-198.3916
	8	61	-.6783	-167.0841	-179.2062
		71	.6783	170.7244	-167.8698
116	1	71	-.0998	-187.4174	-202.5637
		81	.0998	219.3826	-211.6638
	2	71	-.0831	-156.1812	-168.8031
		81	.0831	182.8188	-176.3865
	3	71	-.0018	-45.7462	-48.2693
		81	.0018	47.7655	-48.6021

	4	71	-.0012	-31.3688	-33.0990
		81	.0012	32.7535	-33.3272
	5	71	.9463	-266.5618	-266.0479
		81	-.9463	270.1483	-283.3364
	6	71	.7571	-213.2495	-212.8383
		81	-.7571	216.1187	-226.6691
	7	71	-2.9283	-102.3257	-132.3954
		81	2.9283	105.4340	-81.6490
	8	71	-2.4778	-86.5833	-112.0269
		81	2.4778	89.2134	-69.0877
117	1	81	.2524	-191.3605	-203.4909
		91	-.2524	223.3256	-218.7666
	2	81	.2103	-159.4671	-169.5757
		91	-.2103	186.1047	-182.3055
	3	81	.0065	-45.8687	-48.3211
		91	-.0065	47.8881	-48.7999
	4	81	.0045	-31.4529	-33.1345
		91	-.0045	32.8375	-33.4628
	5	81	-.3343	-279.3421	-293.3139
		91	.3343	285.9071	-288.1744
	6	81	-.2674	-223.4737	-234.6511
		91	.2674	228.7257	-230.5395
	7	81	-.5920	-14.4020	-19.8556
		91	.5920	14.4020	-9.4744
	8	81	-.5009	-12.1863	-16.8009
		91	.5009	12.1863	-8.0168
118	1	91	-.5880	-182.6916	-202.0322
		101	.5880	214.6567	-202.5707
	2	91	-.4900	-152.2430	-168.3602
		101	.4900	178.8806	-168.8089
	3	91	-.0630	-44.4115	-47.4464
		101	.0630	46.4308	-46.7068
	4	91	-.0432	-30.4536	-32.5347
		101	.0432	31.8383	-32.0275
	5	91	-.4459	-260.8220	-273.7546
		101	.4459	265.7861	-266.6952
	6	91	-.3567	-208.6576	-219.0037
		101	.3567	212.6289	-213.3562
	7	91	-.0743	2.8085	2.2087
		101	.0743	-2.8085	3.5107
	8	91	-.0628	2.3764	1.8689
		101	.0628	-2.3764	2.9706
119	1	101	10.4426	-437.2441	-364.5211
		111	-10.4426	469.2093	-558.4819
	2	101	8.7022	-364.3701	-303.7676
		111	-8.7022	391.0077	-465.4015
	3	101	.2872	-50.2052	-50.2756
		111	-.2872	52.2246	-55.6767
	4	101	.1970	-34.4265	-34.4747
		111	-.1970	35.8111	-38.1783
	5	101	1.6264	-291.3143	-286.6348
		111	-1.6264	296.2784	-315.9131

	6	101	1.3011	-233.0514	-229.3078
		111	-1.3011	237.0227	-252.7305
	7	101	-.0411	5.7880	5.5334
		111	.0411	-5.7880	6.2540
	8	101	-.0348	4.8975	4.6821
		111	.0348	-4.8975	5.2918

ELEMENT NUMBER	LOAD COMB.	JOINT NO.	TORSION - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
208	1	10	10.4435	469.2175	558.4982
		20	-10.4435	-437.2523	364.5215
	2	10	8.7029	391.0146	465.4152
		20	-8.7029	-364.3769	303.7679
	3	10	.2876	53.8904	55.7235
		20	-.2876	-51.8711	50.3165
	4	10	.1972	36.9534	38.2104
		20	-.1972	-35.5687	34.5028
	5	10	.5082	94.4580	100.2744
		20	-.5082	-93.9575	91.2299
	6	10	.4065	75.5664	80.2195
		20	-.4065	-75.1660	72.9839
	7	10	-1.1964	580.7452	580.5441
		20	1.1964	-580.3113	601.4063
	8	10	-1.0123	491.3998	491.2296
		20	1.0123	-491.0327	508.8822
209	1	20	-.5882	214.6459	202.5582
		30	.5882	-182.6807	202.0227
	2	20	-.4902	178.8716	168.7985
		30	.4902	-152.2339	168.3522
	3	20	-.0630	48.0895	46.7428
		30	.0630	-46.0701	47.4836
	4	20	-.0432	32.9756	32.0522
		30	.0432	-31.5910	32.5602
	5	20	-.2127	87.9810	86.3022
		30	.2127	-86.3264	89.7786
	6	20	-.1702	70.3848	69.0418
		30	.1702	-69.0611	71.8229
	7	20	-.8657	635.0115	637.7842
		30	.8657	-633.5775	652.7449
	8	20	-.7325	537.3174	539.6636
		30	.7325	-536.1041	552.3227
210	1	30	.2522	223.3249	218.7640
		40	-.2522	-191.3597	203.4921
	2	30	.2102	186.1040	182.3033
		40	-.2102	-159.4664	169.5767
	3	30	.0065	49.5495	48.8389
		40	-.0065	-47.5301	48.3609
	4	30	.0044	33.9768	33.4895
		40	-.0044	-32.5921	33.1618

	5	30	-.5900	108.7144	104.1065
		40	.5900	-107.0597	114.1983
	6	30	-.4720	86.9715	83.2852
		40	.4720	-85.6478	91.3586
	7	30	.4174	646.5908	660.8251
		40	-.4174	-645.1567	653.2866
	8	30	.3532	547.1153	559.1597
		40	-.3532	-545.9019	552.7809
211	1	40	-.0998	219.3878	211.6690
		50	.0998	-187.4227	202.5689
	2	40	-.0831	182.8232	176.3908
		50	.0831	-156.1856	168.8074
	3	40	-.0018	49.4282	48.6428
		50	.0018	-47.4089	48.3100
	4	40	-.0012	33.8936	33.3551
		50	.0012	-32.5090	33.1269
	5	40	-1.9741	175.4923	159.4078
		50	1.9741	-173.3040	193.7838
	6	40	-1.5793	140.3939	127.5263
		50	1.5793	-138.6432	155.0270
	7	40	5.3202	498.8563	552.8929
		50	-5.3202	-496.9598	459.3946
	8	40	4.5017	422.1092	467.8325
		50	-4.5017	-420.5045	388.7185
212	1	50	-.0279	222.6863	215.6577
		60	.0279	-190.7212	205.2980
	2	50	-.0233	185.5719	179.7148
		60	.0233	-158.9343	171.0816
	3	50	.0004	49.4646	48.6989
		60	-.0004	-47.4452	48.3280
	4	50	.0003	33.9186	33.3935
		60	-.0003	-32.5339	33.1392
	5	50	-.7570	243.8728	241.6884
		60	.7570	-243.8728	254.9627
	6	50	-.6056	195.0983	193.3507
		60	.6056	-195.0983	203.9702
	7	50	2.1552	303.8809	328.3251
		60	-2.1552	-303.8809	290.5335
	8	50	1.8236	257.1300	277.8135
		60	-1.8236	-257.1300	245.8361
213	1	60	.0052	223.2735	216.5461
		70	-.0052	-191.3083	205.6050
	2	60	.0043	186.0612	180.4551
		70	-.0043	-159.4236	171.3375
	3	60	-.0001	49.4561	48.6865
		70	.0001	-47.4368	48.3232
	4	60	.0000	33.9128	33.3850
		70	.0000	-32.5281	33.1359
	5	60	-.0493	264.7008	269.1014
		70	.0493	-264.7008	269.9657
	6	60	-.0394	211.7606	215.2812
		70	.0394	-211.7606	215.9726

	7	60	.4438	236.7457	244.9595
		70	-.4438	-236.7457	237.1768
	8	60	.3756	200.3233	207.2734
		70	-.3756	-200.3233	200.6881
214	1	70	.0511	221.8195	215.4676
		80	-.0511	-189.8543	203.7224
	2	70	.0426	184.8495	179.5563
		80	-.0426	-158.2119	169.7687
	3	70	-.0004	49.4672	48.6949
		80	.0004	-47.4478	48.3372
	4	70	-.0003	33.9203	33.3908
		80	.0003	-32.5357	33.1455
	5	70	.3544	256.8202	264.6161
		80	-.3544	-256.8202	258.4021
	6	70	.2835	205.4561	211.6929
		80	-.2835	-205.4561	206.7217
	7	70	1.1333	196.0069	209.5217
		80	-1.1333	-196.0069	189.6493
	8	70	.9589	165.8520	177.2876
		80	-.9589	-165.8520	160.4725
215	1	80	.1238	217.3028	211.5059
		90	-.1238	-185.3377	198.4858
	2	80	.1032	181.0857	176.2549
		90	-.1032	-154.4481	165.4048
	3	80	.0005	49.4631	48.6987
		90	-.0005	-47.4438	48.3251
	4	80	.0004	33.9175	33.3934
		90	-.0004	-32.5329	33.1372
	5	80	-.9571	272.3890	268.9709
		90	.9571	-272.3890	285.7536
	6	80	-.7657	217.9112	215.1767
		90	.7657	-217.9112	228.6029
	7	80	2.8918	92.0344	119.0688
		90	-2.8918	-92.0344	68.3607
	8	80	2.4469	77.8753	100.7505
		90	-2.4469	-77.8753	57.8437
216	1	90	-.2029	219.3467	210.7229
		100	.2029	-187.3816	203.4313
	2	90	-.1691	182.7889	175.6024
		100	.1691	-156.1513	169.5261
	3	90	-.0033	49.5352	48.7383
		100	.0033	-47.5158	48.4323
	4	90	-.0023	33.9670	33.4205
		100	.0023	-32.5823	33.2107
	5	90	.4679	291.5278	295.0121
		100	-.4679	-284.9628	286.0850
	6	90	.3743	233.2223	236.0097
		100	-.3743	-227.9702	228.8680
	7	90	.3089	9.3578	12.2366
		100	-.3089	-9.3578	6.8206
	8	90	.2614	7.9181	10.3541
		100	-.2614	-7.9181	5.7713

217	1	100	-.3196	232.8420	223.4422
		110	.3196	-200.8768	218.1961
	2	100	-.2663	194.0350	186.2018
		110	.2663	-167.3974	181.8301
	3	100	.0293	48.8628	48.3402
		110	-.0293	-46.8435	47.4614
	4	100	.0201	33.5059	33.1475
		110	-.0201	-32.1213	32.5450
	5	100	.1855	273.0069	275.3644
		110	-.1855	-268.0511	271.3528
	6	100	.1484	218.4055	220.2915
		110	-.1484	-214.4408	217.0822
	7	100	.0906	-.9619	-.1848
		110	-.0906	.9619	-1.7742
	8	100	.0767	-.8140	-.1564
		110	-.0767	.8140	-1.5012
218	1	110	-8.5042	460.7689	383.7707
		120	8.5042	-428.8038	522.0421
	2	110	-7.0868	383.9741	319.8089
		120	7.0868	-357.3365	435.0350
	3	110	-.0954	50.5700	48.9844
		120	.0954	-48.5507	50.2935
	4	110	-.0654	34.6766	33.5893
		120	.0654	-33.2919	34.4870
	5	110	-.4582	280.0511	276.8928
		120	.4582	-275.0953	284.1682
	6	110	-.3665	224.0409	221.5142
		120	.3665	-220.0762	227.3345
	7	110	.0266	-3.9906	-3.8302
		120	-.0266	3.9906	-4.2967
	8	110	.0225	-3.3767	-3.2409
		120	-.0225	3.3767	-3.6357

SUPPORT REACTIONS

JOINT NO.	LOAD COMBINATION	MOMENT - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
1	1	263.3079	-255.0199	.0001
	2	219.4232	-212.5166	.0001
	3	25.4209	-31.6500	.0000
	4	17.4314	-21.7029	.0000
	5	46.1408	-62.4573	.0000
	6	36.9126	-49.9658	.0000
	7	256.5766	-381.5445	.0001
	8	217.1033	-322.8453	.0001

11	1	314.2231	439.7004	.0006
	2	261.8526	366.4170	.0005
	3	48.4102	33.9046	.0001
	4	33.1955	23.2489	.0001
	5	89.4854	53.5718	.0001
	6	71.5883	42.8575	.0001
	7	561.7479	226.0435	.0012
	8	475.3252	191.2676	.0010
21	1	216.7766	177.2180	.0002
	2	180.6472	147.6817	.0002
	3	48.5152	31.5957	.0000
	4	33.2676	21.6656	.0000
	5	96.5758	42.7988	.0001
	6	77.2606	34.2391	.0001
	7	586.1826	305.7063	.0006
	8	496.0007	258.6746	.0005
31	1	206.3645	161.3260	-.0004
	2	171.9704	134.4383	-.0004
	3	48.7147	32.3625	-.0001
	4	33.4043	22.1915	-.0001
	5	129.4171	11.8471	-.0001
	6	103.5337	9.4777	-.0001
	7	526.7787	369.3007	.0000
	8	445.7359	312.4852	.0000
41	1	208.5182	157.0844	.0000
	2	173.7652	130.9036	.0000
	3	48.7028	32.2697	.0000
	4	33.3962	22.1278	.0000
	5	206.3393	50.3445	.0000
	6	165.0715	40.2756	.0000
	7	385.3677	344.0817	.0001
	8	326.0804	291.1461	.0001
51	1	211.4201	161.9982	-.0001
	2	176.1834	134.9985	-.0001
	3	48.6951	32.2769	.0000
	4	33.3909	22.1327	.0000
	5	259.2718	128.7174	-.0003
	6	207.4174	102.9739	-.0003
	7	277.6735	226.4178	-.0004
	8	234.9545	191.5843	-.0003
61	1	211.8583	164.3941	-.0002
	2	176.5486	136.9951	-.0002
	3	48.6923	32.2541	-.0001
	4	33.3890	22.1171	.0000
	5	270.2905	171.5320	-.0004
	6	216.2324	137.2256	-.0003
	7	227.8862	172.4918	-.0001
	8	192.8268	145.9546	-.0001
71	1	210.0168	166.4107	-.0002
	2	175.0140	138.6756	-.0002
	3	48.6871	32.2961	-.0001
	4	33.3854	22.1459	.0000

	5	264.9702	140.6740	-.0004
	6	211.9762	112.5392	-.0003
	7	166.9581	201.8996	-.0002
	8	141.2722	170.8381	-.0002
81	1	208.6305	158.5011	-.0004
	2	173.8587	132.0842	-.0003
	3	48.6946	32.1324	.0000
	4	33.3906	22.0336	.0000
	5	288.2711	160.4530	-.0005
	6	230.6169	128.3624	-.0004
	7	56.1978	117.3257	-.0001
	8	47.5520	99.2756	-.0001
91	1	209.6784	171.8908	-.0001
	2	174.7320	143.2424	-.0001
	3	48.2924	33.5612	-.0001
	4	33.1148	23.0134	-.0001
	5	282.5660	188.1342	-.0002
	6	226.0528	150.5074	-.0002
	7	5.5456	17.9673	.0000
	8	4.6925	15.2031	.0000
101	1	289.9078	-63.1529	-.0002
	2	241.5898	-52.6274	-.0002
	3	48.9606	26.3945	-.0001
	4	33.5730	18.0991	.0000
	5	279.7926	134.4034	-.0002
	6	223.8341	107.5227	-.0001
	7	-4.0978	-.0029	.0000
	8	-3.4674	-.0025	.0000
111	1	263.2418	663.1476	-.0002
	2	219.3682	552.6230	-.0002
	3	27.9813	70.4411	.0000
	4	19.1872	48.3025	.0000
	5	159.1245	393.0239	.0000
	6	127.2996	314.4191	.0000
	7	-2.9516	-7.7143	.0000
	8	-2.4975	-6.5275	.0000

JOINT NO.	LOAD COMBINATION	MOMENT - X KN - m	SHEAR - Z KN	MOMENT - Y KN - m
10	1	-263.2482	663.1603	.0002
	2	-219.3735	552.6336	.0002
	3	-28.0038	72.1111	.0000
	4	-19.2026	49.4476	.0000
	5	-50.6740	125.1466	.0000
	6	-40.5392	100.1173	.0000
	7	-301.3921	753.4779	-.0004
	8	-255.0241	637.5582	-.0004
20	1	-289.9024	-63.1763	-.0005
	2	-241.5853	-52.6469	-.0005
	3	-48.9985	26.3943	-.0001

	4	-33.5989	18.0990	-.0001
	5	-90.1531	45.0286	-.0001
	6	-72.1225	36.0229	-.0001
	7	-623.2164	403.8418	-.0014
	8	-527.3370	341.7123	-.0012
30	1	-209.6725	171.8972	-.0001
	2	-174.7271	143.2477	-.0001
	3	-48.3295	33.5707	.0000
	4	-33.1402	23.0199	.0000
	5	-98.9887	77.5747	-.0001
	6	-79.1909	62.0598	-.0001
	7	-656.8627	399.2758	.0006
	8	-555.8069	337.8488	.0005
40	1	-208.6337	158.5081	.0002
	2	-173.8614	132.0901	.0002
	3	-48.7339	32.1415	.0001
	4	-33.4175	22.0399	.0000
	5	-140.9940	146.1892	.0002
	6	-112.7952	116.9513	.0002
	7	-596.1453	236.9831	.0011
	8	-504.4307	200.5242	.0009
50	1	-210.0216	166.4101	.0004
	2	-175.0180	138.6751	.0003
	3	-48.7267	32.3034	.0001
	4	-33.4126	22.1509	.0001
	5	-219.5584	201.0502	.0006
	6	-175.6467	160.8401	.0005
	7	-394.0847	43.8259	.0006
	8	-333.4563	37.0834	.0005
60	1	-211.8605	164.3904	.0000
	2	-176.5504	136.9920	.0000
	3	-48.7312	32.2608	-.0001
	4	-33.4157	22.1217	.0000
	5	-263.4523	174.8449	-.0001
	6	-210.7619	139.8759	-.0001
	7	-268.2808	84.0422	-.0002
	8	-227.0068	71.1126	-.0002
70	1	-211.4167	161.9902	.0003
	2	-176.1806	134.9918	.0003
	3	-48.7328	32.2827	.0000
	4	-33.4168	22.1367	.0000
	5	-268.5140	147.2273	.0001
	6	-214.8112	117.7818	.0001
	7	-221.5622	90.7133	.0004
	8	-187.4758	76.7574	.0004
80	1	-208.5112	157.0783	.0004
	2	-173.7593	130.8986	.0004
	3	-48.7395	32.2757	.0002
	4	-33.4214	22.1319	.0001
	5	-266.8339	165.8641	.0002
	6	-213.4671	132.6913	.0001
	7	-150.3774	-12.2937	.0002

	8	-127.2424	-10.4024	.0001
90	1	-206.3605	161.3322	.0002
	2	-171.9671	134.4435	.0002
	3	-48.7521	32.3716	.0000
	4	-33.4300	22.1977	.0000
	5	-290.6868	190.9496	.0003
	6	-232.5495	152.7597	.0003
	7	-40.9156	-66.4994	.0001
	8	-34.6209	-56.2687	.0001
100	1	-216.7822	177.2276	.0004
	2	-180.6518	147.6896	.0003
	3	-48.5546	31.6044	.0001
	4	-33.2946	21.6716	.0001
	5	-282.1867	150.1555	.0002
	6	-225.7493	120.1244	.0002
	7	-2.9111	-8.9737	.0000
	8	-2.4633	-7.5931	.0000
110	1	-314.2233	439.6819	.0004
	2	-261.8527	366.4016	.0004
	3	-48.4499	33.9151	.0001
	4	-33.2228	23.2561	.0001
	5	-275.4818	171.4013	.0002
	6	-220.3855	137.1210	.0002
	7	2.9506	-4.1866	.0000
	8	2.4967	-3.5425	.0000
120	1	-263.2991	-255.0138	-.0004
	2	-219.4159	-212.5115	-.0003
	3	-25.4422	-33.3103	.0000
	4	-17.4461	-22.8414	.0000
	5	-143.9410	-195.7284	-.0001
	6	-115.1528	-156.5827	-.0001
	7	2.2746	3.0937	.0000
	8	1.9247	2.6178	.0000

COMPARISON OF ELEMENT-END FORCES

COMPARISON OF FORCES ALONG ELEMENTS 1 THRU 9 AT STEP 1

LOAD COMB	ELEM END	Max/Min TORSION - X	On EL.	Max/Min SHEAR - Z	On EL.	Max/Min MOMENT - Y	On EL.
1	A-End	14.37	1	173.79	1	458.96	1
		-7.99	7	-146.29	9	-270.27	6
	B-End	7.99	7	193.94	9	279.74	5
		-14.37	1	-126.14	1	-491.66	9

2	A-End	11.97	1	144.83	1	382.47	1
		-6.66	7	-121.91	9	-225.23	6
	B-End	6.66	7	161.62	9	233.12	5
		-11.97	1	-105.12	1	-409.72	9
3	A-End	.89	9	15.24	1	43.82	1
		-.71	5	-14.52	9	-27.42	6
	B-End	.71	5	18.22	9	27.26	5
		-.89	9	-11.54	1	-48.68	9
4	A-End	.61	9	10.45	1	30.05	1
		-.49	5	-9.96	9	-18.80	6
	B-End	.49	5	12.49	9	18.69	5
		-.61	9	-7.91	1	-33.38	9
5	A-End	1.88	9	25.72	1	79.55	1
		-1.45	5	-25.20	9	-54.97	6
	B-End	1.45	5	30.69	9	55.05	5
		-1.88	9	-20.23	1	-87.60	9
6	A-End	1.50	9	20.57	1	63.64	1
		-1.16	5	-20.16	9	-43.98	6
	B-End	1.16	5	24.55	9	44.04	5
		-1.50	9	-16.18	1	-70.08	9
7	A-End	15.28	9	138.21	2	441.76	1
		-9.48	4	-167.97	9	-236.04	6
	B-End	9.48	4	172.73	9	227.14	5
		-15.28	9	-133.45	2	-505.15	9
8	A-End	12.93	9	116.95	2	373.79	1
		-8.02	4	-142.13	9	-199.73	6
	B-End	8.02	4	146.16	9	192.20	5
		-12.93	9	-112.92	2	-427.43	9

COMPARISON OF FORCES ALONG ELEMENTS 100 THRU 108 AT STEP 1

LOAD COMB	ELEM END	Max/Min TORSION - X	On EL.	Max/Min SHEAR - Z	On EL.	Max/Min MOMENT - Y	On EL.
1	A-End	14.37	108	193.94	100	491.64	100
		-7.99	102	-126.14	108	-279.73	104
	B-End	7.99	102	173.79	108	270.26	103
		-14.37	108	-146.29	100	-458.95	108
2	A-End	11.97	108	161.62	100	409.70	100
		-6.66	102	-105.12	108	-233.11	104
	B-End	6.66	102	144.83	108	225.21	103
		-11.97	108	-121.91	100	-382.46	108
3	A-End	.89	100	18.22	100	48.64	100
		-.71	104	-11.54	108	-27.27	104
	B-End	.71	104	15.24	108	27.42	103
		-.89	100	-14.52	100	-43.86	108
4	A-End	.61	100	12.49	100	33.36	100
		-.49	104	-7.92	108	-18.70	104
	B-End	.49	104	10.45	108	18.80	103
		-.61	100	-9.96	100	-30.08	108

5	A-End	5.42	100	96.75	100	276.00	100
		-4.45	104	-62.87	108	-172.37	104
	B-End	4.45	104	79.37	108	173.42	103
		-5.42	100	-80.25	100	-247.78	108
6	A-End	4.33	100	77.40	100	220.80	100
		-3.56	104	-50.29	108	-137.90	104
	B-End	3.56	104	63.49	108	138.74	103
		-4.33	100	-64.20	100	-198.22	108
7	A-End	.14	102	.90	108	2.99	104
		-.19	108	-1.93	100	-5.47	100
	B-End	.19	108	1.93	100	3.76	108
		-.14	102	-.90	108	-3.53	103
8	A-End	.12	102	.76	108	2.53	104
		-.16	108	-1.63	100	-4.63	100
	B-End	.16	108	1.63	100	3.18	108
		-.12	102	-.76	108	-2.99	103

COMPARISON OF FORCES ALONG ELEMENTS 10 THRU 99 AT STEP 1

LOAD COMB	ELEM END	Max/Min TORSION - X	On EL.	Max/Min SHEAR - Z	On EL.	Max/Min MOMENT - Y	On EL.
1	A-End	11.51	10	179.79	10	520.38	10
		-6.74	15	-150.39	99	-289.94	96
	B-End	6.74	15	179.79	99	289.93	13
		-11.51	10	-150.39	10	-520.38	99
2	A-End	9.59	10	149.83	10	433.65	10
		-5.61	15	-125.32	99	-241.61	96
	B-End	5.61	15	149.82	99	241.61	13
		-9.59	10	-125.33	10	-433.65	99
3	A-End	1.09	73	30.27	28	84.49	28
		-.87	50	-23.56	81	-46.75	69
	B-End	.87	50	30.28	81	46.76	40
		-1.09	73	-23.55	28	-84.55	81
4	A-End	.75	73	20.76	28	57.93	28
		-.59	50	-16.16	81	-32.06	69
	B-End	.59	50	20.76	81	32.06	40
		-.75	73	-16.15	28	-57.98	81
5	A-End	6.79	45	169.65	73	502.97	73
		-5.48	77	-137.31	81	-314.14	78
	B-End	5.48	77	171.81	81	311.47	76
		-6.79	45	-135.15	73	-506.63	81
6	A-End	5.43	45	135.72	73	402.38	73
		-4.38	77	-109.85	81	-251.31	78
	B-End	4.38	77	137.45	81	249.17	76
		-5.43	45	-108.12	73	-405.30	81
7	A-End	15.39	28	287.44	19	1018.29	19
		-9.87	23	-377.60	27	-637.65	32
	B-End	9.87	23	386.26	27	651.19	31
		-15.39	28	-278.78	19	-1144.93	27

8	A-End	13.02	28	243.22	19	861.63	19
		-8.35	23	-319.51	27	-539.55	32
	B-End	8.35	23	326.84	27	551.01	31
		-13.02	28	-235.89	19	-968.79	27

COMPARISON OF FORCES ALONG ELEMENTS 120 THRU 207 AT STEP 1

LOAD COMB	ELEM END	Max/Min TORSION - X	On EL.	Max/Min SHEAR - Z	On EL.	Max/Min MOMENT - Y	On EL.
1	A-End	.09	169	14.40	185	14.13	185
		-5.20	154	-14.40	142	-15.19	142
	B-End	5.20	154	14.40	142	15.19	185
		-.09	169	-14.40	185	-14.13	142
2	A-End	.07	169	12.00	185	11.77	185
		-4.33	154	-12.00	142	-12.66	142
	B-End	4.33	154	12.00	142	12.66	185
		-.07	169	-12.00	185	-11.77	142
3	A-End	.18	196	.83	207	.88	197
		-.17	186	-.84	120	-.88	120
	B-End	.17	186	.84	120	.88	207
		-.18	196	-.83	207	-.88	130
4	A-End	.12	196	.57	207	.60	197
		-.11	186	-.57	120	-.60	120
	B-End	.11	186	.57	120	.60	207
		-.12	196	-.57	207	-.61	130
5	A-End	2.24	146	5.88	167	5.98	167
		-2.16	177	-5.02	139	-5.35	139
	B-End	2.16	177	5.02	139	6.17	178
		-2.24	146	-5.88	167	-5.05	137
6	A-End	1.79	146	4.71	167	4.78	167
		-1.72	177	-4.02	139	-4.28	139
	B-End	1.72	177	4.02	139	4.93	178
		-1.79	146	-4.71	167	-4.04	137
7	A-End	5.57	154	12.10	186	11.51	186
		-4.10	146	-14.58	145	-15.94	145
	B-End	4.10	146	14.58	145	13.13	186
		-5.57	154	-12.10	186	-13.76	145
8	A-End	4.71	154	10.24	186	9.74	186
		-3.47	146	-12.34	145	-13.48	145
	B-End	3.47	146	12.34	145	11.11	186
		-4.71	154	-10.24	186	-11.64	145

```
D Line£ 1     7                                Microsoft FORTRAN77 V3.30 March 198
      1 C
      2 C
      3       PROGRAM GRID1
      4       CHARACTER DR1*2,FNINN*10,FNOUT*10,SN*2,TITLE*80,CAS*50,COM(10)*50
      5      1,AS*1,FF*1,DR2*2
      6 C
      7       COMMON /JD/C(200,2),JR(200,3),NSJ(60)
      8       COMMON /ED/MC(360,2),MS(360),S(50,2),XL(360),M(360,6)
      9       COMMON /LD/FE(3600,6),Q(5500),F(10,10),CL(3),D(6)
     10       COMMON /TR/XK(6,6)
     11 C
     12       WRITE(*,10)'Enter Data Disk Drive [A:,B:,C:] '
     13    10 FORMAT(5X,A$)
     14       READ(*,15)DR1
     15    15 FORMAT(3A)
     16       WRITE(*,10)'Enter Structure Number [2 Digits] '
     17       READ(*,15)SN
     18       WRITE(*,10)'Enter Analysis Disk Drive [A:,B:] '
     19       READ(*,15)DR2
     20       FNINN(1:2)=DR1
     21       FNOUT(1:2)=DR1
     22       FNINN(3:2+6)='DATA.G'
     23       FNOUT(3:2+6)='DOUT.G'
     24       FNINN(9:10)=SN
     25       FNOUT(9:10)=SN
     26       OPEN(1,FILE=FNINN)
     27       OPEN(2,FILE=FNOUT,STATUS='NEW')
     28       OPEN(3,FILE='A:GRIL.DAT',ACCESS='DIRECT',FORM='FORMATTED',
     29      1        STATUS='NEW',RECL=6)
     30       WRITE(3,15)DR2,SN,DR1
     31       CLOSE(3)
     32       FF=CHAR(12)
     33 C
     34 C READ TITLE OF STRUCTURE
     35 C
     36       READ(1,'(A)')TITLE
     37 C
     38 C  READ JOINT CO-ORDINATES
     39 C
     40       READ(1,20)JCO
     41       IF(JCO)30,30,40
     42    30 TH=0
     43       READ(1,20)NJ
     44    20 FORMAT(I5,5X,2E10.0,I5)
     45    70 READ(1,20)J,(C(J,I),I=1,2),IS
     46       IF(J)45,45,50
     47    50 IF(IS)70,70,80
     48    80 READ(1,20)N,(C(N,I),I=1,2)
     49       DF=(N-J)/IS
     50       RX=(C(N,1)-C(J,1))/DF
     51       RY=(C(N,2)-C(J,2))/DF
     52       DO 60 I=J+IS,N-IS,IS
1    53       C(I,1)=C(I-IS,1)+RX
1    54    60 C(I,2)=C(I-IS,2)+RY
     55       GOTO 70
     56    40 CALL SUBJC(TH,NL,NT,NJ)
```

```
      57 C
      58 C  READ ELEMENT CONNECTIVITY & SECTION NUMBERS
      59 C
      60     45 READ(1,20)MCO
      61        IF(MCO)90,90,100
      62     90 READ(1,110)NE
      63    140 READ(1,110)J,(MC(J,I),I=1,2),MS(J),IS
      64    110 FORMAT(5I5)
      65        IF(J)120,120,130
      66    130 IF(IS)140,140,150
      67    150 READ(1,110)N
      68        ID=IABS(IABS(MC(J,1))-IABS(MC(J,2)))
      69        DO 160 I=J+IS,N,IS
 1    70        MC(I,1)=MC(I-IS,2)
 1    71        MC(I,2)=MC(I-IS,2)+ID
 1    72    160 MS(I)=MS(J)
      73        GOTO 140
      74    100   CALL SUBMC(NL,NT,NE)
      75 C
      76 C  READ JOINT RELEASES
      77 C
      78    120 READ(1,110)J,(JR(J,I),I=1,3),IS
      79        IF(J)170,170,180
      80    180 IF(IS)120,120,190
      81    190 READ(1,110)N
      82        DO 200 I=J+IS,N,IS
 1    83        DO 200 L=1,3
 2    84    200 JR(I,L)=JR(I-IS,L)
      85        GOTO 120
      86 C
      87 C COMPUTE NO. OF SUPPORTED JOINTS
      88 C
      89    170 NSU=0
      90        DO 176 I=1,NJ
 1    91        DO 175 L=1,3
 2    92        IF(JR(I,L)-1)175,177,175
 2    93    177 NSU=NSU+1
 2    94        NSJ(NSU)=I
 2    95        GOTO 176
 2    96    175 CONTINUE
 1    97    176 CONTINUE
      98 C
      99 C  READ MATERIAL PROPERTIES
     100 C
     101        READ(1,20)NS,E,G
     102        READ(1,310)((S(I,J),J=1,2),I=1,NS)
     103    310 FORMAT(2E10.0)
     104 C
     105 C  READ LOAD INFORMATION
     106        READ(1,110)LC,NLC
     107 C
     108 C  WRITE INPUT DATA TO FILE 2
     109 C
     110        WRITE(2,'(A///3X,A)')FF,'STRUCTURAL ANALYSIS OF PLANE GRILLAGES'
     111        CALL SPAC1
     112        WRITE(2,385)SN,TITLE
```

```
D Line£ 1     7                                  Microsoft FORTRAN77 V3.30 March 198
     113   385 FORMAT(///3X'STRUCTURE NO. 'A2,3X,A)
     114       CALL SPAC1
     115       WRITE(2,390)NE,NJ,LC,NLC,E,G,TH
     116   390 FORMAT(///3X'CONTROL INFORMATION'//10X
     117      1'NO. OF ELEMENTS                  = 'I5/10X
     118      2'NO. OF JOINTS                    = 'I5/10X
     119      3'NO. OF LOAD CASES                = 'I5/10X
     120      4'NO. OF LOAD COMBINATIONS         = 'I5//3X
     121      5'GENERAL DATA'//10X
     122      6'ELASTICITY MODULUS       = 'E10.4/10X
     123      7'SHEAR MODULUS            = 'E10.4/10X
     124      8'ANGLE OF SKEW (Degrees) = 'E10.4/)
     125       CALL SPAC1
     126
     127       WRITE(2,400)
     128   400 FORMAT(//3X'JOINT DATA'//3X
     129      1'JOINT'2X'X-FREEDOM'3X'Z-FREEDOM'3X'Y-FREEDOM'3X'X-COORDINATE'
     130      23X'Y-COORDINATE'/3X,2X'NO.'42X'(METRES)'7X'(METRES)'/)
     131       LP=36
     132       DO 410 I=1,NJ
  1  133       AS=' '
  1  134       DO 415 J=1,NSU
  2  135       IF(I-NSJ(J))415,416,415
  2  136   416 AS='S'
  2  137       GOTO 417
  2  138   415 CONTINUE
  1  139   417 WRITE(2,420)I,AS,(JR(I,J),J=1,3),(C(I,J),J=1,2)
  1  140   420 FORMAT(3X,I5,1X,A1,8X,I1,2(11X,I1),2(3X,F12.4))
  1  141       LP=LP+1
  1  142   410 IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
     143       CALL SPAC1
     144       LP=LP+2
     145       IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     146   999 FORMAT(A)
     147 C
     148 C FORM EQUATION NUMBERS IN JOINT RELEASES
     149 C
     150       L=1
     151       DO 210 I=1,NJ
  1  152       DO 210 J=1,3
  2  153       IF(JR(I,J)-1)220,230,240
  2  154   220 JR(I,J)=L
  2  155       L=L+1
  2  156       GOTO 210
  2  157   230 JR(I,J)=0
  2  158       GOTO 210
  2  159   240 K=JR(I,J)
  2  160       JR(I,J)=JR(K,J)
  2  161   210 CONTINUE
     162 C
     163 C  FORM MEMBER CODE MATRIX
     164 C
     165       DO 250 I=1,NE
  1  166       DO 250 L=1,2
  2  167       DO 250 K=L*L,3*L
  3  168       J=IABS(MC(I,L))
```

```
'D Line£ 1     7                                  Microsoft FORTRAN77 V3.30 March 1985
 3   169       N=K-3*(L-1)
 3   170   250 M(I,K)=JR(J,N)
     171 C
     172 C  REMOVE D.O.F. CORRESSPONDING TO PINNED ENDS
     173 C
     174       DO 260 N=1,NE
 1   175       DO 260 J=1,2
 2   176       IF(MC(N,J))270,280,260
 2   177   280 WRITE(*,'(5X,A,I5,A)')'Element ',N,' Connects to Joint ZERO'
 2   178   270 L=M(N,(J-1)*3+3)
 2   179       M(N,(J-1)*3+3)=0
 2   180       DO 290 I=1,NE
 3   181       DO 290 K=1,6
 4   182       IF(M(I,K)-L)290,290,300
 4   183   300 M(I,K)=M(I,K)-1
 4   184   290 CONTINUE
 2   185   260 CONTINUE
     186 C
     187 C  RE-ADJUST JOINT RELEASES
     188 C
     189       DO 320 N=1,NJ
 1   190       DO 330 NN=1,2
 2   191       DO 330 L=1,NE
 3   192       DO 330 J=1,2
 4   193       IF(NN-1)340,340,350
 4   194   340 IF(MC(L,J)-N)330,360,330
 4   195   350 IF(IABS(MC(I,J)-N))330,360,330
 4   196   360 JJ=L
 4   197       KK=J
 4   198       GOTO 370
 4   199   330 CONTINUE
 1   200   370 DO 380 J=1,3
 2   201       K=(KK-1)*3+J
 2   202   380 JR(N,J)=M(JJ,K)
 1   203   320 CONTINUE
     204 C
     205       FNOUT(3:2+6)='INFO.G'
     206       OPEN(3,FILE=FNOUT,STATUS='NEW')
     207       WRITE(3,'((3I5))')((JR(I,J),J=1,3),I=1,NJ)
     208       DO 321 N=1,8
 1   209       IF(MOD(LP+N,56))321,322,321
 1   210   322 WRITE(2,999)FF
 1   211       LP=LP+N
 1   212       GOTO 323
 1   213   321 CONTINUE
     214   323 WRITE(2,430)
     215   430 FORMAT(//3X'ELEMENT DATA'//3X'Section Property Data :'//3X
     216      14X'SECTION'12X'TORS. CONST.'12X'MOM. INERTIA'/3X
     217      25X'NUMBER'11X' 1.0E-06 (M4)'11X' 1.0E-06 (M4)'/)
     218       LP=LP+8
     219       DO 444 I=1,NS
 1   220       WRITE(2,440)I,(S(I,J),J=1,2)
 1   221       LP=LP+1
 1   222   444 IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     223   440 FORMAT((9X,I5,2(11X,F13.4)))
     224       CALL SPAC1
```

```
D Line£ 1      7                          Microsoft FORTRAN77 V3.30 March 1985
    225        LP=LP+2
    226        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
    227 C
    228 C COMPUTE ELEMENT LENGTHS & TRANSFORM MATERIAL PROPERTIES
    229 C
    230        DO 500 I=1,NE
1   231        J=IABS(MC(I,1))
1   232        N=IABS(MC(I,2))
1   233        XL(I)=SQRT((C(N,1)-C(J,1))**2+(C(N,2)-C(J,2))**2)
1   234        IF(XL(I))490,490,500
1   235    490 WRITE(*,'(5X,A,I5,A,E10.4)')'Error Length of Element',I,' =',XL(I)
1   236    500 CONTINUE
    237        TH=TH*ATAN(1.0)/45.0
    238        DO 510 I=1,NS
1   239        DO 510 J=1,2
2   240        S(I,J)=S(I,J)*1E-6/COS(TH)
2   241    510 CONTINUE
    242 C
    243        DO 511 N=1,6
1   244        IF(MOD(LP+N,56))511,522,511
1   245    522 WRITE(2,999)FF
1   246        LP=LP+N
1   247        GOTO 523
1   248    511 CONTINUE
    249    523 WRITE(2,450)
    250    450 FORMAT(//3X'Element Connectivity Data :'//3X
    251       1'ELEMENT'6X'LOWER'6X'GREATER'6X'SECTION'10X'ELEMENT'/3X
    252       2'NUMBER'6X'JOINT'8X'JOINT'7X'NUMBER'11X'LENGTH'/)
    253        LP=LP+6
    254        DO 460 I=1,NE
1   255        WRITE(2,470)I,(MC(I,J),J=1,2),MS(I),XL(I)
1   256    470 FORMAT((5X,I5,6X,I5,2(8X,I5),5X,F12.4))
1   257        LP=LP+1
1   258    460 IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
    259        CALL SPAC1
    260 C
    261 C COMPUTE SYSTEM DEGREE-OF-FREEDOM & HALF BAND WIDTH
    262 C
    263        ND=M(1,1)
    264        NB=0
    265        DO 520 I=1,NE
1   266        KB=IABS(IABS(MC(I,1))-IABS(MC(I,2)))
1   267        IF(KB.GT.NB)NB=KB
1   268        DO 520 J=1,6
2   269        IF(ND-M(I,J))530,520,520
2   270    530 ND=M(I,J)
2   271    520 CONTINUE
    272        NB=(NB+1)*3
    273 C
    274 C  READ/WRITE LOADINGS, AND COMPUTE FIXED-END FORCES
    275 C
    276        WRITE(2,'(A//3X,A)')FF,'LOAD DATA'
    277        LP=0
    278        DO 525 K=1,LC
1   279        READ(1,'(A)')CAS
1   280        DO 541 N=1,9
```

```
2    281        IF(MOD(LP+N,56))541,542,541
2    282    542 WRITE(2,999)FF
2    283        LP=LP+N
2    284        GOTO 543
2    285    541 CONTINUE
1    286    543 WRITE(2,535)K,CAS
1    287    535 FORMAT(/3X'LOAD CASE'I5,5X,A/)
1    288        CALL SPAC1
1    289 C UNIFORM LOAD
1    290        WRITE(2,540)
1    291    540 FORMAT(3X'Element Uniform Load :'/3X
1    292       12X'ELEMENT'10X'UNIFORM'13X'DISTANCE FROM A-END'/3X
1    293       23X'NUMBER'6X'LOAD (KN/m)'9X'START (m)'10X'END (m)'/)
1    294        LP=LP+9
1    295        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
1    296    630 READ(1,550)N,W,A1,A3,IS
1    297    550 FORMAT(I5,3E10.0,I5)
1    298        IF(N)560,560,570
1    299    570 IF(IS)580,580,590
1    300    580 NN=N
1    301        IS=1
1    302        GOTO 600
1    303    590 READ(1,550)NN
1    304    600 DO 610 J=N,NN,IS
2    305        IF(A3)601,601,602
2    306    601 A2=XL(J)
2    307        GOTO 603
2    308    602 A2=A3
2    309    603 WRITE(2,620)J,W,A1,A2
2    310    620 FORMAT(7X,I5,5X,F12.4,6X,F12.2,5X,F12.2)
2    311        LP=LP+1
2    312        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2    313        I=(K-1)*NE+J
2    314        FE(I,2)=FE(I,2)+W*(A2-A1)*((A1+A2+XL(J))*(XL(J)-(A1+A2)/2.0)**2
2    315       1+(A1+A2-XL(J))/4.0*(A2-A1)**2)/XL(J)**3
2    316        FE(I,3)=FE(I,3)+W*XL(J)*((XL(J)-A1)**3*(XL(J)+3*A1)-(XL(J)-A2)
2    317       1**3*(XL(J)+3*A2))/(12*XL(J)**2*(A2-A1))
2    318        FE(I,5)=FE(I,5)+W*(A2-A1)*((3*XL(J)-A1-A2)*(A1+A2)**2/4.0
2    319       1-(A1+A2-XL(J))/4.0*(A2-A1)**2)/XL(J)**3
2    320        FE(I,6)=FE(I,6)-W*XL(J)*(A2**3*(4*XL(J)-3*A2)-A1**3*(4*XL(J)
2    321       1-3*A1))/(12*XL(J)**2*(A2-A1))
2    322    610 CONTINUE
1    323        GOTO 630
1    324    560 CALL SPAC1
     325        LP=LP+2
     326        DO 641 N=1,5
     327        IF(MOD(LP+N,56))641,642,641
     328    642 WRITE(2,999)FF
     329        LP=LP+N
     330        GOTO 643
     331    641 CONTINUE
     332 C  ELEMENT POINT LOADS
     333    643 WRITE(2,640)
     334    640 FORMAT(/3X'Element Point Loads'//3X,
     335       1'ELEMENT'4X'PT. LOAD'4X'DIST.'4X'PT. LOAD'4X'DIST.'4X'PT. LOAD'
     336       24X'DIST.'/3X,1X'NUMBER'4X'1 (KN) '5X'(M)'6X'2 (KN) '5X'(M)'6X
```

```
1   337       3'3 (KN) '5X'(M)'/)
1   338        LP=LP+5
1   339        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
1   340    730 READ(1,650)N,(CL(I),D(I),I=1,3),IS
1   341    650 FORMAT(I5,6E10.0,I5)
1   342        IF(N)660,660,670
1   343    670 IF(IS)680,680,690
1   344    680 NN=N
1   345        IS=1
1   346        GOTO 700
1   347    690 READ(1,650)NN
1   348    700 DO 710 J=N,NN,IS
2   349        WRITE(2,720)J,(CL(I),D(I),I=1,3)
2   350    720 FORMAT(5X,I5,3(2X,F10.3,3X,F6.3))
2   351        LP=LP+1
2   352        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2   353        I=(K-1)*NE+J
2   354        DO 710 L=1,3
3   355        FE(I,2)=FE(I,2)+CL(L)*(XL(J)-D(L))**2*(2*D(L)+XL(J))/XL(J)**3
3   356        FE(I,3)=FE(I,3)+CL(L)*D(L)*(XL(J)-D(L))**2/XL(J)**2
3   357        FE(I,5)=FE(I,5)+CL(L)*D(L)**2*(3*XL(J)-2*D(L))/XL(J)**3
3   358        FE(I,6)=FE(I,6)-CL(L)*D(L)**2*(XL(J)-D(L))/XL(J)**2
3   359    710 CONTINUE
1   360        GOTO 730
1   361    660 CALL SPAC1
1   362 C JOINT LOADS
1   363        LP=LP+2
1   364        DO 741 N=1,5
2   365        IF(MOD(LP+N,56))741,742,741
2   366    742 WRITE(2,999)FF
2   367        LP=LP+N
2   368        GOTO 743
2   369    741 CONTINUE
1   370    743 WRITE(2,740)
1   371    740 FORMAT(/3X'Joint Loads'//3X,
1   372       11X'LOADED'13X'EXTERNAL'13X'VERTICAL'13X'EXTERNAL'/3X,
1   373       22X'JOINT'8X'MOM.-X (KN-m)'10X'LOAD-Z (KN)'8X'MOM.-Y (KN-m)'/)
1   374        LP=LP+5
1   375        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
1   376    830 READ(1,750)J,(D(I),I=1,3),IS
1   377    750 FORMAT(I5,3E10.0,I5)
1   378        IF(J)760,760,770
1   379    770 IF(IS)780,780,790
1   380    780 JJ=J
1   381        IS=1
1   382        GOTO 800
1   383    790 READ(1,750)JJ
1   384    800 DO 810 N=J,JJ,IS
2   385        WRITE(2,840)N,(D(I),I=1,3)
2   386    840 FORMAT(5X,I5,3(9X,F12.4))
2   387        LP=LP+1
2   388        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2   389        DO 810 L=1,3
3   390        IF(JR(N,L))810,810,820
3   391    820 I=(K-1)*ND+JR(N,L)
3   392        Q(I)=Q(I)+D(L)
```

```
3    393    810 CONTINUE
1    394        GOTO 830
1    395    760 CALL SPAC1
1    396    525 CONTINUE
     397 C
     398 C READ & WRITE LOAD COMBINATION DATA
     399 C
     400        DO 850 I=1,NLC
1    401        DO 850 J=1,LC
2    402    850 F(I,J)=0.0
     403        DO 860 I=1,NLC
1    404        READ(1,'(A)')COM(I)
1    405    870 READ(1,750)K,F(I,K)
1    406        IF(K)860,860,870
1    407    860 CONTINUE
     408        WRITE(2,880)FF,(I,I=1,NLC)
     409    880 FORMAT(A,//3X'LOAD COMBINATION DATA'//3X,
     410       16X'LOAD COMBINATION NO./FACTORS'/3X'LC',10(I5,2X)/)
     411        LP=6
     412        DO 890 I=1,LC
1    413        WRITE(2,900)I,(F(J,I),J=1,NLC)
1    414    900 FORMAT(3X,I2,10(2X,F5.2))
1    415        LP=LP+1
1    416    890 IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
     417        WRITE(2,'(///)')
     418        LP=LP+3
     419        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     420        DO 910 I=1,NLC
1    421        WRITE(2,920)I,COM(I)
1    422        LP=LP+1
1    423    910 IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     424    920 FORMAT(3X'LOAD COMBINATION 'I5,3X,A/)
     425 C
     426 C READ & WRITE OUTPUT INFORMATION
     427 C
     428        CALL SPAC1
     429        LP=LP+2
     430        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     431        DO 921 N=1,3
1    432        IF(MOD(LP+N,56))921,922,921
1    433    922 WRITE(2,999)FF
1    434        LP=LP+N
1    435        GOTO 923
1    436    921 CONTINUE
     437    923 WRITE(2,'(//3X,A/)')'OUTPUT INFORMATION'
     438        LP=LP+3
     439        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
     440        DO 930 I=1,5
1    441        READ(1,'(A)')CAS
1    442        WRITE(2,'(A)')CAS
1    443        LP=LP+1
1    444        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
1    445    950 READ(1,940)J,N,IS
1    446        WRITE(3,940)J,N,IS
1    447        IF(J)930,930,960
1    448    960 WRITE(2,940)J,N,IS
```

08-23-87
16:16:12

```
D Line£ 1     7                              Microsoft FORTRAN77 V3.30 March 1985
1    449        LP=LP+1
1    450        IF(MOD(LP,56).EQ.0)WRITE(2,999)FF
1    451        GOTO 950
1    452   930 CONTINUE
     453        CLOSE(3)
     454   940 FORMAT(3I5)
     455        CALL SPAC1
     456        LP=LP+2
     457        DO 941 N=1,6
1    458        IF(MOD(LP+N,56))941,942,941
1    459   942 WRITE(2,999)FF
1    460        LP=LP+N
1    461        GOTO 943
1    462   941 CONTINUE
     463   943 WRITE(2,970)ND,NB,NSU
     464   970 FORMAT(3X'SYSTEM DEGREES-OF-FREEDOM    ='I5/3X
     465      1          'BAND-WIDTH                  ='I5/3X
     466      2          'NO. OF SUPPORTED JOINTS     ='I5/)
     467        CALL SPAC1
     468 C
     469        CLOSE(1)
     470        CLOSE(2)
     471 C
     472 C RESOLVE APPLIED ACTIONS
     473 C
     474        OPEN(1,FILE='A:Q.GGG',ACCESS='DIRECT',FORM='FORMATTED',
     475      1  STATUS='NEW',RECL=15)
     476        DO 1185 I=1,ND*LC
1    477  1185 WRITE(1,1130,REC=I)Q(I)
     478        DO 1000 I=1,NE
1    479        DO 1000 J=1,6
2    480        IF(M(I,J))1000,1000,1010
2    481  1010 CALL TRANS(I)
2    482        JJ=M(I,J)
2    483        DO 1020 K=1,LC
3    484        DO 1030 L=1,6
4    485  1030 D(L)=0.0
3    486        DO 1040 L=1,6
4    487        DF=0.0
4    488        DO 1050 N=1,6
5    489  1050 DF=DF+XK(N,L)*FE((K-1)*NE+I,N)
4    490  1040 D(L)=DF
3    491  1020 Q((K-1)*ND+JJ)=Q((K-1)*ND+JJ)+D(J)
2    492  1000 CONTINUE
     493        DO 1060 I=1,ND*LC
1    494        READ(1,1130,REC=I)QQ
1    495  1060 Q(I)=QQ-Q(I)
     496        CLOSE(1,STATUS='DELETE')
     497 C
     498 C WRITE DATA FOR FURTHER ANALYSIS INTO FILE 2
     499 C
     500        FNOUT(1:2)=DR2
     501        FNOUT(3:2+6)='DANA.G'
     502        OPEN(2,FILE=FNOUT,ACCESS='DIRECT',FORM='UNFORMATTED',
     503      1  STATUS='NEW',RECL=102)
     504        WRITE(2,REC=1)NE,NJ,LC,ND,NB,NLC,NSU
```

```
D Line# 1      7                                  Microsoft FORTRAN77 V3.30 March 1985
     505       WRITE(2,REC=2)NS,E,G
     506       JJ=2
     507       DO 1120 I=1,NS
 1   508  1120 WRITE(2,REC=I+JJ)(S(I,J),J=1,2)
     509       JJ=JJ+NS
     510       DO 1140 I=1,NE
 1   511  1140 WRITE(2,REC=I+JJ)(MC(I,J),J=1,2),(M(I,J),J=1,6),MS(I)
     512       JJ=JJ+NE
     513       DO 1150 I=1,NJ
 1   514  1150 WRITE(2,REC=I+JJ)(C(I,J),J=1,2)
     515       JJ=JJ+NJ
     516       DO 1160 I=1,NSU
 1   517  1160 WRITE(2,REC=I+JJ)NSJ(I)
     518       JJ=JJ+NSU
     519       DO 1170 I=1,NE*LC
 1   520  1170 WRITE(2,REC=I+JJ)(FE(I,J),J=2,3),(FE(I,J),J=5,6)
     521       JJ=JJ+NE*LC
     522       DO 1180 I=1,ND*LC
*1   523  1180 WRITE(2,REC=I+JJ)Q(I)
     524       JJ=JJ+ND*LC
     525       DO 1190 I=1,NLC
 1   526  1190 WRITE(2,REC=I+JJ)(F(I,J),J=1,LC)
     527  1100 FORMAT(9I5)
     528  1110 FORMAT(I5,2E14.7)
     529  1130 FORMAT(10E14.7)
     530       CLOSE(2)
     531       END

Name     Type          Offset P Class

A1       REAL            2480
A2       REAL            2512
A3       REAL            2484
AS       CHAR*1          1622
ATAN                             INTRINSIC
C        REAL               0    /JD     /
CAS      CHAR*50         2222
*CHAR                            INTRINSIC
CL       REAL           43264    /LD     /
COM      CHAR*50           16
COS                              INTRINSIC
D        REAL           43276    /LD     /
DF       REAL             686
DR1      CHAR*2           524
DR2      CHAR*2           532
E        REAL             764
F        REAL           42864    /LD     /
FE       REAL               0    /LD     /
FF       CHAR*1           554
FNINN    CHAR*10          534
FNOUT    CHAR*10          544
G        REAL             768
I        INTEGER*4        670
IABS                             INTRINSIC
ID       INTEGER*4        728
IS       INTEGER*4        678
```

J	INTEGER*4	666	
JCO	INTEGER*4	636	
JJ	INTEGER*4	1766	
JR	INTEGER*4	1600	/JD /
K	INTEGER*4	1734	
KB	INTEGER*4	2214	
KK	INTEGER*4	1770	
L	INTEGER*4	748	
LC	INTEGER*4	836	
LP	INTEGER*4	1614	
M	INTEGER*4	6160	/ED /
MC	INTEGER*4	0	/ED /
MCO	INTEGER*4	714	
MOD			INTRINSIC
MS	INTEGER*4	2880	/ED /
N	INTEGER*4	682	
NB	INTEGER*4	2206	
ND	INTEGER*4	2202	
NE	INTEGER*4	718	
NJ	INTEGER*4	644	
NL	INTEGER*4	706	
NLC	INTEGER*4	840	
NN	INTEGER*4	1758	
NS	INTEGER*4	760	
NSJ	INTEGER*4	4000	/JD /
NSU	INTEGER*4	752	
NT	INTEGER*4	710	
Q	REAL	20864	/LD /
QQ	REAL	3454	
RX	REAL	690	
RY	REAL	694	
S	REAL	4320	/ED /
SN	CHAR*2	530	
SQRT			INTRINSIC
TH	REAL	640	
TITLE	CHAR*80	555	
W	REAL	2476	
XK	REAL	0	/TR /
XL	REAL	4720	/ED /

```
      SUBROUTINE SUBJC(TH,NL,NT,NJ)
      COMMON /JD/C(200,2),JR(200,3),NSJ(60)
C
C GENERATES JOINT COORDINATE AUTOMATICALLY
C
      READ(1,70)NL,NT,SPAN,TH,H
   70 FORMAT(2I5,3E10.0)
      XNL=SPAN/(NT-1)
      THR=TH*ATAN(1.0)/45.0
      K=1
      M2=NT*(NL-1)+1
      M3=NT
      IF(NL-NT)10,20,20
   10 M2=NL
      M3=1
```

```
D Line£ 1      7
     547     20 DO 30 I=1,M2,M3
1    548        C(I,1)=-(K-1)*H*TAN(TH)
1    549        C(I,2)=(K-1)*H
1    550        N1=I+1
1    551        N2=K*NT
1    552        N3=1
1    553        IF(NL-NT)40,50,50
1    554     40 N1=I+NL
1    555        N2=NL*(NT-1)+I
1    556        N3=NL
1    557     50 DO 60 J=N1,N2,N3
2    558        C(J,1)=C(J-N3,1)+XNL
2    559        C(J,2)=C(J-N3,2)
2    560     60 CONTINUE
1    561        K=K+1
1    562     30 CONTINUE
     563        NJ=NT*NL
     564        RETURN
     565        END
```

```
Name     Type          Offset P Class

ATAN                             INTRINSIC
C        REAL               0    /JD    /
H        REAL            3518
I        INTEGER*4       3554
J        INTEGER*4       3578
JR       INTEGER*4       1600    /JD    /
K        INTEGER*4       3542
M2       INTEGER*4       3546
M3       INTEGER*4       3550
N1       INTEGER*4       3566
N2       INTEGER*4       3570
N3       INTEGER*4       3574
NJ       INTEGER*4         12 *
NL       INTEGER*4          4 *
NSJ      INTEGER*4       4000    /JD    /
NT       INTEGER*4          8 *
SPAN     REAL            3514
TAN                              INTRINSIC
TH       REAL               0 *
THR      REAL            3538
XNL      REAL            3534
```

```
     566        SUBROUTINE SUBMC(NL,NT,NE)
     567        COMMON /ED/MC(360,2),MS(360),S(50,2),XL(360),M(360,6)
     568 C
     569 C GENERATES MEMBER CONNECTIVITY AUTOMATICALLY
     570 C
     571        NH=NL
     572        NV=NT
     573        IF(NT-NL)20,20,10
     574     10 NH=NT
     575        NV=NL
     576     20 DO 30 I=1,NH
```

08-23-87
16:16:12

```
D Line£ 1     7                          Microsoft FORTRAN77 V3.30 March 1985
1    577        DO 30 J=1,NV-1
2    578        L=(I-1)*(NV-1)+J
2    579        MC(L,1)=(I-1)*NV+J
2    580        MC(L,2)=MC(L,1)+1
2    581     30 CONTINUE
     582        DO 40 I=1,NV
1    583        J1=I
1    584        DO 40 J=1,NH-1
2    585        L=(NV-1)*NH+(I-1)*(NH-1)+J
2    586        MC(L,1)=J1
2    587        J1=J1+NT
2    588        MC(L,2)=J1
2    589     40 CONTINUE
     590 C
     591        NE=(NT-1)*NL+(NL-1)*NT
     592 C
     593 C READ & GENERATE ELEMENT SECTION NUMBER
     594 C
     595    140 READ(1,150)N,MS(N),IS
     596    150 FORMAT(3I5)
     597        IF(N)160,160,170
     598    170 IF(IS)140,140,180
     599    180 READ(1,150)NN
     600        DO 190 I=N+IS,NN,IS
1    601        MS(I)=MS(N)
1    602    190 CONTINUE
     603        GOTO 140
     604    160 RETURN
     605        END

Name     Type          Offset P Class

I        INTEGER*4       3598
IS       INTEGER*4       3634
J        INTEGER*4       3606
J1       INTEGER*4       3622
L        INTEGER*4       3614
M        INTEGER*4       6160    /ED     /
MC       INTEGER*4          0    /ED     /
MS       INTEGER*4       2880    /ED     /
N        INTEGER*4       3630
NE       INTEGER*4          8 *
NH       INTEGER*4       3590
NL       INTEGER*4          0 *
NN       INTEGER*4       3644
NT       INTEGER*4          4 *
NV       INTEGER*4       3594
S        REAL            4320    /ED     /
XL       REAL            4720    /ED     /

     606        SUBROUTINE TRANS(I)
     607 C
     608 C FORM TRANSFORMATION MATRIX XK
     609 C
     610        COMMON /JD/C(200,2),JR(200,3),NSJ(60)
```

```
D Line£ 1      7                                  Microsoft FORTRAN77 V3.30 March 1985
     611       COMMON /ED/MC(360,2),MS(360),S(50,2),XL(360),M(360,6)
     612       COMMON /TR/XK(6,6)
     613       J1=IABS(MC(I,1))
     614       J2=IABS(MC(I,2))
     615       X=C(J2,1)-C(J1,1)
     616       Y=C(J2,2)-C(J1,2)
     617       XL(I)=SQRT(X*X+Y*Y)
     618       IF(XL(I))10,10,20
     619    20 C1=X/XL(I)
     620       C2=Y/XL(I)
     621       DO 30 K=1,6
1    622       DO 30 L=1,6
2    623    30 XK(K,L)=0.0
     624       XK(1,1)=C1
     625       XK(3,3)=C1
     626       XK(4,4)=C1
     627       XK(6,6)=C1
     628       XK(1,3)=C2
     629       XK(4,6)=C2
     630       XK(3,1)=-C2
     631       XK(6,4)=-C2
     632       XK(2,2)=1.0
     633       XK(5,5)=1.0
     634       RETURN
     635    10 WRITE(*,'(5X,A,I5,A,F15.4)')'Length of Element ',I,' = ',XL(I)
     636       RETURN
     637       END

Name     Type          Offset P Class

C        REAL             0   /JD     /
C1       REAL          3672
C2       REAL          3676
I        INTEGER*4        0 *
IABS                          INTRINSIC
J1       INTEGER*4     3656
J2       INTEGER*4     3660
JR       INTEGER*4     1600   /JD     /
K        INTEGER*4     3680
L        INTEGER*4     3684
M        INTEGER*4     6160   /ED     /
MC       INTEGER*4        0   /ED     /
MS       INTEGER*4     2880   /ED     /
NSJ      INTEGER*4     4000   /JD     /
S        REAL          4320   /ED     /
SQRT                          INTRINSIC
X        REAL          3664
XK       REAL             0   /TR     /
XL       REAL          4720   /ED     /
Y        REAL          3668

     638       SUBROUTINE SPAC1
     639       WRITE(2,10)('-',I=1,70)
     640    10 FORMAT(3X,70A1,/)
     641       RETURN
```

```
    642         END

Name     Type          Offset P Class

I       INTEGER*4       3688


    643

Name     Type            Size   Class

ED                      14800   COMMON
GRID1                           PROGRAM
JD                       4240   COMMON
LD                      43300   COMMON
SPAC1                           SUBROUTINE
SUBJC                           SUBROUTINE
SUBMC                           SUBROUTINE
TR                        144   COMMON
TRANS                           SUBROUTINE

 Pass One     No Errors Detected
             643 Source Lines
```

06-26-8
22:28:5

```
D Line£ 1      7                                  Microsoft FORTRAN77 V3.30 March 198
      1 C
      2        PROGRAM GRID2
      3 C
      4        CHARACTER DR*2,SN*2,FN*10
      5 C
      6        COMMON /ON/E,G
      7        COMMON /JD/C(200,2)
      8        COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
      9        COMMON /LD/Q(5500),BK(21120)
     10 C
     11        OPEN(1,FILE='A:GRIL.DAT',ACCESS='DIRECT',FORM='FORMATTED',RECL=6)
     12        READ(1,10,REC=1)DR,SN
     13        CLOSE(1)
     14        FN(1:2)=DR
     15        FN(3:2+6)='DANA.G'
     16        FN(9:10)=SN
     17        OPEN(2,FILE=FN,ACCESS='DIRECT',FORM='UNFORMATTED',RECL=102)
     18        READ(2,REC=1)NE,NJ,LC,ND,NB,NLC,NSU
     19        READ(2,REC=2)NS,E,G
     20        JJ=2
     21        DO 40 I=1,NS
 1   22     40 READ(2,REC=I+JJ)(S(I,J),J=1,2)
     23        JJ=JJ+NS
     24        DO 60 I=1,NE
 1   25     60 READ(2,REC=I+JJ)(MC(I,J),J=1,2),(M(I,J),J=1,6),MS(I)
     26        JJ=JJ+NE
     27        DO 70 I=1,NJ
 1   28     70 READ(2,REC=I+JJ)(C(I,J),J=1,2)
     29        JJ=JJ+NJ+NSU+NE*LC
     30        DO 80 I=1,ND*LC
 1   31     80 READ(2,REC=I+JJ)Q(I)
     32 C
     33        DO 90 I=1,ND*NB
 1   34     90 BK(I)=0.0
     35        CALL ASS(ND,NB,NE)
     36        KC=1
     37        CALL SOLVER(ND,NB,LC,KC)
     38        IF(KC.LT.1)STOP
     39 C
     40        DO 100 I=1,ND*LC
 1   41    100 WRITE(2,REC=I+JJ)Q(I)
     42        CLOSE(2)
     43     10 FORMAT(2A)
     44     20 FORMAT(9I5)
     45     30 FORMAT(I5,2E14.7)
     46     50 FORMAT(4E14.7)
     47        END

Name     Type         Offset P Class

BK       REAL          22000   /LD     /
C        REAL              0   /JD     /
DR       CHAR*2           16
E        REAL              0   /ON     /
FN       CHAR*10          20
G        REAL              4   /ON     /
```

06-26-87
22:28:54

```
D Linef 1     7                                  Microsoft FORTRAN77 V3.30 March 1985
I       INTEGER*4          66
J       INTEGER*4          74
JJ      INTEGER*4          62
KC      INTEGER*4         102
LC      INTEGER*4          38
M       INTEGER*4        4720    /ED     /
MC      INTEGER*4           0    /ED     /
MS      INTEGER*4        2880    /ED     /
NB      INTEGER*4          46
ND      INTEGER*4          42
NE      INTEGER*4          30
NJ      INTEGER*4          34
NLC     INTEGER*4          50
NS      INTEGER*4          58
NSU     INTEGER*4          54
Q       REAL                0    /LD     /
S       REAL             4320    /ED     /
SN      CHAR*2             18
```

```
      48        SUBROUTINE ASS(ND,NB,NE)
      49        COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
      50        COMMON /LD/Q(5500),BK(21120)
      51        COMMON /ST/XK(6,6)
      52        INTEGER TC(6,6),TR(6,6)
      53 C
      54 C SYSTEM STIFFNESS MATRIX TRANSFORMATION
      55 C
      56        DO 10 I=1,NE
 1    57        CALL STIF(I)
 1    58        DO 20 K=1,6
 2    59        DO 20 L=1,6
 3    60        TC(K,L)=0
 3    61     20 TR(K,L)=0
 1    62        DO 30 K=1,6
 2    63        IF(M(I,K))30,30,40
 2    64     40 DO 50 L=1,6
 3    65        TC(K,L)=M(I,L)
 3    66     50 TR(L,K)=M(I,L)
 2    67     30 CONTINUE
 1    68        DO 60 J=1,6
 2    69        DO 60 K=1,6
 3    70        IF(TC(J,K))60,60,70
 3    71     70 L=TC(J,K)
 3    72        N=TR(J,K)
 3    73        IF(N-L)80,80,60
 3    74     80 JJ=L-N+1
 3    75        IF(JJ-NB)100,100,90
 3    76     90 WRITE(*,200)I,N
 3    77    100 BK((J-1)*ND+N)=BK((J-1)*ND+N)+XK(J,K)
 3    78     60 CONTINUE
 1    79     10 CONTINUE
      80        RETURN
      81    200 FORMAT(5X'Column > NB at Element'I5' Row'I5)
      82        END
```

06-26-87
22:28:54

D Line£ 1 7 Microsoft FORTRAN77 V3.30 March 1985

Name	Type	Offset	P	Class
BK	REAL	22000		/LD /
I	INTEGER*4	428		
J	INTEGER*4	444		
JJ	INTEGER*4	452		
K	INTEGER*4	436		
L	INTEGER*4	440		
M	INTEGER*4	4720		/ED /
MC	INTEGER*4	0		/ED /
MS	INTEGER*4	2880		/ED /
N	INTEGER*4	448		
NB	INTEGER*4	4	*	
ND	INTEGER*4	0	*	
NE	INTEGER*4	8	*	
Q	REAL	0		/LD /
S	REAL	4320		/ED /
TC	INTEGER*4	140		
TR	INTEGER*4	284		
XK	REAL	0		/ST /

```
     83        SUBROUTINE STIF(I)
     84        COMMON /ON/E,G
     85        COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
     86        COMMON /ST/XK(6,6)
     87        COMMON /TR/TC(6,6),TR(6,6)
     88        COMMON /TW/XL
     89 C
     90 C FORM ELEMENT MODEL
     91 C
     92        CALL TRANS(I)
     93        DO 10 K=1,6
     94        DO 10 L=1,6
2    95     10 XK(K,L)=0.0
     96        L=MS(I)
     97        A=S(L,1)
     98        XI=S(L,2)
     99        IF(XL)20,20,30
    100     20 WRITE(*,300)I,XL
    101     30 AL=E*XI/XL**3
    102        IF(A)40,40,50
    103     40 WRITE(*,310)I,A
    104     50 IF(XI)60,60,70
    105     60 WRITE(*,320)I,XI
    106     70 B=G*A*XL*XL/(E*XI)
    107        XK(1,1)=AL*B
    108        XK(4,4)=AL*B
    109        XK(1,4)=-AL*B
    110        XK(4,1)=-AL*B
    111        IF(MC(I,1).LT.0 .OR. MC(I,2).LT.0)GOTO 80
    112        XK(2,2)=12*AL
    113        XK(5,5)=12*AL
    114        XK(5,2)=-12*AL
    115        XK(2,5)=-12*AL
```

```
D Line£ 1     7
     116        XK(2,3)=6*XL*AL
     117        XK(3,2)=XK(2,3)
     118        XK(2,6)=XK(2,3)
     119        XK(6,2)=XK(2,3)
     120        XK(3,5)=-XK(2,3)
     121        XK(5,3)=XK(3,5)
     122        XK(5,6)=XK(3,5)
     123        XK(6,5)=XK(3,5)
     124        XK(3,3)=4*XL*XL*AL
     125        XK(6,6)=XK(3,3)
     126        XK(3,6)=XK(3,3)/2.0
     127        XK(6,3)=XK(3,6)
     128        GOTO 90
     129     80 XK(2,2)=3*AL
     130        XK(5,5)=3*AL
     131        XK(2,5)=-3*AL
     132        XK(5,2)=XK(2,5)
     133        IF(MC(I,1))110,100,120
     134    100 WRITE(*,330)I
     135    110 XK(2,6)=3*AL*XL
     136        XK(6,2)=XK(2,6)
     137        XK(5,6)=-XK(2,6)
     138        XK(6,5)=XK(5,6)
     139        XK(6,6)=XK(2,6)*XL
     140    120 IF(MC(I,2))140,130,90
     141    130 WRITE(*,330)I
     142    140 XK(2,3)=3*AL*XL
     143        XK(3,2)=XK(2,3)
     144        XK(3,5)=-XK(2,3)
     145        XK(5,3)=XK(3,5)
     146        XK(3,3)=XK(2,3)*XL
     147     90 DO 150 K=1,6
1    148        DO 150 L=1,6
2    149        SUM=0.0
2    150        DO 160 J=1,6
3    151    160 SUM=SUM+XK(K,J)*TC(J,L)
2    152    150 TR(K,L)=SUM
     153        DO 170 K=1,6
1    154        DO 170 L=1,6
2    155        SUM=0.0
2    156        DO 180 J=1,6
3    157    180 SUM=SUM+TC(J,K)*TR(J,L)
2    158    170 XK(K,L)=SUM
     159        RETURN
     160    300 FORMAT(5X'Length OF Element'I5' ='F15.4)
     161    310 FORMAT(5X'Torsion Const. of Element'I5' ='E10.4)
     162    320 FORMAT(5X'Inertia of Element'I5' ='E10.4)
     163    330 FORMAT(5X'Element'I5'Connects to ZERO Joint')
     164        END

Name     Type         Offset P Class

A        REAL            504
AL       REAL            512
B        REAL            516
E        REAL              0   /ON     /
```

```
G       REAL              4   /ON    /
I       INTEGER*4         0 *
J       INTEGER*4       524
K       INTEGER*4       496
L       INTEGER*4       500
M       INTEGER*4      4720   /ED    /
MC      INTEGER*4         0   /ED    /
MS      INTEGER*4      2880   /ED    /
S       REAL           4320   /ED    /
SUM     REAL            520
TC      REAL              0   /TR    /
TR      REAL            144   /TR    /
XI      REAL            508
XK      REAL              0   /ST    /
XL      REAL              0   /TW    /
```

```
      SUBROUTINE TRANS(I)
C
C FORM TRANSFORMATION MATRIX
C
      COMMON /JD/C(200,2)
      COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
      COMMON /TR/TC(6,6),TR(6,6)
      COMMON /TW/XL
      J1=IABS(MC(I,1))
      J2=IABS(MC(I,2))
      X=C(J2,1)-C(J1,1)
      Y=C(J2,2)-C(J1,2)
      XL=SQRT(X*X+Y*Y)
      IF(XL)10,10,20
   20 C1=X/XL
      C2=Y/XL
      DO 30 K=1,6
1     DO 30 L=1,6
2  30 TC(K,L)=0.0
      TC(1,1)=C1
      TC(3,3)=C1
      TC(4,4)=C1
      TC(6,6)=C1
      TC(1,3)=C2
      TC(4,6)=C2
      TC(3,1)=-C2
      TC(6,4)=-C2
      TC(2,2)=1.0
      TC(5,5)=1.0
      RETURN
   10 WRITE(*,'(5X,A,I5,A,F15.4)')'Length of Element ',I,' = ',XL
      RETURN
      END
```

```
Name    Type          Offset P Class

C       REAL               0   /JD    /
C1      REAL             700
C2      REAL             704
```

```
D Line£ 1     7
I       INTEGER*4          0 *
IABS                          INTRINSIC
J1      INTEGER*4        684
J2      INTEGER*4        688
K       INTEGER*4        708
L       INTEGER*4        712
M       INTEGER*4       4720   /ED    /
MC      INTEGER*4          0   /ED    /
MS      INTEGER*4       2880   /ED    /
S       REAL            4320   /ED    /
SQRT                          INTRINSIC
TC      REAL               0   /TR    /
TR      REAL             144   /TR    /
X       REAL             692
XL      REAL               0   /TW    /
Y       REAL             696
```

```
     198        SUBROUTINE SOLVER(ND,NB,LC,KC)
     199        COMMON /LD/Q(5500),BK(21120)
     200 C
     201 C TRIPLE MATRIX DECOMPOSITION TECHNIQUE
     202 C
     203        DO 600 I=1,ND
1    204        IF(BK(I))600,1060,600
1    205    600 CONTINUE
     206        DO 650 I=2,ND
1    207        IL1=I-1
1    208        NBL=IL1+NB
1    209        IF(NBL-ND)615,615,610
1    210    610 NBL=ND
1    211    615 DO 650 J=I,NBL
2    212        IJ=(J-I)*ND+I
2    213        SUM=BK(IJ)
2    214        NNB=J-NB+1
2    215        IF(NNB)620,620,630
2    216    620 NNB=1
2    217    630 IF(NNB-IL1)632,632,642
2    218    632 DO 640 N=NNB,IL1
3    219    640 SUM=SUM-BK((I-N)*ND+N)*BK((J-N)*ND+N)/BK(N)
2    220    642 BK(IJ)=SUM
2    221    650 CONTINUE
     222        DO 666 II=1,LC
1    223        LI=ND*(II-1)
1    224        Q(LI+1)=Q(LI+1)/BK(1)
1    225        DO 665 I=2,ND
2    226        IR=LI+I
2    227        SUM=Q(IR)
2    228        I1=I-1
2    229        NNB=I-NB+1
2    230        IF(NNB)655,655,656
2    231    655 NNB=1
2    232    656 DO 662 K=NNB,I1
3    233        KR=LI+K
3    234        SUM=SUM-BK((I-K)*ND+K)*Q(KR)
3    235    662 CONTINUE
```

06-26-87
22:28:54

```
D Line£ 1      7                              Microsoft FORTRAN77 V3.30 March 1985
2    236    665 Q(IR)=SUM/BK(I)
1    237    666 CONTINUE
     238        DO 680 II=1,LC
1    239        LI=ND*(II-1)
1    240        DO 675 JJ=2,ND
2    241        I=ND-JJ+1
2    242        IR=LI+I
2    243        SUM=0.0
2    244        I1=I+1
2    245        NNB=I-1+NB
2    246        IF(NNB-ND)672,672,671
2    247    671 NNB=ND
2    248    672 DO 673 K=I1,NNB
3    249        KR=LI+K
3    250    673 SUM=SUM+BK((K-I)*ND+I)*Q(KR)
2    251    675 Q(IR)=Q(IR)-SUM/BK(I)
1    252    680 CONTINUE
     253        RETURN
     254   1060 WRITE(*,'(A)')'ZERO Leading Coefficient Encountered'
     255        KC=0
     256        RETURN
     257        END
```

Name	Type	Offset	P	Class
BK	REAL	22000		/LD /
I	INTEGER*4	716		
I1	INTEGER*4	784		
II	INTEGER*4	764		
IJ	INTEGER*4	744		
IL1	INTEGER*4	728		
IR	INTEGER*4	780		
J	INTEGER*4	736		
JJ	INTEGER*4	804		
K	INTEGER*4	788		
KC	INTEGER*4	12	*	
KR	INTEGER*4	796		
LC	INTEGER*4	8	*	
LI	INTEGER*4	772		
N	INTEGER*4	756		
NB	INTEGER*4	4	*	
NBL	INTEGER*4	732		
ND	INTEGER*4	0	*	
NNB	INTEGER*4	752		
Q	REAL	0		/LD /
SUM	REAL	748		

Name	Type	Size	Class
ASS			SUBROUTINE
ED		13360	COMMON
GRID2			PROGRAM
JD		1600	COMMON
LD		40944	COMMON

D Line£ 1 7 Microsoft FORTRAN77 V3.30 March 1985

ON	8	COMMON
SOLVER		SUBROUTINE
ST	144	COMMON
STIF		SUBROUTINE
TR	288	COMMON
TRANS		SUBROUTINE
TW	4	COMMON

Pass One No Errors Detected
257 Source Lines

```
D Line£ 1      7                                Microsoft FORTRAN77 V3.30 March 1985
      1 C
      2 C
      3       PROGRAM GRID3
      4 C
      5       CHARACTER DR*2,SN*2,FN*10
      6 C
      7       COMMON /ON/E,G
      8       COMMON /JD/C(200,2),NSJ(60)
      9       COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
     10       COMMON /RS/P(600,3)
     11       DIMENSION F(10)
     12 C
     13       OPEN(1,FILE='A:GRIL.DAT',ACCESS='DIRECT',FORM='FORMATTED',RECL=6)
     14       READ(1,10,REC=1)DR,SN
     15       CLOSE(1)
     16       FN(1:2)=DR
     17       FN(3:2+6)='DANA.G'
     18       FN(9:10)=SN
     19       OPEN(2,FILE=FN,ACCESS='DIRECT',FORM='UNFORMATTED',RECL=102)
     20       READ(2,REC=1)NE,NJ,LC,ND,NB,NLC,NSU
     21       READ(2,REC=2)NS,E,G
     22       JJ=2
     23       DO 1120 I=1,NS
1    24  1120 READ(2,REC=I+JJ)(S(I,J),J=1,2)
     25       JJ=JJ+NS
     26       DO 1140 I=1,NE
1    27  1140 READ(2,REC=I+JJ)(MC(I,J),J=1,2),(M(I,J),J=1,6),MS(I)
     28       JJ=JJ+NE
     29       DO 1150 I=1,NJ
1    30  1150 READ(2,REC=I+JJ)(C(I,J),J=1,2)
     31       JJ=JJ+NJ
     32       DO 1160 I=1,NSU
1    33  1160 READ(2,REC=I+JJ)NSJ(I)
     34 C
     35       CALL EFORCE(ND,NE,LC,NJ,NS,NSU)
     36 C
     37       CALL JFORCE(NSU,NE,NJ,LC,NS)
     38 C
     39       FN(3:2+6)='JFOR.G'
     40       OPEN(3,FILE=FN,ACCESS='DIRECT',STATUS='NEW',RECL=420)
     41       DO 2100 I=1,NSU
1    42  2100 WRITE(3,REC=I)((P((K-1)*NSU+I,J),J=1,3),K=1,LC)
     43       CLOSE(2)
     44       CLOSE(3)
     45 C
     46    10 FORMAT(2A)
     47  1100 FORMAT(9I5)
     48  1110 FORMAT(I5,10E14.7)
     49  1130 FORMAT(12E14.7)
     50       END

Name     Type         Offset P Class

C        REAL              0   /JD     /
DR       CHAR*2           56
E        REAL              0   /ON     /
```

07-07-87
22:56:39

D Line£ 1 7 Microsoft FORTRAN77 V3.30 March 1985

F	REAL	16		
FN	CHAR*10	60		
G	REAL	4	/ON /	
I	INTEGER*4	106		
J	INTEGER*4	114		
JJ	INTEGER*4	102		
K	INTEGER*4	142		
LC	INTEGER*4	78		
M	INTEGER*4	4720	/ED /	
MC	INTEGER*4	0	/ED /	
MS	INTEGER*4	2880	/ED /	
NB	INTEGER*4	86		
ND	INTEGER*4	82		
NE	INTEGER*4	70		
NJ	INTEGER*4	74		
NLC	INTEGER*4	90		
NS	INTEGER*4	98		
NSJ	INTEGER*4	1600	/JD /	
NSU	INTEGER*4	94		
P	REAL	0	/RS /	
S	REAL	4320	/ED /	
SN	CHAR*2	58		

```
      SUBROUTINE EFORCE(ND,NE,LC,NJ,NS,NSU)
C
      COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
      COMMON /RS/P(600,3) /FF/FE(6)
      COMMON /ST/XK(6,6) /TR/T(6,6) /DD/DT(6),D(6)
C
      DO 110 KK=1,LC
1     DO 110 I=(KK-1)*NE+1,KK*NE
2     DO 120 K=1,6
3   120 D(K)=0.0
2     I1=I-(KK-1)*NE
2   C
2   C GLOBAL DISPLACEMENT TRANSFORMATION
2   C
2     JJ=2+NS+NE+NJ+NSU+LC*NE
2     DO 130 K=1,6
3     IF(M(I1,K))130,130,140
3   140 L=M(I1,K)
3     READ(2,REC=(KK-1)*ND+L+JJ)D(K)
3   130 CONTINUE
2   C
2   C LOCAL DISPLACEMENT TRANSFORMATION
2   C
2     CALL TRANS(I1)
2     DO 280 J=1,6
3     SUM=0.0
3     DO 290 K=1,6
4   290 SUM=SUM+T(J,K)*D(K)
3   280 DT(J)=SUM
2   C
2   C COMPUTATION OF ELEMENT FORCES
2   C
```

```
D Line£ 1      7                                  Microsoft FORTRAN77 V3.30 March 198
2     83       CALL STIF(I1)
2     84       JJ=2+NS+NE+NJ+NSU
2     85       READ(2,REC=I+JJ)(FE(J),J=2,3),(FE(J),J=5,6)
2     86       DO 160 J=1,6
3     87       SUM=0.0
3     88       DO 170 K=1,6
4     89   170 SUM=SUM+XK(J,K)*DT(K)
3     90   160 D(J)=SUM+FE(J)
2     91       WRITE(2,REC=I+JJ)(D(J),J=1,6),(DT(J),J=1,6)
2     92   110 CONTINUE
      93  1130 FORMAT(12E14.7)
      94       RETURN
      95       END

 Name     Type          Offset P Class

 D        REAL            24   /DD     /
 DT       REAL             0   /DD     /
 FE       REAL             0   /FF     /
 I        INTEGER*4      186
 Ii       INTEGER*4      198
 J        INTEGER*4      210
 JJ       INTEGER*4      202
 K        INTEGER*4      194
 KK       INTEGER*4      178
 L        INTEGER*4      206
 LC       INTEGER*4        8 *
 M        INTEGER*4     4720   /ED     /
 MC       INTEGER*4        0   /ED     /
 MS       INTEGER*4     2880   /ED     /
 ND       INTEGER*4        0 *
 NE       INTEGER*4        4 *
 NJ       INTEGER*4       12 *
 NS       INTEGER*4       16 *
 NSU      INTEGER*4       20 *
 P        REAL             0   /RS     /
 S        REAL          4320   /ED     /
 SUM      REAL           214
 T        REAL             0   /TR     /
 XK       REAL             0   /ST     /


     96       SUBROUTINE JFORCE(NSU,NE,NJ,LC,NS)
     97 C
     98       COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
     99       COMMON /RS/P(600,3) /DD/DT(6),D(6)
    100       COMMON /JD/C(200,2),NSJ(60) /TR/T(6,6)
    101 C
    102 C
    103 C COMPUTATION OF JOINT FORCES
    104 C
    105       JJ=2+NS+NE+NJ+NSU
    106       DO 300 J=1,NSU
1   107       DO 300 I=1,NE
2   108       IF(IABS(MC(I,1))-NSJ(J))310,320,310
2   109   320 CALL TRANS(I)
```

07-07-87
22:56:39

```
D Line# 1      7                                  Microsoft FORTRAN77 V3.30 March 1985
2    110       DO 322 N=1,LC
3    111       READ(2,REC=(N-1)*NE+I+JJ,ERR=1000)(D(L),L=1,6)
3    112       DO 324 L=1,3
4    113       SUM=0.0
4    114       DO 326 K=1,3
5    115   326 SUM=SUM+T(K,L)*D(K)
4    116   324 P((N-1)*NSU+J,L)=P((N-1)*NSU+J,L)+SUM
3    117   322 CONTINUE
2    118   310 IF(IABS(MC(I,2))-NSJ(J))300,340,300
2    119   340 CALL TRANS(I)
2    120       DO 342 N=1,LC
3    121       READ(2,REC=(N-1)*NE+I+JJ,ERR=1000)(D(L),L=1,6)
3    122       DO 344 L=1,3
4    123       SUM=0.0
4    124       DO 346 K=1,3
5    125   346 SUM=SUM+T(K,L)*D(K+3)
4    126   344 P((N-1)*NSU+J,L)=P((N-1)*NSU+J,L)+SUM
3    127   342 CONTINUE
2    128   300 CONTINUE
     129       RETURN
     130  1000 WRITE(*,'(A,I5)')' ERROR IN READING FILE 3 ',I
     131  1230 FORMAT(12E14.7)
     132       RETURN
     133       END

Name    Type          Offset P Class

C       REAL               0   /JD     /
D       REAL              24   /DD     /
DT      REAL               0   /DD     /
I       INTEGER*4        248
IABS                             INTRINSIC
J       INTEGER*4        240
JJ      INTEGER*4        236
K       INTEGER*4        276
L       INTEGER*4        264
LC      INTEGER*4         12 *
M       INTEGER*4       4720   /ED     /
MC      INTEGER*4          0   /ED     /
MS      INTEGER*4       2880   /ED     /
N       INTEGER*4        256
NE      INTEGER*4          4 *
NJ      INTEGER*4          8 *
NS      INTEGER*4         16 *
NSJ     INTEGER*4       1600   /JD     /
NSU     INTEGER*4          0 *
P       REAL               0   /RS     /
S       REAL            4320   /ED     /
SUM     REAL             272
T       REAL               0   /TR     /

    134       SUBROUTINE TRANS(I)
    135 C
    136 C FORM TRANSFORMATION MATRIX
    137 C
```

```
     138        COMMON /JD/C(200,2),NSJ(60)
     139        COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
     140        COMMON /TR/T(6,6)
     141        J1=IABS(MC(I,1))
     142        J2=IABS(MC(I,2))
     143        X=C(J2,1)-C(J1,1)
     144        Y=C(J2,2)-C(J1,2)
     145        XL=SQRT(X*X+Y*Y)
     146        IF(XL)10,10,20
     147     20 C1=X/XL
     148        C2=Y/XL
     149        DO 30 K=1,6
1    150        DO 30 L=1,6
2    151     30 T(K,L)=0.0
     152        T(1,1)=C1
     153        T(3,3)=C1
     154        T(4,4)=C1
     155        T(6,6)=C1
     156        T(1,3)=C2
     157        T(4,6)=C2
     158        T(3,1)=-C2
     159        T(6,4)=-C2
     160        T(2,2)=1.0
     161        T(5,5)=1.0
     162        RETURN
     163     10 WRITE(*,'(5X,A,I5,A,F15.4)')'Length of Element ',I,' = ',XL
     164        RETURN
     165        END
```

Name	Type	Offset	P	Class
C	REAL	0		/JD /
C1	REAL	314		
C2	REAL	318		
I	INTEGER*4	0	*	
IABS				INTRINSIC
J1	INTEGER*4	294		
J2	INTEGER*4	298		
K	INTEGER*4	322		
L	INTEGER*4	326		
M	INTEGER*4	4720		/ED /
MC	INTEGER*4	0		/ED /
MS	INTEGER*4	2880		/ED /
NSJ	INTEGER*4	1600		/JD /
S	REAL	4320		/ED /
SQRT				INTRINSIC
T	REAL	0		/TR /
X	REAL	302		
XL	REAL	310		
Y	REAL	306		

```
     166        SUBROUTINE STIF(I)
     167 C
     168        COMMON /ON/E,G
     169        COMMON /ED/MC(360,2),MS(360),S(50,2),M(360,6)
```

```
    170       COMMON /ST/XK(6,6)
    171       COMMON /JD/C(200,2),NSJ(60)
    172 C
    173 C FORM ELEMENT MODEL
    174 C
    175       K=IABS(MC(I,1))
    176       J=IABS(MC(I,2))
    177       XL=SQRT((C(J,1)-C(K,1))**2+(C(J,2)-C(K,2))**2)
    178       DO 10 K=1,6
1   179       DO 10 L=1,6
2   180    10 XK(K,L)=0.0
    181       L=MS(I)
    182       A=S(L,1)
    183       XI=S(L,2)
    184       IF(XL)20,20,30
    185    20 WRITE(*,300)I,XL
    186    30 AL=E*XI/XL**3
    187       IF(A)40,40,50
    188    40 WRITE(*,310)I,A
    189    50 IF(XI)60,60,70
    190    60 WRITE(*,320)I,XI
    191    70 B=G*A*XL*XL/(E*XI)
    192       XK(1,1)=AL*B
    193       XK(4,4)=AL*B
    194       XK(1,4)=-AL*B
    195       XK(4,1)=-AL*B
    196       IF(MC(I,1).LT.0 .OR. MC(I,2).LT.0)GOTO 80
    197       XK(2,2)=12*AL
    198       XK(5,5)=12*AL
    199       XK(5,2)=-12*AL
    200       XK(2,5)=-12*AL
    201       XK(2,3)=6*XL*AL
    202       XK(3,2)=XK(2,3)
    203       XK(2,6)=XK(2,3)
    204       XK(6,2)=XK(2,3)
    205       XK(3,5)=-XK(2,3)
    206       XK(5,3)=XK(3,5)
    207       XK(5,6)=XK(3,5)
    208       XK(6,5)=XK(3,5)
    209       XK(3,3)=4*XL*XL*AL
    210       XK(6,6)=XK(3,3)
    211       XK(3,6)=XK(3,3)/2.0
    212       XK(6,3)=XK(3,6)
    213       GOTO 90
    214    80 XK(2,2)=3*AL
    215       XK(5,5)=3*AL
    216       XK(2,5)=-3*AL
    217       XK(5,2)=XK(2,5)
    218       IF(MC(I,1))110,100,120
    219   100 WRITE(*,330)I
    220   110 XK(2,6)=3*AL*XL
    221       XK(6,2)=XK(2,6)
    222       XK(5,6)=-XK(2,6)
    223       XK(6,5)=XK(5,6)
    224       XK(6,6)=XK(2,6)*XL
    225   120 IF(MC(I,2))140,130,90
```

```
    226   130 WRITE(*,330)I
    227   140 XK(2,3)=3*AL*XL
    228       XK(3,2)=XK(2,3)
    229       XK(3,5)=-XK(2,3)
    230       XK(5,3)=XK(3,5)
    231       XK(3,3)=XK(2,3)*XL
    232    90 RETURN
    233   300 FORMAT(5X'Length OF Element'I5' ='F15.4)
    234   310 FORMAT(5X'Torsion Const. of Element'I5' ='E10.4)
    235   320 FORMAT(5X'Inertia of Element'I5' ='E10.4)
    236   330 FORMAT(5X'Element'I5'Connects to ZERO Joint')
    237       END
```

Name	Type	Offset	P	Class
A	REAL	346		
AL	REAL	354		
B	REAL	358		
C	REAL	0		/JD /
E	REAL	0		/ON /
G	REAL	4		/ON /
I	INTEGER*4	0	*	
IABS				INTRINSIC
J	INTEGER*4	334		
K	INTEGER*4	330		
L	INTEGER*4	342		
M	INTEGER*4	4720		/ED /
MC	INTEGER*4	0		/ED /
MS	INTEGER*4	2880		/ED /
NSJ	INTEGER*4	1600		/JD /
S	REAL	4320		/ED /
SQRT				INTRINSIC
XI	REAL	350		
XK	REAL	0		/ST /
XL	REAL	338		

Name	Type	Size	Class
DD		48	COMMON
ED		13360	COMMON
EFORCE			SUBROUTINE
FF		24	COMMON
GRID3			PROGRAM
JD		1840	COMMON
JFORCE			SUBROUTINE
ON		8	COMMON
RS		7200	COMMON
ST		144	COMMON
STIF			SUBROUTINE
TR		144	COMMON
TRANS			SUBROUTINE

07-07-87
22:56:39

```
'D Line£ 1      7                    Microsoft FORTRAN77 V3.30 March 1985
  Pass One      No Errors Detected
                237 Source Lines
```

07-02-87
21:45:04

D Linef 1 7 Microsoft FORTRAN77 V3.30 March 1985

```
      1 C
      2 C
      3       PROGRAM GRID4
      4 C
      5       CHARACTER DR1*2,SN*2,FN*10,FF*1,DR2*2,C2,EN*2,EF*2,DN*2,DF*2
      6 C
      7       COMMON /ED/MC(360,2)  /RS/NSJ(60) /JD/JR(200,3) /FF/F(10,10)
      8       COMMON /PP/EN,EF,DN,DF
      9 C
     10       OPEN(1,FILE='A:GRIL.DAT',ACCESS='DIRECT',FORM='FORMATTED',RECL=6)
     11       READ(1,10,REC=1)DR2,SN,DR1
     12       CLOSE(1)
     13       FN(1:2)=DR2
     14       FN(3:2+6)='DANA.G'
     15       FN(9:10)=SN
     16       OPEN(1,FILE=FN,ACCESS='DIRECT',FORM='UNFORMATTED',RECL=102)
     17       FN(3:2+6)='JFOR.G'
     18       OPEN(4,FILE=FN,ACCESS='DIRECT',RECL=420)
     19       FN(1:2)=DR1
     20       FN(3:2+6)='INFO.G'
     21       OPEN(3,FILE=FN)
     22       FN(3:2+6)='RESU.G'
     23       OPEN(2,FILE=FN,STATUS='NEW')
     24 C
     25       READ(1,REC=1)NE,NJ,LC,ND,NB,NLC,NSU
     26       READ(1,REC=2)NS
     27       FF=CHAR(12)
     28       DO 20 I=1,NJ
1    29    20 READ(3,1100)(JR(I,J),J=1,3)
     30       JJ=2+NS
     31       DO 30 I=1,NE
1    32    30 READ(1,REC=I+JJ)(MC(I,J),J=1,2)
     33       JJ=JJ+NE+NJ
     34       DO 50 I=1,NSU
1    35    50 READ(1,REC=I+JJ)NSJ(I)
     36       JJ=JJ+NSU+NE*LC+ND*LC
     37       DO 40 I=1,NLC
1    38    40 READ(1,REC=I+JJ)(F(I,J),J=1,LC)
     39 C
     40       C2=CHAR(27)
     41       EN(1:1)=C2
     42       EF(1:1)=C2
     43       DN(1:1)=C2
     44       DF(1:1)=C2
     45       EN(2:2)='E'
     46       EF(2:2)='F'
     47       DN(2:2)='G'
     48       DF(2:2)='H'
     49 C
     50       CALL GDIS(NE,NJ,NSU,ND,LC,NLC,NS,FF)
     51       CALL LDIS(NE,NJ,LC,NLC,NS,NSU,FF)
     52       CALL EFORCE(NE,NJ,LC,NLC,NSU,NS,FF)
     53       CALL REACT(NE,NJ,LC,NLC,NSU,NS,FF)
     54       CALL CACTION(NE,NJ,LC,NLC,NSU,NS,FF)
     55 C
     56       CLOSE(1)
```

```
D Line£ 1      7                          Microsoft FORTRAN77 V3.30 March 1985
      57       CLOSE(2)
      58       CLOSE(3)
      59       CLOSE(4)
      60    10 FORMAT(3A)
      61  1100 FORMAT(9I5)
      62  1130 FORMAT(10E14.7)
      63       END

 Name     Type          Offset P Class

 C2      CHAR*1             98
 CHAR                              INTRINSIC
 DF      CHAR*2              6    /PP     /
 DN      CHAR*2              4    /PP     /
 DR1     CHAR*2             20
 DR2     CHAR*2             16
 EF      CHAR*2              2    /PP     /
 EN      CHAR*2              0    /PP     /
 F       REAL                0    /FF     /
 FF      CHAR*1             64
 FN      CHAR*10            22
 I       INTEGER*4          66
 J       INTEGER*4          74
 JJ      INTEGER*4          82
 JR      INTEGER*4           0    /JD     /
 LC      INTEGER*4          40
 MC      INTEGER*4           0    /ED     /
 NB      INTEGER*4          48
 ND      INTEGER*4          44
 NE      INTEGER*4          32
 NJ      INTEGER*4          36
 NLC     INTEGER*4          52
 NS      INTEGER*4          60
 NSJ     INTEGER*4           0    /RS     /
 NSU     INTEGER*4          56
 SN      CHAR*2             18

      64          SUBROUTINE GDIS(NE,NJ,NSU,ND,LC,NLC,NS,FF)
      65 C
      66 C  PRINT GLOBAL DISPLACEMENTS
      67 C
      68        CHARACTER FF,EN*2,EF*2,DN*2,DF*2
      69        COMMON /JD/JR(200,3)  /DD/D(12),DT(12) /FF/F(10,10)
      70        COMMON /PP/EN,EF,DN,DF
      71        WRITE(2,1000)FF,EN,DN,EF,DF
      72        CALL SPAC
      73        LP=4
      74        JJ=2+NS+NE+NJ+NSU+NE*LC
      75     10 READ(3,1010)J,N,IS
      76        IF(J)100,100,110
      77    110 DO 111 K=1,3
1     78        IF(MOD(LP+K,56))111,112,111
      79    112 WRITE(2,'(A)')FF
      80        LP=LP+K
      81        GOTO 113
```

07-02-87
21:45:04

```
"D Line£ 1     7                          Microsoft FORTRAN77 V3.30 March 1985
 1     82   111 CONTINUE
       83   113 WRITE(2,1030)EN,DN,EF,DF
       84       LP=LP+3
       85       DO 20 L=J,N,IS
 1     86       DO 20 I=1,NLC
 2     87       DO 30 K=1,3
 3     88    30 D(K)=0.0
 2     89       DO 40 KK=1,LC
 3     90       IF(F(I,KK))50,40,50
 3     91    50 DO 60 K=1,3
 4     92       IF(JR(L,K))60,60,70
 4     93    70 II=JR(L,K)
 4     94       READ(1,REC=(KK-1)*ND+II+JJ)QQ
 4     95       D(K)=D(K)+QQ*F(I,KK)*1000.0
 4     96    60 CONTINUE
 3     97    40 CONTINUE
 2     98       IF(I-1)80,90,80
 2     99    90 WRITE(2,1040)L,I,(D(K),K=1,3)
 2    100       LP=LP+1
 2    101       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
 2    102       GOTO 20
 2    103    80 WRITE(2,1050)I,(D(K),K=1,3)
 2    104       LP=LP+1
 2    105       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
 2    106    20 CONTINUE
      107       CALL SPAC
      108       LP=LP+2
      109       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
      110       GOTO 10
      111   100 CALL SPAC
      112       RETURN
      113  1000 FORMAT(3A,//5X'GLOBAL DISPLACEMENTS'2A)
      114  1010 FORMAT(3I5)
      115  1020 FORMAT(6E14.7)
      116  1030 FORMAT(2A,3X'JOINT'12X'LOAD'3X'X - ROTATION'3X'Z - MOVEMENT'3X
      117      1'Y - ROTATION'/5X'NO.'5X'COMBINATION'4X'1.0E-3 rad.'7X'(mm)'
      118     28X'1.0E-3 rad.'/2A)
      119  1040 FORMAT(3X,I5,11X,I5,3(3X,F12.4))
      120  1050 FORMAT(19X,I5,3(3X,F12.4))
      121       END

Name     Type          Offset P Class

D        REAL               0   /DD     /
DF       CHAR*2             6   /PP     /
DN       CHAR*2             4   /PP     /
DT       REAL              48   /DD     /
EF       CHAR*2             2   /PP     /
EN       CHAR*2             0   /PP     /
F        REAL               0   /FF     /
FF       CHAR*1            28 *
I        INTEGER*4        156
II       INTEGER*4        172
IS       INTEGER*4        136
         INTEGER*4        128
JJ       INTEGER*4        124
```

D Line£ 1 7 Microsoft FORTRAN77 V3.30 March 1985

```
JR      INTEGER*4          0   /JD    /
K       INTEGER*4        140
KK      INTEGER*4        164
L       INTEGER*4        144
LC      INTEGER*4         16 *
LP      INTEGER*4        120
MOD                          INTRINSIC
N       INTEGER*4        132
ND      INTEGER*4         12 *
NE      INTEGER*4          0 *
NJ      INTEGER*4          4 *
NLC     INTEGER*4         20 *
NS      INTEGER*4         24 *
NSU     INTEGER*4          8 *
QQ      REAL             176
```

```
      SUBROUTINE LDIS(NE,NJ,LC,NLC,NS,NSU,FF)
C
C PRINT ELEMENT END DISPLACEMENTS
C
      CHARACTER FF,EN*2,EF*2,DN*2,DF*2
      COMMON /ED/MC(360,2) /DD/D(12),DT(12)   /FF/F(10,10)
      COMMON /PP/EN,EF,DN,DF
      DIMENSION DU(6)
      WRITE(2,1000)FF,EN,DN,EF,DF
      CALL SPAC
      LP=4
      JJ=2+NS+NE+NJ+NSU
  120 READ(3,1010)J,N,IS
      IF(J)130,130,140
  140 DO 111 K=1,3
1     IF(MOD(LP+K,56))111,112,111
1 112 WRITE(2,'(A)')FF
1     LP=LP+K
1     GOTO 113
1 111 CONTINUE
  113 WRITE(2,1030)EN,DN,EF,DF
      LP=LP+3
      DO 150 L=J,N,IS
1     DO 150 I=1,NLC
2     DO 160 K=1,6
3 160 D(K)=0.0
2     DO 170 KK=1,LC
3     IF(F(I,KK))180,170,180
3 180 READ(1,REC=(KK-1)*NE+L+JJ)(DU(K),K=1,6),(DT(K),K=1,6)
3     DO 190 K=1,6
4 190 D(K)=D(K)+DT(K)*F(I,KK)*1000.0
3 170 CONTINUE
2     IF(I-1)200,210,200
2 210 WRITE(2,1040)L,I,MC(L,1),(D(K),K=1,3)
2     LP=LP+1
2     IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2     GOTO 220
2 200 WRITE(2,1050)I,MC(L,1),(D(K),K=1,3)
2     LP=LP+1
```

07-02-87
21:45:04

```
J Line£ 1      7                                  Microsoft FORTRAN77 V3.30 March 1985
!    161       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2    162    220 WRITE(2,1060)MC(L,2),(D(K),K=4,6)
2    163       LP=LP+1
2    164       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2    165    150 CONTINUE
     166       CALL SPAC
     167       LP=LP+2
     168       IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
     169       GOTO 120
     170    130 CALL SPAC
     171       RETURN
     172   1000 FORMAT(3A,//5X'ELEMENT - END  DISPLACEMENTS'2A)
     173   1010 FORMAT(3I5)
     174   1020 FORMAT(84X,6E14.7)
     175   1030 FORMAT(2A,3X'ELEMENT'4X'LOAD'3X'JOINT'3X'X - ROTATION'3X
     176      1'Z - MOVEMENT'3X'Y - ROTATION'/4X'NUMBER'3X'COMB.',5X
     177      2'NO.'4X'1.0E-3 rad.'7X'(mm)'8X'1.0E-3 rad'/2A)
     178   1040 FORMAT(5X,I5,3X,I5,3X,I5,3(3X,F12.4))
     179   1050 FORMAT(13X,I5,3X,I5,3(3X,F12.4))
     180   1060 FORMAT(21X,I5,3(3X,F12.4))
     181       END

Name     Type          Offset P Class

D        REAL             0    /DD     /
DF       CHAR*2           6    /PP     /
DN       CHAR*2           4    /PP     /
DT       REAL            48    /DD     /
DU       REAL           426
EF       CHAR*2           2    /PP     /
EN       CHAR*2           0    /PP     /
F        REAL             0    /FF     /
FF       CHAR*1          24 *
I        INTEGER*4      486
IS       INTEGER*4      466
J        INTEGER*4      458
JJ       INTEGER*4      454
K        INTEGER*4      470
KK       INTEGER*4      494
L        INTEGER*4      474
LC       INTEGER*4        8 *
LP       INTEGER*4      450
MC       INTEGER*4        0    /ED     /
MOD                            INTRINSIC
N        INTEGER*4      462
NE       INTEGER*4        0 *
NJ       INTEGER*4        4 *
NLC      INTEGER*4       12 *
NS       INTEGER*4       16 *
NSU      INTEGER*4       20 *

     182       SUBROUTINE EFORCE(NE,NJ,LC,NLC,NSU,NS,FF)
     183 C
     184 C PRINT ELEMENT END FORCES
     185 C
```

```
      CHARACTER FF,EN*2,EF*2,DN*2,DF*2
      COMMON /ED/MC(360,2) /DD/D(12),DT(12)  /FF/F(10,10)
      COMMON /PP/EN,EF,DN,DF
      WRITE(2,1000)FF,EN,DN,EF,DF
      CALL SPAC
      LP=4
      JJ=2+NS+NE+NJ+NSU
  120 READ(3,1010)J,N,IS
      IF(J)130,130,140
  140 DO 111 K=1,3
      IF(MOD(LP+K,56))111,112,111
  112 WRITE(2,'(A)')FF
      LP=LP+K
      GOTO 113
  111 CONTINUE
  113 WRITE(2,1030)EN,DN,EF,DF
      LP=LP+3
      DO 150 L=J,N,IS
      DO 150 I=1,NLC
      DO 160 K=1,6
  160 D(K)=0.0
      DO 170 KK=1,LC
      IF(F(I,KK))180,170,180
  180 READ(1,REC=(KK-1)*NE+L+JJ)(DT(K),K=1,6)
      DO 190 K=1,6
  190 D(K)=D(K)+DT(K)*F(I,KK)
  170 CONTINUE
      IF(I-1)200,210,200
  210 WRITE(2,1040)L,I,MC(L,1),(D(K),K=1,3)
      LP=LP+1
      IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
      GOTO 220
  200 WRITE(2,1050)I,MC(L,1),(D(K),K=1,3)
      LP=LP+1
      IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
  220 WRITE(2,1060)MC(L,2),(D(K),K=4,6)
      LP=LP+1
      IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
  150 CONTINUE
      CALL SPAC
      LP=LP+2
      IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
      GOTO 120
  130 CALL SPAC
      RETURN
 1000 FORMAT(3A,//5X'ELEMENT - END FORCES'2A)
 1010 FORMAT(3I5)
 1020 FORMAT(6E14.7)
 1030 FORMAT(2A,3X'ELEMENT'4X'LOAD'3X'JOINT'4X'TORSION - X'6X'SHEAR - Z'
     15X'MOMENT - Y'/4X'NUMBER'3X'COMB.'5X'NO.'6X'KN - m'12X'KN'11X
     2'KN - m'/2A)
 1040 FORMAT(5X,I5,3X,I5,3X,I5,3(3X,F12.4))
 1050 FORMAT(13X,I5,3X,I5,3(3X,F12.4))
 1060 FORMAT(21X,I5,3(3X,F12.4))
      END
```

07-02-87
21:45:04

D Line£ 1 7 Microsoft FORTRAN77 V3.30 March 1985

Name	Type	Offset	P	Class
D	REAL	0		/DD /
DF	CHAR*2	6		/PP /
DN	CHAR*2	4		/PP /
DT	REAL	48		/DD /
EF	CHAR*2	2		/PP /
EN	CHAR*2	0		/PP /
F	REAL	0		/FF /
FF	CHAR*1	24	*	
I	INTEGER*4	858		
IS	INTEGER*4	838		
J	INTEGER*4	830		
JJ	INTEGER*4	826		
K	INTEGER*4	842		
KK	INTEGER*4	866		
L	INTEGER*4	846		
LC	INTEGER*4	8	*	
LP	INTEGER*4	822		
MC	INTEGER*4	0		/ED /
MOD				INTRINSIC
N	INTEGER*4	834		
NE	INTEGER*4	0	*	
NJ	INTEGER*4	4	*	
NLC	INTEGER*4	12	*	
NS	INTEGER*4	20	*	
NSU	INTEGER*4	16	*	

```
      SUBROUTINE REACT(NE,NJ,LC,NLC,NSU,NS,FF)
C
C  PRINT SUPPORT REACTIONS
C
      CHARACTER FF,EN*2,EF*2,DN*2,DF*2
      COMMON /JD/JR(200,3)  /DD/D(12),DT(12) /FF/F(10,10)
      COMMON /RS/NSJ(60) /PP/EN,EF,DN,DF
      DIMENSION DP(30)
      WRITE(2,1000)FF,EN,DN,EF,DF
      CALL SPAC
      LP=4
   10 READ(3,1010)J,N,IS
      IF(J)100,100,110
  110 DO 111 K=1,3
1     IF(MOD(LP+K,56))111,112,111
1  112 WRITE(2,'(A)')FF
1     LP=LP+K
1     GOTO 113
1  111 CONTINUE
   113 WRITE(2,1030)EN,DN,EF,DF
      LP=LP+3
      DO 150 L=J,N,IS
1     DO 70 K=1,NSU
2     IF(L-NSJ(K))70,140,70
2  140 II=K
2     GOTO 130
```

07-02-87
21:45:04

```
D Line£ 1      7                          Microsoft FORTRAN77 V3.30 March 1985
2    267     70 CONTINUE
1    268        GOTO 150
1    269    130 READ(4,REC=II)(DP(K),K=1,3*LC)
1    270        DO 20 I=1,NLC
2    271        DO 30 K=1,3
3    272     30 D(K)=0.0
2    273        DO 40 KK=1,LC
3    274        IF(F(I,KK))50,40,50
3    275     50 DO 60 K=1,3
4    276     60 D(K)=D(K)+DP((KK-1)*3+K)*F(I,KK)
3    277     40 CONTINUE
2    278        IF(I-1)80,90,80
2    279     90 WRITE(2,1040)L,I,(D(K),K=1,3)
2    280        LP=LP+1
2    281        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2    282        GOTO 20
2    283     80 WRITE(2,1050)I,(D(K),K=1,3)
2    284        LP=LP+1
2    285        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
2    286     20 CONTINUE
1    287    150 CONTINUE
     288        CALL SPAC
     289        LP=LP+2
     290        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
     291        GOTO 10
     292    100 CALL SPAC
     293        RETURN
     294   1000 FORMAT(3A,//5X'SUPPORT REACTIONS'2A)
     295   1010 FORMAT(3I5)
     296   1020 FORMAT(5X,10E14.7)
     297   1030 FORMAT(2A,3X'JOINT'12X'LOAD'5X'MOMENT - X'6X'SHEAR - Z'5X
     298       1'MOMENT - Y'/5X'NO.'5X'COMBINATION'6X'KN - m'12X'KN'11X
     299       2'KN - m'/2A)
     300   1040 FORMAT(3X,I5,11X,I5,3(3X,F12.4))
     301   1050 FORMAT(19X,I5,3(3X,F12.4))
     302        END

Name     Type          Offset P Class

D        REAL               0   /DD     /
DF       CHAR*2             6   /PP     /
DN       CHAR*2             4   /PP     /
DP       REAL            1146
DT       REAL              48   /DD     /
EF       CHAR*2             2   /PP     /
EN       CHAR*2             0   /PP     /
F        REAL               0   /FF     /
FF       CHAR*1            24 *
I        INTEGER*4       1310
II       INTEGER*4       1302
IS       INTEGER*4       1278
J        INTEGER*4       1270
JR       INTEGER*4          0   /JD     /
K        INTEGER*4       1282
KK       INTEGER*4       1318
L        INTEGER*4       1286
```

```
D Line£ 1     7                                  Microsoft FORTRAN77 V3.30 March 1985
LC      INTEGER*4          8 *
LP      INTEGER*4       1266
MOD                             INTRINSIC
N       INTEGER*4       1274
NE      INTEGER*4          0 *
NJ      INTEGER*4          4 *
NLC     INTEGER*4         12 *
NS      INTEGER*4         20 *
NSJ     INTEGER*4          0    /RS    /
NSU     INTEGER*4         16 *


     303        SUBROUTINE CACTION(NE,NJ,LC,NLC,NSU,NS,FF)
     304 C
     305 C COMPARE ELEMENT ACTIONS & PRINT
     306 C
     307        CHARACTER FF,EN*2,EF*2,DN*2,DF*2
     308        COMMON /BB/IB(2,6),LL(360),A(360,6),B(2,6)
     309        COMMON /DD/D(12),DT(12) /FF/F(10,10) /PP/EN,EF,DN,DF
     310 C
     311        WRITE(2,1700)FF,EN,DN,EF,DF
     312        CALL SPAC
     313        LP=4
     314        II=2+NS+NE+NJ+NSU
     315    100 READ(3,1100)J,N,IS
     316        IF(J)20,20,10
     317     10 DO 111 K=1,3
1    318        IF(MOD(LP+K,56))111,112,111
1    319    112 WRITE(2,'(A)')FF
1    320        LP=LP+K
1    321        GOTO 113
1    322    111 CONTINUE
     323    113 WRITE(2,1000)EN,DN,J,N,IS,EF,DF
     324        CALL SPAC
     325        LP=LP+3
     326        DO 211 K=1,3
1    327        IF(MOD(LP+K,56))211,212,211
1    328    212 WRITE(2,'(A)')FF
1    329        LP=LP+K
1    330        GOTO 213
1    331    211 CONTINUE
     332    213 WRITE(2,1200)EN,DN,EF,DF
     333        LP=LP+3
     334        DO 30 I=1,NLC
1    335        JJ=0
1    336        DO 40 L=J,N,IS
2    337        DO 50 K=1,6
3    338     50 D(K)=0.0
2    339        DO 60 KK=1,LC
3    340        IF(F(I,KK))70,60,70
3    341     70 READ(1,REC=(KK-1)*NE+L+II)(DT(K),K=1,6)
3    342        DO 80 K=1,6
4    343     80 D(K)=D(K)+DT(K)*F(I,KK)
3    344     60 CONTINUE
2    345        JJ=JJ+1
2    346        LL(JJ)=L
```

07-02-87
21:45:04

```
D Line£ 1     7                          Microsoft FORTRAN77 V3.30 March 1985
2    347        DO 90 K=1,6
3    348     90 A(JJ,K)=D(K)
2    349     40 CONTINUE
1    350        CALL MACTION(JJ)
1    351        WRITE(2,1400)I,(B(1,K),IB(1,K),K=1,3)
1    352        LP=LP+1
1    353        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
1    354        WRITE(2,1500)(B(2,K),IB(2,K),K=1,3)
1    355        LP=LP+1
1    356        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
1    357        WRITE(2,1600)(B(1,K),IB(1,K),K=4,6)
1    358        LP=LP+1
1    359        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
1    360        WRITE(2,1500)(B(2,K),IB(2,K),K=4,6)
1    361        LP=LP+1
1    362        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
1    363     30 CONTINUE
     364        CALL SPAC
     365        LP=LP+2
     366        IF(MOD(LP,56).EQ.0)WRITE(2,'(A)')FF
     367        GOTO 100
     368     20 CALL SPAC
     369        RETURN
     370   1000 FORMAT(2A,3X'COMPARISON OF FORCES ALONG ELEMENTS 'I4' THRU 'I4
     371       1' AT STEP 'I4,2A)
     372   1100 FORMAT(3I5)
     373   1200 FORMAT(2A,4X'LOAD'3X'ELEM'8X'Max/Min'3X'On'2(7X'Max/Min'3X'On')/4X
     374       1'COMB'4X'END'4X'TORSION - X'2X'EL.'5X'SHEAR - Z'2X'EL.'4X
     375       2'MOMENT - Y'2X'EL.'/2A)
     376   1300 FORMAT(6E14.7)
     377   1400 FORMAT(3X,I5,2X'A-End'3X,3(F12.2,1X,I4,2X))
     378   1500 FORMAT(18X,3(F12.2,1X,I4,2X))
     379   1600 FORMAT(10X'B-End'3X,3(F12.2,1X,I4,2X))
     380   1700 FORMAT(3A,//3X'COMPARISON OF ELEMENT-END FORCES'2A)
     381        END

Name     Type          Offset P Class

A        REAL            1488   /BB     /
B        REAL           10128   /BB     /
D        REAL               0   /DD     /
DF       CHAR*2             6   /PP     /
DN       CHAR*2             4   /PP     /
DT       REAL              48   /DD     /
EF       CHAR*2             2   /PP     /
EN       CHAR*2             0   /PP     /
F        REAL               0   /FF     /
FF       CHAR*1            24 *
I        INTEGER*4       1588
IB       INTEGER*4          0   /BB     /
II       INTEGER*4       1568
IS       INTEGER*4       1580
J        INTEGER*4       1572
JJ       INTEGER*4       1596
K        INTEGER*4       1584
K        INTEGER*4       1612
```

07-02-87
21:45:04

```
D Line£ 1     7                              Microsoft FORTRAN77 V3.30 March 1985
L       INTEGER*4       1600
LC      INTEGER*4          8 *
LL      INTEGER*4         48   /BB    /
LP      INTEGER*4       1564
MOD                             INTRINSIC
N       INTEGER*4       1576
NE      INTEGER*4          0 *
NJ      INTEGER*4          4 *
NLC     INTEGER*4         12 *
NS      INTEGER*4         20 *
NSU     INTEGER*4         16 *


     382        SUBROUTINE MACTION(N)
     383 C
     384 C FINDS THE MAX/MIN OF FORCES & THEIR POSITIONS
     385 C
     386        COMMON /BB/IB(2,6),LL(360),A(360,6),B(2,6)
     387        DIMENSION IP(2,6)
     388 C
     389        DO 10 J=1,6
1    390        XMAX=A(1,J)
1    391        IMAX=1
1    392        XMIN=A(1,J)
1    393        IMIN=1
1    394        DO 20 I=1,N
2    395        IF(XMIN-A(I,J))40,40,30
2    396     30 XMIN=A(I,J)
2    397        IMIN=I
2    398     40 IF(XMAX-A(I,J))50,20,20
2    399     50 XMAX=A(I,J)
2    400        IMAX=I
2    401     20 CONTINUE
1    402        B(1,J)=XMAX
1    403        B(2,J)=XMIN
1    404        IP(1,J)=IMAX
1    405        IP(2,J)=IMIN
1    406     10 CONTINUE
     407        DO 60 I=1,2
1    408        DO 60 J=1,6
2    409        IMAX=IP(I,J)
2    410     60 IB(I,J)=LL(IMAX)
     411        RETURN
     412        END

Name     Type          Offset P Class

A       REAL            1488   /BB    /
B       REAL           10128   /BB    /
I       INTEGER*4       2074
J       INTEGER*4          0   /BB    /
IMAX    INTEGER*4       2062
IMIN    INTEGER*4       2070
IP      INTEGER*4       2006
J       INTEGER*4       2054
LL      INTEGER*4         48   /BB    /
```

07-02-87
21:45:04

```
 Line£ 1      7                          Microsoft FORTRAN77 V3.30 March 1985
N        INTEGER*4          0 *
XMAX     REAL            2058
XMIN     REAL            2066


     413         SUBROUTINE SPAC
     414         CHARACTER*2 EN,EF,DN,DF
     415         COMMON /PP/EN,EF,DN,DF
     416         WRITE(2,10)EN,DN,('-',I=1,70),EF,DF
     417      10 FORMAT(2A,3X,70A1,/2A)
     418         RETURN
     419         END

Name     Type         Offset P Class

DF       CHAR*2            6   /PP    /
DN       CHAR*2            4   /PP    /
EF       CHAR*2            2   /PP    /
EN       CHAR*2            0   /PP    /
I        INTEGER*4      2082


Name     Type            Size   Class

BB                      10176   COMMON
CACTIO                          SUBROUTINE
DD                         96   COMMON
ED                       2880   COMMON
EFORCE                          SUBROUTINE
FF                        400   COMMON
GDIS                            SUBROUTINE
GRID4                           PROGRAM
JD                       2400   COMMON
LDIS                            SUBROUTINE
MACTIO                          SUBROUTINE
PP                          8   COMMON
 EACT                           SUBROUTINE
RS                        240   COMMON
SPAC                            SUBROUTINE

 Pass One     No Errors Detected
             419 Source Lines
```

APPENDIX IV

SAMPLE - Bridge Response Determination Using Simplified Approach

The following gives a sample of analysis aid charts. For each chart a brief description of the bridge response concerned is given. The following notes explain the details of what the columns represent.

Notes

1. Bridge response description for:
   - Longitudinal girders
     . Numerically maximum/minimum bending moments
     . ,, ,, torsional ,,
     . ,, ,, shear forces
   - Transverse elements
     . Numerically maximum/minimum slab moment
     . ,, ,, diaphragm moment
2. THETA represents angle of skew.
3. MEMBERS - Corresponding to any span configuration, there are two choices for members, hence this column represents the two different material properties.

TABLE ▽-1	Maximum / Minimum Span Bending moments — KN-m						
THETA	MEMBERS	SPAN L=15m	L=18m	L=21m	L=24m	L=27m	L=30m
θ=0°	Box-Beam1		±1101.41				
	M-Beam1		±1729.18				
	Box-Beam2		±1342				
	M-Beam2		±1934				
θ=5°	Box-B·1		484/-509				
	M-B·1		1099/-1098				
	Box-B·2		529/-680				
	M-B·2		±1254				
θ=10°	Box-B·1		490/-449				
	M-B·1		1041/-1059				
	Box-B·2		544/-689				
	M-B·2		±1173				
θ=15°	Box-B·1		470/-510				
	M-B 1		897/-1111				
	Box-B·2		483/-539				
	M-B 2		982/-1242				
θ=20°	Box-B·1		498/-430				
	M-B·1		1061/1136				
	Box-B·2		502/-493				
	M-B·2		1183/1204				
θ=25°	Box-B·1		±579				
	M-B·1		±1072				
	Box-B·2		±643				
	M-B·2		±1218				
θ=30°	Box-B·1	±453	472/-522	481/-607	408/-686	523/-781	531/-789
	M-B·1	792/-908	830/-1076	834/-1186	853/-1164	907/-1192	923/-1213
	Box-B·2		507/-621				
	M-B·2		880/-1113				

TABLE IV.2		Maximum / Minimum Torsional Moments — KN-m					
THETA	MEMBERS	SPAN L=15m	L=18m	L=21m	L=24m	L=27m	L=30m
θ=0°	Box-Beam1		± 14.95				
	M-Beam 1		± 13.11				
	Box-B.1		± 16.82				
	M-B.2		± 14.31				
θ=5°	Box-B.1		± 10.62				
	M-B.1		± 12.11				
	Box-B.2		± 12.34				
	M-B.2		± 13.83				
θ=10°	Box-B.1		± 13.12				
	M-B.1		± 11.96				
	Box-B.2		± 15.25				
	M-B.2		± 13.32				
θ=15°	Box-B.1		± 13.41				
	M-B.1		± 12.73				
	Box-B.2		± 15.87				
	M-B.2		± 13.92				
θ=20°	Box-B.1		± 14.55				
	M-B.1		± 15.62				
	Box-B.2		± 16.85				
	M-B.2		± 16.94				
θ=25°	Box-B.1		± 15.99				
	M-B.1		± 16.80				
	Box-B.2		± 17.22				
	M-B.2		± 17.34				
θ=30°	Box-B.1	± 3.52	± 4.32	± 5.48	± 5.93	± 6.01	± 6.59
	M-B.1	± 4.39	± 5.22	± 5.93	± 6.34	± 6.98	± 7.23
	Box-B.2		± 5.83				
	M-B.2		± 6.23				

TABLE IV·3	Maximum / Minimum Shear Forces — KN						
THETA	MEMBERS	SPAN L=15m	L=18m	L=21m	L=24m	L=27m	L=30m
θ=0°	Box-Beam 1		230/-225				
	M-Beam 1		107/-25				
	Box-B·2		245/-239				
	M-B·2		120/-42				
θ=5°	Box-B·1		202/-154				
	M-B·1		347/-338				
	Box-B 2		230/-182				
	M-B·2		365/-359				
θ=10°	Box-B·1		183/-161				
	M-B·1		355/-346				
	Box-B·2		203/-185				
	M-B·2		383/-364				
θ=15°	Box-B·1		170/-165				
	M-B·1		351/-343				
	Box-B·2		195/-172				
	M-B·2		392/-375				
θ=20°	Box-B·1		196/-164				
	M-B·1		369/-359				
	Box-B·2		209/-183				
	M-B·2		392/-377				
θ=25°	Box-B·1		176/-171				
	M-B·1		350/-341				
	Box-B·2		193/-189				
	M-B·2		363/-357				
θ=30°	Box-B·1	206/-162	212/-165	236/-172	253/-185	274/-197	297/-205
	M-B·1	396/-387	401/-391	445/-403	463/-413	482/-423	503/-442
	Box-B·2		253/-182				
	M-B·2		443/-407				

TABLE IV.4 Maximum / Minimum Bending moments for Slab/Diaphragm-KN-m

THETA	MEMBERS	SPAN L=15m	L=18m	L=21m	L=24m	L=27m	L=30m
θ=0°	Slab-1		10.39 / -18.38				
	Diap. 1		±1845				
	Slab-2		12.43 / -19.42				
	Diap. 2		±1935				
θ=5°	Slab-1		±17.51				
	Diap. 1		±1357				
	Slab-2		±19.32				
	Diap. 2		±1495				
θ=10°	Slab-1		10.98 / -12.81				
	Diap. 1		±1213				
	Slab-2		12.52 / -14.21				
	Diap. 2		±1346				
θ=15°	Slab-1		11.28 / -13.46				
	Diap. 1		±1147				
	Slab-2		13.34 / -15.42				
	Diap. 2		±1199				
θ=20°	Slab-1		±16.91				
	Diap. 1		±1484				
	Slab-2		16.49 / -17.38				
	Diap. 2		±1912				
θ=25°	Slab-1		15.49 / -17.38				
	Diap. 1		±1552				
	Slab-2		16.33 / -18.47				
	Diap. 2		±1589				
θ=30°	Slab-1	±11.52	±12.68	±15.23	±15.97	±16.83	±19.24
	Diap. 1	±1342	±1412	±1441	±1493	±1557	±1692
	Slab-2		±15.33				
	Diap. 2		±1345				