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EVALUATION AND USE OF DYNAMIC ANALYSIS CAPABILITIES
OF ICES STRUDL II

BY

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RESEARCH REPORT

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degree of Master of Science in the Graduate Studies
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Dr. David R. Jenkins

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iii
Section	
I. INTRODUCTION	1
II. STRUDEL DYNAMIC ANALYSIS	3
III. STRUDEL COMMANDS AND EXAMPLES	7
A. Specification of Structural Properties	7
1. Structural Type, Geometry, Cross Section and Material Properties	7
2. Inertia of Joints	7
3. Damping Properties	9
4. Degrees of Freedom	10
B. Dynamic Loading	11
1. Optional User Storage of Dynamic Loading Data	11
2. Dynamic Loading Identification	14
3. Joint Loading	14
4. Support Accelerations	17
5. Initial Conditions	19
6. Integration Parameters	21
C. Dynamic Analysis	22
1. Eigenvalues and Eigenvectors	22
2. Structural Response	24
3. Inoperative Features	25
D. Output	25
1. Input Data	26
2. Dynamic Analysis Results	26

Section

E.	Optional Matrix Input	30
1.	Structural Properties Input as Matrices . .	30
2.	Normal Modes Analysis	32
F.	Rules For Use of the STRUDL Dynamics Program . .	34
IV.	STRUDL EXAMPLES	36
A.	Example Calculations-Eigenvalues/Eigenvectors .	36
1.	All Degrees of Freedom	36
2.	Two Degrees of Freedom	42
3.	Matrix Input	45
4.	Eigenvectors Normalized With Respect to Mass	47
B.	Example Calculations-Dynamic Structural Response	50
1.	Sinusoidal Joint Loading	50
2.	Sinusoidal Joint Loading - Normal Modes Input	58
3.	E1 Centro Earthquake - Stored Accelerations.	63
4.	E1 Centro Earthquake - Response Spectrum . .	69
V.	COMPARATIVE RESULTS OF STRUDL EXAMPLES	75
VI.	CONCLUDING REMARKS	80
	LIST OF REFERENCES	81

I. INTRODUCTION

The Structural Design Language (STRUJDL) is a series of computer programs for solving problems in structural engineering. STRUJDL II, as the major subsystem of the Integrated Civil Engineering System (ICES), was developed at the Massachusetts Institute of Technology over the four year period from 1965 to 1968. The STRUJDL program is capable of static and dynamic structural analysis of many different types of structures. The structural elements which may be used in STRUJDL are truss and beam elements, various plate and shallow shell finite elements, plane stress and plane strain finite elements and composite structures consisting of combinations of structural elements. All of the STRUJDL analysis capabilities are highly developed and widely used and are documented by the STRUJDL user's manual (Logcher 1968 and 1971). The other structural capabilities of STRUJDL include optimum design of some structural types and nonlinear and buckling analysis.

Since both STRUJDL user's manuals were written many changes have been made in the dynamic analysis program. These changes included addition of features requiring new commands, deletion of features and various improvements. There are thus several versions of the STRUJDL dynamics program. The Central Florida

Regional Data Center version of STRUDL is Version 2, Mod 2 with update 3 and works well. However, the user's manual (Logcher 1971) does not provide adequate guidance for the beginning user of the program. For this reason, the beginning user might easily conclude that certain features of the program don't work at all when, in fact, these features may work quite well.

Thus the object of this report is to provide the user with detailed documentation for the use of the STRUDL dynamics program at the Central Florida Regional Data Center. The report also demonstrates the features of the program by examples, including correct usage of the various input commands and resulting output. Because the dynamic analysis commands and resulting output format are nearly identical for all types of structures, this report considers the dynamic analysis of plane frame structures only.

II. STRUDL DYNAMIC ANALYSIS

The STRUDL dynamics program is very versatile because of its many dynamic analysis features. The program can handle a large variety of engineering systems provided the system can be modeled with dynamic equilibrium equations of the form

$$MU + CU + KU = F(t) \quad (1)$$

where M is the system mass matrix, C is the system damping matrix, K is the stiffness matrix, F(t) is the time dependent forcing function matrix and U is the matrix of displacements of the system.

The present version of STRUDL will solve the above matrix equation for eigenvalues and eigenvectors, or for the displacements which result from a specified forcing function or support accelerations.

The structural system for use in STRUDL may be described by reading in the coefficient matrices of equation (1) directly or by specifying geometry, connectivity and properties of the various structural elements that make up the structure. For this case STRUDL will compute the coefficients of equation (1). The user of STRUDL also has the option of reducing the degrees of

freedom to be considered.

Once the structural system has been specified the user may request an analysis for the determination of eigenvalues and eigenvectors only, or an analysis of structural response to several types of dynamic loading, including stored accelerations for the EL Centro earthquake. The user may also specify any conceivable time dependent force, support accelerations or response spectra. The structural response results then available are internal member forces and joint displacements, velocities and accelerations. The user also has the option of obtaining structural responses to dynamic loading by the input of known eigenvalues and eigenvectors and the dynamic loading condition for the structure. Structural response results then available in this option are forces, displacements, velocities and accelerations for each dynamic degree of freedom. All structural response calculations are carried out internally by the normal mode superposition technique (Timoshenko 1974).

This report is divided into two main sections. The first section describes the commands and gives examples for each command. Also included in the first section is documentation of the subtleties and pitfalls involved in use of the commands. It is hoped that this section of the report will also be useful to the user in the following two ways: (1) by specifying which commands are optional and which are required for a given dynamic analysis

(2) by ordering the commands in a logical input sequence. Also included is a list of 'RULES FOR USE OF THE STRUDL DYNAMICS PROGRAM'. This list is intended for use as a checklist to help keep the user out of trouble.

The second section of the report gives the actual computer command input and resulting computer output for a number of plane frame example problems. This section illustrates the use of the various STRUDL features.

In writing this report, the author presupposes a good knowledge, on the part of the reader, of the basic STRUDL commands.

Figure 1 on the following page provides an overview and flow chart of STRUDL dynamic analysis commands. By following the chart of Figure 1, the user can determine which commands are optional and can determine the ordering of the commands in a logical input sequence. The first section of the report describing the STRUDL commands will follow the sequence shown in Figure 1.

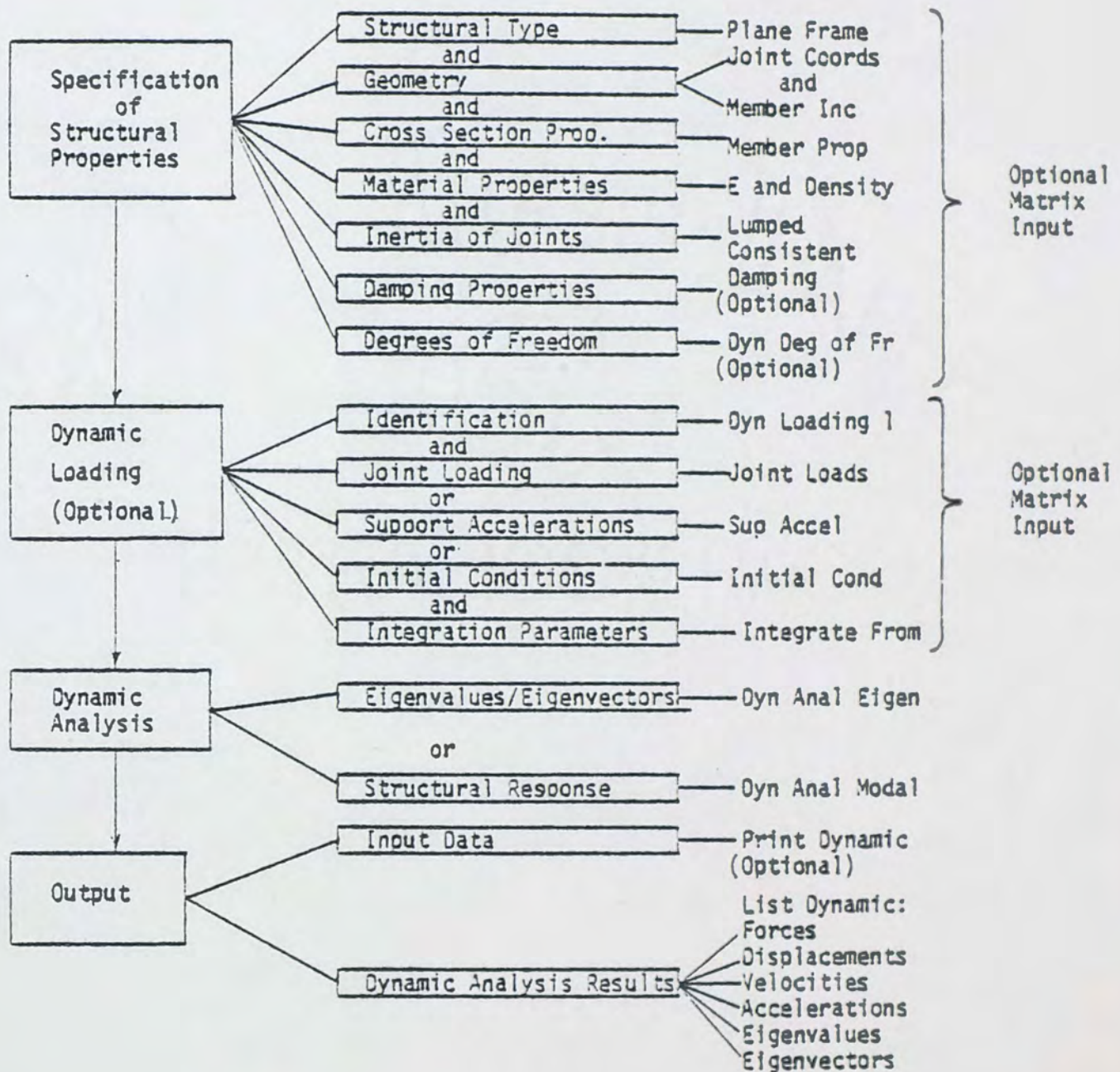


Fig. 1. Flow Chart of STRUDL Dynamic Analysis Commands

III. STRUDL COMMANDS AND EXAMPLES

This section of the report presents the STRUDL commands and examples of commands. The section is organized following the flow chart presented in Figure 1.

A. Specification of Structural Properties

1. Structural Type, Geometry, Cross Section and Material Properties

Input of all the structural element properties, in some form, (eg, matrix input, normal member and joint input) is required for any dynamic analysis except a NORMAL MODES analysis. For the NORMAL MODES analysis eigenvalues and eigenvectors are the required input.

The JOINT COORDINATES, MEMBER INCIDENCES and MEMBER PROPERTIES are input in the same manner as used in a static structural analysis. The required material properties are E (modulus of elasticity) and DENSITY. These material properties are input using the CONSTANTS command first (Logcher 1968). Input of density is required because STRUDL uses the density value to calculate inertia when inertia is treated as LUMPED or CONSISTENT.

2. Inertia of Joints

The INERTIA OF JOINTS command must be used in one of its forms except when matrix input is used.

Use of the STRUDL command

INERTIA OF JOINTS LUMPED

results in the assumption that all the inertia (mass) of a member is concentrated at its extremities (joints). The program utilizes DENSITY and member cross sectional area in making the calculation of joint inertia.

Use of the STRUDL command

INERTIA OF JOINTS CONSISTENT

results in the assumption that the inertia of a member is distributed. STRUDL calculates the inertia values using density and member cross sectional area. Use of the command INERTIA OF JOINTS CONSISTENT gives erroneous results for some loading conditions.

For example, in an INITIAL CONDITIONS dynamic loading the input initial conditions (joint displacements) were printed out correctly from internal storage (result of the PRINT DYNAMIC DATA command). However, the dynamic analysis results for displacement at time equals zero were incorrect. In addition, the member forces were also incorrect. Specifying INERTIA OF JOINTS LUMPED solved the problem.

Use of the STRUDL command

```
INERTIA OF JOINTS 6 TO 19, 17, 18 LINEAR X 4.54
```

is an example of the inertia of joints specified command. Inertia properties must here be calculated by the user. This command specifies the joint inertia values directly, and is an alternate command to INERTIA OF JOINTS LUMPED or INERTIA OF JOINTS CONSISTENT. If inertia of joints values are specified directly using this command and an INITIAL CONDITIONS dynamic loading is requested, the analysis will terminate and print the following message:

```
DATA LEVEL HAS BEEN REFERENCED BY IFIND OR ALCOAT (Jones 1974)
```

3. Damping Properties

The DAMPING PERCENTS command specifies percentage of critical damping in each degree of freedom. If this command is omitted, zero damping is assumed in the analysis. Use of this command is not necessary in an analysis where only eigenvalues and eigenvectors are desired (DYNAMIC ANALYSIS EIGENVALUE).

Use of the STRUDL command

```
DAMPING PERCENTS 2.0 3
```

or the command

DAMPING .02 3

defines the following damping matrix:

$$\begin{bmatrix} 2.0 & & \\ & 2.0 & \\ & & 2.0 \end{bmatrix}$$

Use of the STRUDL command

DAMPING PERCENTS 5.0 2.0 2

defines the following damping matrix:

$$\begin{bmatrix} 5.0 & & \\ & 2.0 & \\ & & 2.0 \end{bmatrix}$$

4. Degrees of Freedom

The command DYNAMIC DEGREES OF FREEDOM enables the user to eliminate certain degrees of freedom of the structure in the dynamic analysis. The eliminated degrees of freedom are assumed to have zero mass associated with them, and thus, the size of the dynamic analysis is reduced. If this command is omitted, all degrees of freedom are considered in the analysis.

Use of the STRUDL command

DYNAMIC DEGREES OF FREEDOM

JOINTS 7 8 9 10 DISPLACEMENT X

specifies that the structural dynamic degrees of freedom are only translational, in the X direction, at joints 7, 8, 9 and 10 and that the structure only has four degrees of freedom.

B. Dynamic Loading

1. Optional User Storage of Dynamic Loading Data

Use of this feature is supposed to allow the user to store dynamic loading data for future use. The stored data may be a force time history or response spectra and is supposed to have the capability of being retrieved in a future run by referencing the data name in the JOINT LOADS, SUPPORT ACCELERATIONS or ROW (matrix) commands. In fact, the stored information is available only within the same computer run in which it is stored and is not available for future runs on the Central Florida Regional Data Center computer.

a. Store Time History

This command is used when a time history is to be stored.

Use of the STRUDL command

```
STORE TIME HISTORY FORCE TRANS 'GRANTORO'
```

```
FAC 2.0 0.0 0.0 0.5 0.1 1.0 0.2
```


causes storage of the time history called GRANTORO in the user data set (DDI) of the following force history (Units are assumed to be kips and seconds. Units kips must have been given in a prior command.):

zero kips at time zero seconds

1.0 kips at time 0.1 seconds

2.0 kips at time 0.2 seconds

As mentioned, this force history is then available only within the same run in which it is input by referencing the data in the JOINT LOADS, SUPPORT ACCELERATIONS or ROW (matrix) commands. If retrieval of this force history is attempted in a later run, the analysis will fail and the STRUDL message is printed:

UNABLE TO RETRIEVE FILE 'GRANTORO'

The STORE TIME HISTORY feature thus has little usefulness since the same loading may be specified directly in the appropriate command.

The El Centro earthquake accelerations are on file in the user data set (DDI) and may be retrieved and used in any STRUDL dynamics run by referencing file 'EL CENTRO' in the SUPPORT ACCELERATIONS command.

The stored accelerations were at one time believed to be incorrect because the acceleration vs. time values, printed out from internal storage to verify input (the PRINT command) were too great by a factor of 3.0. However, the author has verified the correctness of the stored El Centro earthquake accelerations by

comparing structural responses to these accelerations to responses to the El Centro earthquake response spectra (see section V.F. of this report).

b. Store Response Spectra

Use of the STRUDL command

STORE RESPONSE SPECTRA ACCELERATION VS FREQUENCY 'MASTORO'

DAMPING 0.0 FACTOR 386.4

.10 1.0 .20 5.0 .30 8.0

DAMPING .05 FACTOR 386.4

.08 1.0 .15 5.0 .23 8.0

is supposed to cause storage, in the user data set (DDI), of the following spectra (units are assumed to be inches, cycles and seconds. Cycles must have been given in a prior command):

For zero damping:

38.64 in/sec² at 1.0 cps

77.28 in/sec² at 5.0 cps

115.92 in/sec² at 8.0 cps

For 5% damping:

30.91 in/sec² at 1.0 cps

57.96 in/sec² at 5.0 cps

88.87 in/sec² at 8.0 cps

As mentioned previously, the stored response spectrum is then available for use only within the same run in which it is input by referencing the data in the JOINT LOADS, SUPPORT ACCELERATIONS or ROW (matrix) commands.

Note that the only way response spectra may be utilized as dynamic loading is through use of the STORE RESPONSE SPECTRA command.

If response spectra are stored it is recommended that the user store response for frequencies in increments as small as possible because STRUDL uses straight line interpolation when retrieving response values. Care should be exercised also so that response values are stored at the critical frequencies of the structure being analyzed.

2. Dynamic Loading Identification

Use of the STRUDL command

```
DYNAMIC LOADING 1 'FUERZADETORO'
```

is an example of the dynamic loading identification command and identifies the succeeding loading condition. Dynamic loading identification must precede each dynamic loading condition.

3. Joint Loading

This command allows the user to specify directly a time de-

pendent loading which is applied to one or more (a list of) joints. This loading may be in the form of a time function of forces or moments or in the form of a displacement, velocity or acceleration response spectrum.

a. Time Function of Forces of Moments

(1) Forces or moments may be specified by direct input of force or moment values, combined with, in the next command, the respective times at which forces or moment values occur.

Use of the STRUDL command

```
JOINTS 4 TO 7 LOADS FORCE X FACTOR  2.0  53.8  76.9  84.2
TIME POINTS  1.0  2.0  3.0
```

applies the following force as a step function, at the times shown, to joints 4, 5, 6 and 7 (Units are assumed to be kips and seconds. KIPS must have been previously specified with the UNITS command):

107.6 kips at 1.0 seconds

153.8 kips at 2.0 seconds

168.4 kips at 3.0 seconds

(2) Forces or moments may also be applied to joints by the specification of a sine or cosine loading function, as follows:

$$F(t) = V_2 \text{ COSINE } (V_3 t + V_4) \text{ or}$$

$$F(t) = V_2 \text{ SINE } (V_3 t + V_4)$$

$F(t)$ = the load at time t (force or moment)

V_2 = the amplitude of the function

V_3 = the frequency of the function

V_4 = the phase angle of the function

Use of the STRUDL command

JOI 3 TO 7 LOADS FOR X FUNCTION SINE AMPLI 30.0 FREQ 10.0

results in the application of a harmonic loading with an amplitude of 30 kips at a frequency of 10 cycles per second to joints 3, 4, 5, 6 and 7. Or in equation form:

$$F(t) = 30.0 \sin(10.0t)$$

(Units kips, cycles and seconds are assumed. KIPS and CYCLES must have been previously specified with the UNITS command).

b. Response Spectra

Response spectra may only be specified by reference to and retrieval of "stored" response spectra (see also section III.B. of this report). Use of the STRUDL command

JOINT 7 LOAD FORCE X FILE 'PEANUTS' FACTOR 2.5

references 'PEANUTS', a response spectrum which has just been stored within the same STRUDL run. It may be a displacement, velocity or acceleration response spectrum, since STRUDL converts all stored spectra to displacement vs. frequency spectra (Jones 1974, p. 13). All spectrum values in the above example are multiplied by a factor of 2.5.

4. Support Accelerations

This command allows the user to directly specify time dependent accelerations at a support. Accelerations in six directions (three translation and three rotation) may be specified. The only purpose of listing joint numbers in this command is to identify reference joints when rotational accelerations are specified. STRUDL assumes that all supports are connected to a rigid medium, and thus only six total accelerations may be applied per loading condition. These accelerations are assumed applied to all supports.

The accelerations may be specified as accelerations time functions or response spectra.

a. Accelerations Time Functions

(1) Accelerations may be specified by direct input of acceleration values combined with, in the next command, the respective times at which these accelerations occur.

Use of the STRUDL command

```
SUP ACCEL TRANSLATION X FACTOR 386.4 .10 .20 .30
      TIME POINTS .5 1.0 2.0
```

results in the accelerations applied to all supports, with corresponding times as follows (Units are assumed to be inches and seconds):

```
38.64 in/sec2 (.1G) at time = .5 seconds
77.28 in/sec2 (.2G) at time = 1.0 seconds
115.9 in/sec2 (.3G) at time = 2.0 seconds
```

(2) Time function accelerations may also be applied to supports by specifying a sine or cosine function.

Use of the STRUDL command

```
SUP ACCEL TRANS X FUNCTION SINE AMPLI 20.0 FREQ 8.0
```

specifies translational accelerations with an amplitude of 20 in/sec² and a frequency of 8^{rad}/sec for all supports (Units are assumed to be inches, seconds and radians).

b. Response Spectra

Response spectra may only be specified by reference to previously stored response spectra. This reference may only be made to spectra stored within the same run.

Use of the STRUDL command

SUP ACCEL TRANSLATION X FILE 'ELCENRS'

references the response spectrum named 'ELCENRS' which has been stored within the same STRUDL run.

5. Initial Conditions

Caution is advised in the use of the INITIAL CONDITIONS dynamic loading command. The known problem areas are:

(1) A problem exists when INERTIA OF JOINTS CONSISTENT is specified in a dynamic response analysis to INITIAL CONDITIONS. The program runs, but results are incorrect.

(2) The STRUDL users manual (Logcher 1971, p. 152) discusses the problem arising when a DYNAMIC ANALYSIS MODAL is specified in a dynamic response analysis to INITIAL CONDITIONS, and where less than the total number of modes are used in the analysis (Logcher 1971, p. 165).

(3) If INERTIA OF JOINTS values are specified directly by the user in a dynamic response analysis to INITIAL CONDITIONS, the analysis will terminate and print the following message (Jones 1974, p. 13):

DATA LEVEL HAS BEEN REFERENCED BY IFIND OR ALOCAT.

(4) If a dynamic response analysis to INITIAL CONDITIONS is requested using the NORMAL MODES feature (properties specified by input of Eigenvalues and Eigenvectors) the analysis will terminate with the message:

BEYOND THE LIMITS OF A DYNAMIC ARRAY (Jones 1974, p. 13).

Use of the STRUDL commands

INITIAL CONDITIONS JOINTS 2 TO 5, 8, 9

DISPLACEMENT XT 2.5 ZR .12

INITIAL CONDITIONS DISPLACEMENT XT 2.5 ZR .12

JOINTS 2 TO 5, 8, 9

results in a displacement in the X direction of 2.5 inches and a rotation about the Z axis of .12 radians at time = zero for joints 2, 3, 4, 5, 8 and 9 (Units assumed to be inches and radians).

Use of the STRUDL command

INITIAL CONDITIONS ROW

1	DISPLACEMENT YT 2.0
2	DISPLACEMENT YT 1.0
3	DISPLACEMENT YT 1.0
4 to 5	DISPLACEMENT YT 4.0
7	DISPLACEMENT YT 1.2
9	DISPLACEMENT YT .50

results in the following initial displacement column matrix

2.0
1.0
1.0
4.0
4.0
0.0
1.2
0.0
.50

6. Integration Parameters

In a dynamic response analysis, specification of integration parameters is always required except where loading is in the form of referenced RESPONSE SPECTRA. This command specifies the limits used in the Duhamel integral and the times at which the desired structural response values (force, displacements, velocities and accelerations) are to be printed out.

Use of the STRUDL command

```
INTEGRATE FROM 0.0 TO 5.0 AT .10
```

specifies that the program will numerically integrate the equations of motion at an interval of .10 seconds from zero seconds to five seconds. This command also specifies the time interval

at which output data will be printed. The number of integration intervals specified here is 50. The user is cautioned that the number of intervals specified in this command must not be too large, or the dynamic analysis will end abnormally, with no user error message printed to identify the cause of the failure. There will be a system error message printed out, as follows:

```
*** SYSTEM ERROR 5.2 ***
```

This message is not useful to the user.

A method for determining the allowable number of integration intervals is not known to the author and there is no guidance for this in the STRUDL manual.

C. Dynamic Analysis

One of the forms of this command must always be used in any dynamic analysis.

The command initiates a dynamic analysis of the structure. The properties of the structure to be analyzed must have been given, prior to this command, either as matrix input or as normal structural geometry and properties input (See figure 1 for flow chart).

1. Eigenvalues and Eigenvectors

Use of the STRUDL command

DYNAMIC ANALYSIS EIGENVALUE

results in the calculation, by the Householder tridiagonalization technique, of all the eigenvalues and eigenvectors of the structure. The eigenvectors are normalized with respect to unit amplitude.

Use of the STRUDL command

DYNAMIC ANALYSIS EIGENVALUE 4

results in the calculation of the first 4 eigenvalues and corresponding mode shapes (eigenvectors). The tridiagonalization technique is again utilized.

Use of the STRUDL command

DYNAMIC ANALYSIS ITERATION EIGENVALUE

results in calculation of eigenvalues by an iterative routine. This command is not recommended if all degrees of freedom are considered in the analysis and iteration limits are not specified. If the iteration technique is used and ITERATION LIMITS (Logcher 1971, p. 168) are not specified, the program will perform, by default: "125 iteration cycles with a convergence tolerance for eigenvalues of 10^{-10} and for eigenvectors of 10^{-5} " in calculation of eigenvalues and eigenvectors.

If the number of iteration cycles used is insufficient to

achieve the convergence tolerance, then the analysis will fail and the following error message is printed:

```
STRUDL MESSAGE 10.19  
125 ITERATIONS EXCEEDED FOR EIGENVALUE 8  
VALUE USED IS 346.8
```

In addition, no eigenvalues or eigenvectors will be printed. The author recommends the use of the tridiagonalization technique mentioned above for calculation of eigenvalues and eigenvectors.

2. Structural Response

Use of the STRUDL command

```
DYNAMIC ANALYSIS MODAL
```

results in the calculation, by the normal modes technique, of the structural response to a specified dynamic loading. Eigenvalues and eigenvectors are calculated by the Householder tridiagonalization technique and are available for printout.

Use of the STRUDL command

```
DYNAMIC ANALYSIS MODAL 4
```

is the same as above, except that only 4 modes are considered in calculations, and only the first four eigenvalues and eigenvectors

are available for printout.

Use of the STRUDL command

DYNAMIC ANALYSIS ITERATION MODAL

results in the calculation of eigenvalues and eigenvectors by the iteration technique, and the calculation of structural response by the normal modes technique. If the number of iteration cycles used is insufficient to achieve the convergence tolerance (see 1. above) the analysis will run successfully. Eigenvalues and eigenvectors are available for printout.

3. Inoperative Features

DYNAMIC ANALYSIS PHYSICAL is a STRUDL feature, as described in the user's manual (Logcher 1971, p. 196), which calculates structural response by direct integration of the equations of motion. However, this feature is inoperative. If such an analysis is requested, the following error message is printed:

```
*** SYSTEM ERROR 5.26 PROGRAM  
INTERRUPTION HAS OCCURRED ***
```

D. Output

Use of output commands gives the user a printout of dynamic input data and dynamic analysis results, including the results of certain internal computations. The internal computations available

are the normal modes eigenvectors (NORMALIZE EIGENVECTORS OFF) which may be desired for subsequent use in a NORMAL MODES analysis, and the accuracy check of eigenvalue calculations (DUMP ORTHOGONALITY).

1. Input Data

This command provides the user with a printout of all desired input data. The use of this command is optional.

Use of the STRUDL command

PRINT DYNAMIC DATA

results in the printout of all structural and dynamic loading input data.

2. Dynamic Analysis Results

Use of one of the forms of this command is always required in any analysis except a NORMAL MODES analysis.

Use of the STRUDL command

LIST DYNAMIC EIGENVALUES EIGENVECTORS

results in the printout of all eigenvalues and eigenvectors of the structure. No dynamic structural response results will be printed. The command DYNAMIC ANALYSIS EIGENVALUE (or a similar

command) must have been previously given. When STRUDL prints eigenvalues, it also prints the frequencies and periods of the various modes of vibration. The units used in this printout are always $\text{rad}^2/\text{sec}^2$ for eigenvalues, cycles/sec for frequencies and seconds for periods, regardless of the user specified active units.

Use of the STRUDL command

```
LIST DYN EIGENVAL EIGENVEC DISPL VELO ACCEL MAX FORCES ALL
```

results in a printout of eigenvalues and eigenvectors and the dynamic structural responses. The command above also requests all available analysis results. The command DYNAMIC ANALYSIS MODAL (or an equivalent command) must have been previously given.

Caution is advised in the use of this command. The above example command lists all available results. The STRUDL user's manual leaves open to question whether the following results are available:

DISTORTIONS

LOADS

REACTIONS

STRESSES

STRAINS

PRINCIPAL STRESSES

PRINCIPAL STRAINS

These results are not available in the Central Florida Regional Data Center version of STRUDL II. Moreover, if a request is made to LIST any of these results which are not available, the program will terminate with the following statement:

UNABLE TO RETRIEVE MODULE 'QQSTDSEE'

Some results, which are available, will be printed out and some will not be printed. STRUDL always prints the results in the following sequence:

FORCES

DISPLACEMENTS

VELOCITIES

ACCELERATIONS

EIGENVALUES

EIGENVECTORS

STRUDL searches the user's LIST command, in the order the commands are given by the user, for FORCES first. If, for instance, EIGENVALUES are requested just prior to the request for FORCES, STRUDL will bypass the EIGENVALUE command and print FORCES. Then STRUDL proceeds to the next command given by the user. If this command happens to be a command to print information not available, the run will terminate at this point with the statement previously given. FORCES will be the only information printed out.

Other Comments on the LIST command:

(1) Displacements, velocities and accelerations are always printed out for each joint by times. The times used are those specified in the integration parameters command (see section III.B.6.).

(2) Member forces which are printed out for a plane frame are axial force, shear force and bending moment. If MAX FORCES are requested, the maximum axial forces, shear forces and bending moments are printed for each end of each member, together with the time at which the maximum values occur. If FORCES (not MAX FORCES) are requested, these values are printed for each end of each member by times.

(3) Eigenvectors are always printed normalized with respect to unit amplitude unless the command NORMALIZE EIGENVECTORS OFF is given prior to the LIST command. If NORMALIZE EIGENVECTORS OFF is given, the eigenvectors are printed out normalized with respect to mass.

Use of the STRUDL command

NORMALIZE EIGENVECTORS OFF

results in the printout of eigenvectors which are normalized with respect to mass. Use of this command is optional and must be given prior to the LIST command. NORMALIZE EIGENVECTORS OFF

results are required if a subsequent NORMAL MODES analysis is desired.

Use of the STRUDL command

DUMP ORTHOGONALITY

causes the printout of the following internal computations for the purpose of checking accuracy:

$$\phi^T M \phi = I$$

$$\phi^T S \phi = \omega^2$$

where:

ϕ^T is the transpose of the eigenvector matrix normalized with respect to mass

ϕ is the eigenvector matrix normalized with respect to mass

M is the mass matrix

S is the stiffness matrix

I is the unit matrix, which is printed out

ω^2 is the matrix of eigenvalues, which is printed out

Use of this command is optional.

E. Optional Matrix Input

1. Structural Properties Input as Matrices

This feature allows the user to input the structural stiff-

ness, mass and damping matrices of equation (1) and obtain either (a) eigenvalues and eigenvectors only, or (b) eigenvalues and eigenvectors together with structural response to a dynamic loading condition input by matrix.

Use of the STRUDL command

```

MATRIX MASS DIAGONAL
3.3338      4.5840
MATRIX STIFFNESS SYMMETRIC
ROW 1  44480.  -69600.
ROW 2  178000.

```

results in input of the following matrices with two dynamic degrees of freedom:

$$M = \begin{bmatrix} 3.3338 & 0. \\ 0. & 4.5840 \end{bmatrix}$$

$$S = \begin{bmatrix} 44480. & -69600. \\ -69600. & 178000. \end{bmatrix}$$

In this example, damping will be assumed zero. Note that in a symmetric stiffness matrix it is only necessary to input the upper right triangle of matrix values, including values on the matrix diagonal.

2. Normal Modes Analysis

With this feature, the user may input eigenvalues and eigenvectors (eigenvectors must be normalized with respect to mass) for the respective modes of the structure, together with the desired dynamic loading matrix, and obtain dynamic structural response. The response results printed are forces, displacements, velocities and accelerations for each dynamic degree of freedom by times. The following illustrates all the commands used in a NORMAL MODES analysis:

```

NORMAL MODES
MODE 1    4187.6    .4870    .2136
MODE 2    47937.0   -.2505    .4153

DYNAMIC LOADING 1
ROW 1 FUNCTION SINE AMPLITUDE 10000.  FREQ 32.34
ROW 2 FUNCTION SINE AMPLITUDE 10000.  FREQ 32.34
INTEGRATE FROM 0.0 to 1.0 at .01

DYNAMIC ANALYSIS MODAL

FINISH

```

This example is a problem with two degrees of freedom and inputs, in mode 1, the eigenvalue $4187.6 \text{ rad}^2/\text{sec}^2$ and the eigenvectors, normalized with respect to mass, of .4870 and .2136 (see NORMALIZE EIGENVECTORS OFF command). The dynamic loading function input is the following matrix:

$$\begin{bmatrix} 10000 \sin 32.34 t \\ 10000 \sin 32.34 t \end{bmatrix}$$

Note that the LIST command is not required. The LIST command is not required in a NORMAL MODES analysis because results printed out are always forces, displacements, velocities and accelerations, at the times specified in the integration parameters command, for each degree of freedom.

The user is cautioned that, in a NORMAL MODES ANALYSIS, no units conversion is made within the analysis. It is the responsibility of the user to assure that all units used are consistent. For example, suppose that in the example above, the commands were changed as follows:

```

.....
UNITS KIPS
DYNAMIC LOADING 1
ROW 1 FUNCTION SINE AMPLITUDE 10. FREQ 32.34
.....

```

Now, in the normal scheme of STRUDL command usage, this change in commands should result in the same dynamic loading, because 10 kips and 10000 pounds are identical loads. This is, in fact, not true in a NORMAL MODES ANALYSIS. The above UNITS KIPS command has no effect in a NORMAL MODES analysis.

F. Rules For Use of the STRUDL Dynamics Program

1. Do not request any of the following dynamic analysis results for beam elements (Logcher 1971, p. 172).

LOADS, REACTIONS, STRESSES, STRAINS, PRINCIPAL
STRESSES, PRINCIPAL STRAINS, DISTORTIONS

These results are not available and a request to LIST any one of them will result in termination of the program with no STRUDL error message (see section III.D.).

2. Do not use too many integration intervals (Logcher 1971, p. 159) in a dynamic response analysis (see section III.B.).

3. Do not use the command DYNAMIC ANALYSIS ITERATION EIGEN-VALUE unless ITERATION LIMITS (Logcher 1971, p. 168) are specified.

4. Do not use INERTIA OF JOINTS CONSISTENT in a dynamic response analysis to INITIAL CONDITIONS. Results will be incorrect. Use INERTIA OF JOINTS LUMPED.

5. Do not use specified INERTIA OF JOINTS with an INITIAL CONDITIONS dynamic response analysis.

6. Do not expect STORE TIME HISTORY to store a loading history for a future run. This feature works only when the loading history is referenced within the same STRUDL run.

7. Do not expect STORE RESPONSE SPECTRA to store a response spectra for future use. This feature works only when the response spectra is referenced within the same STRUDL run.

8. Do not request DYNAMIC ANALYSIS PHYSICAL. It doesn't work and will not print a STRUDL message to that effect.

9. Do not change active units from run to run when using NORMALIZE EIGENVECTORS OFF followed by a NORMAL MODES analysis. Allow units to be pounds/kips and inches/feet throughout both runs.

IV. STRUDL EXAMPLES

This section presents example calculations using the dynamic analysis features of STRUDL. The two story plane frame structure is considered in a dynamic analysis for the following different cases:

Example A.1. - Eigenvalues/Eigenvectors - All Degrees of Freedom

Example A.2. - Eigenvalues/Eigenvectors - Two Degrees of Freedom

Example A.3. - Eigenvalues/Eigenvectors - Matrix Input

Example A.4. - Eigenvectors Normalized With Respect to Mass

Example B.1. - Sinusoidal Joint Loading

Example B.2. - Sinusoidal Joint Loading - Normal Modes Input

Example B.3. - El Centro Earthquake - Stored Accelerations

Example B.4. - El Centro Earthquake - Response Spectrum

A. Example Calculations - Eigenvalues/Eigenvectors

1. All Degrees of Freedom

In this example, all the eigenvalues and eigenvectors are determined for the frame shown in Figure 2, which has 12 degrees of freedom. This frame is the same as that in the STRUDL manual example frame (Logcher 1971, p. 191). Input for this example is

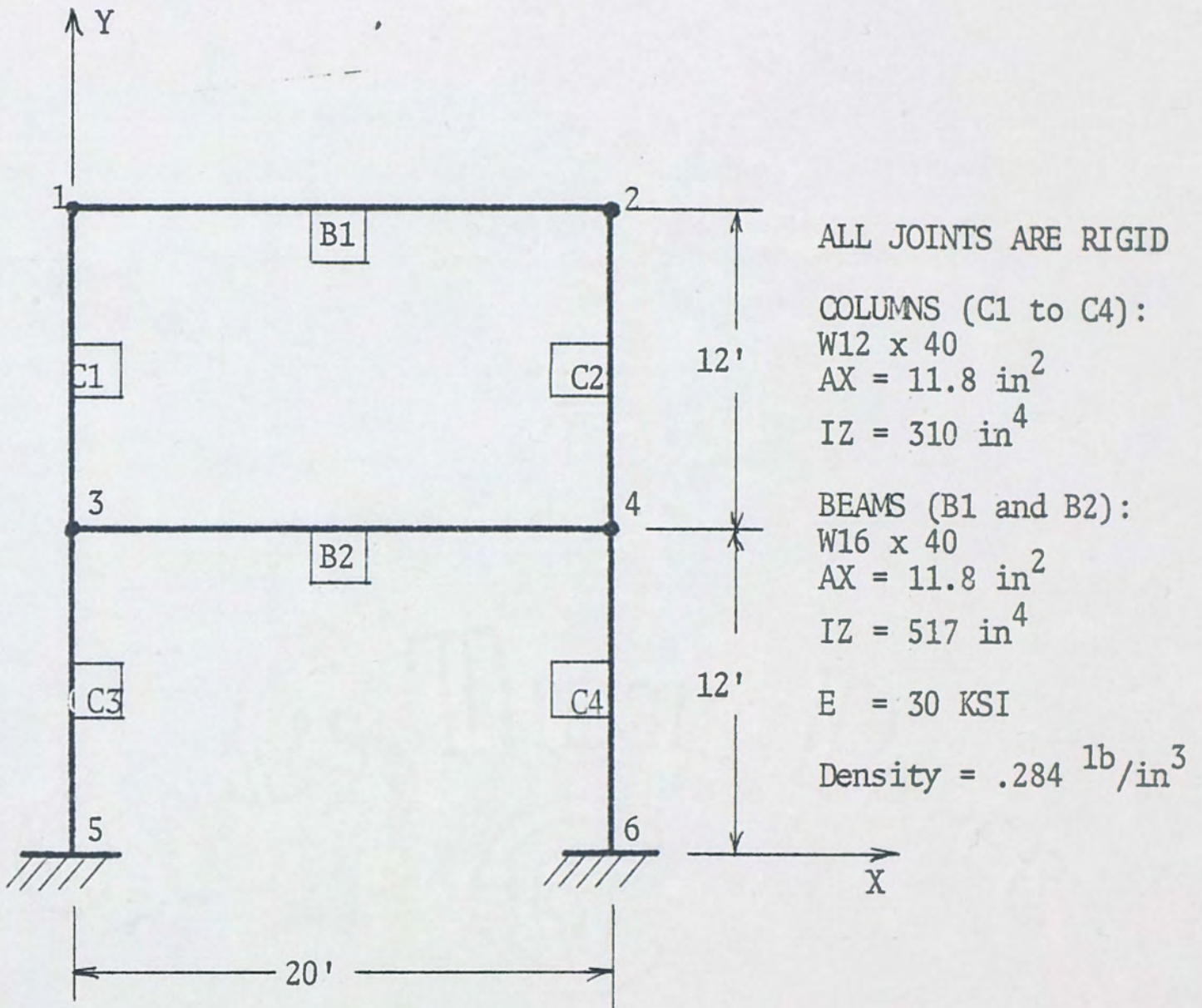


Fig. 2. Two Story Frame

given below followed by the actual computer output.

Example A.1.: Computer Input

STRUDL 'VERIFY' 'MANUAL EXAMPLE'

TYPE PLANE FRAME

UNITS FEET

JOINT COORDINATES

1	0.0	24.0	
2	20.0	24.0	
3	0.0	12.0	
4	20.0	12.0	
5	0.0	0.0	S
6	20.0	0.0	S

MEMBER INCIDENCES

'B1'	1	2
'B1'	3	4
'C1'	1	3
'C2'	2	4
'C3'	3	5
'C4'	4	6

MEMBER PROPERTIES

'B1'	'B2'	TABLE	'STEELWF'	'12WF40'
------	------	-------	-----------	----------

UNITS INCHES

CONSTANTS

DENSITY .284 ALL

E 3.0E7 ALL

INERTIA OF JOINTS LUMPED

DYNAMIC ANALYSIS EIGENVALUE

LIST DYNAMIC EIGENVALUES EIGENVECTORS ALL

FINISH

 RESULTS OF LATEST ANALYSES

PROBLEM TITLE - VERIFICA STR MANUAL EXAMPLE

ACTIVE UNITS INCH LB RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

EIGENVALUES

MODE	EIGENVALUE	FREQUENCY	PERIOD
1	3.943755D 03	9.99483D 00	1.000517D-01
2	3.627680D 04	3.031347D 00	3.298864D-02
3	6.586382D 04	4.084547D 00	2.448252D-02
4	1.142376D 05	5.379291D 00	1.858981D-02
5	1.456240D 05	6.073471D 00	1.646505D-02
6	1.983745D 05	7.088647D 00	1.410706D-02
7	3.084555D 05	1.34872D 02	8.611565D-03
8	5.180868D 05	1.145570D 02	8.729277D-03
9	3.140488D 06	8.42688D 02	5.1226853D-03
10	8.11938D 06	2.142359D 02	4.667753D-03
11	3.112109D 06	2.807682D 02	3.561657D-03
12	3.120253D 06	2.811353D 02	3.557006D-03

EIGENVECTORS

JOINT	MODE	DISPLACEMENT			ROTATION		
		X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
1	1	GLOBAL	0.9999998	0.0072122			0.0027798
	2	GLOBAL	0.9999998	-0.0072122			-0.0027798
	3	GLOBAL	0.4311996	0.0050432			-0.0036551
	4	GLOBAL	0.4311996	-0.0050432			0.0036551
	5	GLOBAL	0.0	0.0			0.0
2	1	GLOBAL	-0.4984271	-0.0246815			0.0156143
	2	GLOBAL	0.9999999	-0.0118955			-0.0015365
	3	GLOBAL	0.9999999	0.0118955			0.0015365
	4	GLOBAL	0.0	0.0			0.0
	5	GLOBAL	0.0	0.0			0.0

Output of Modes 3 through 12 are not shown.

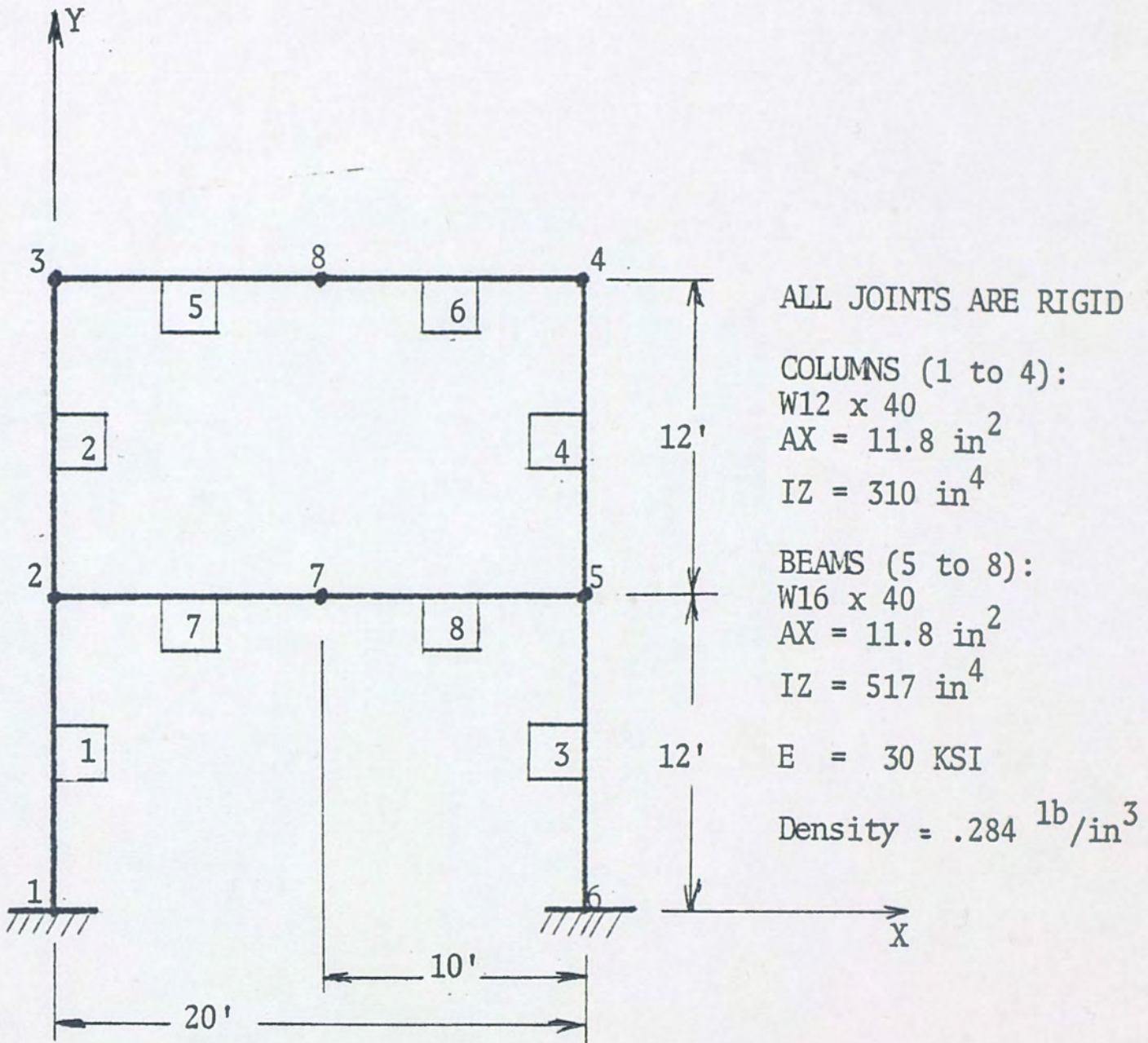


Fig. 3. Two Story Frame

2. Two Degrees of Freedom

In this example, the eigenvalues and eigenvectors are determined for the frame of Example A.1., considering only two horizontal translational degrees of freedom. This frame is shown in Figure 3. Input is given below, followed by actual computer output.

Example A.2.: Input

STRUDL 'VERIFY' '2 STORY 2 DOF FRAME'

TYPE PLANE FRAME

UNITS FEET

JOINT COORDINATES

1 0. 0. S

2 0. 12.

3 0. 24.

4 20. 24.

5 20. 12.

6 20. 0. S

7 10. 12.

8 10. 24.

MEMBER INCIDENCES

1 1 1

2 2 3

3 6 5

4 5 4

5 3 8

7 2 7

8 7 5

UNIT INCHES

MEMBER PROPERTIES

1 TO 4 PRIS AX 11.8 IZ 517.

5 TO 8 PRIS AX 11.8 IZ 310.

CONSTANTS

E 30.E6 ALL

INERTIA OF JOINT 7 LINEAR X 4.5840

INERTIA OF JOINT 8 LINEAR X 3.3338

DYNAMIC DEGREES OF FREEDOM

JOINTS 7, 8 DISPL X

DYNAMIC ANALYSIS EIGENVALUE

LIST DYNAMIC EIGENVALUES EIGENVECTORS ALL

FINISH

 RESULTS OF LATEST ANALYSES

PROBLEM - EXAMPLE TITLE - 2 STORY FRAME DYNAMICS

ACTIVE UNITS INCH LB RAD DEGI SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

EIGENVALUES

MODE	EIGENVALUE	FREQUENCY	PERIOD
1	4.1876150 03	1.029921D 01	9.709483D-02
2	4.7937370 04	3.484637D 01	2.869739D-02

EIGENVECTORS

MODE 1

JOINT	DISPLACEMENT			ROTATION		
	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.4372068	0.0048319	0.0000000	-0.0035788	0.0000000	0.0000000
3	0.9976335	0.0068749	0.0000000	-0.0026495	0.0000000	0.0000000
4	0.4372068	-0.0048319	0.0000000	-0.0035788	0.0000000	0.0000000
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.9999997	0.0000000	0.0000000	0.0017290	0.0000000	0.0012388

MODE 2

JOINT	DISPLACEMENT			ROTATION		
	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.9627548	0.0083356	0.0000000	0.0003719	0.0000000	0.0000000
3	0.5867882	-0.0164328	0.0000000	0.0104108	0.0000000	0.0000000
4	0.9627548	0.0083356	0.0000000	0.0003719	0.0000000	0.0000000
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.9999996	0.0000000	0.0000000	-0.0000017	0.0000000	-0.0005000

LTOP

3. Matrix Input

In this example, eigenvalues and eigenvectors are determined for the two story frame of Figure 3 utilizing matrix input of structural properties. Input and output are given below.

Example A.3.: Input

MATRIX MASS DIAGONAL

3.3338 4.5840

MATRIX STIFFNESS SYMMETRIC

ROW 1 44480. -69600.

ROW 2 178000.

PRINT DYNAMIC DATA

DUMP ORTHOGONALITY

DYNAMIC ANALYSIS EIGENVALUE

LIST DYNAMIC EIGENVALUES EIGENVECTORS ALL

FINISH

RESULTS OF LATEST ANALYSES

PROBLEM = VERIFY TITLE = 2 STORY 2 DOF MATRIX INPUT

ACTIVE UNITS INCH LB RAD DEG SEC

ACTIVE STRUCTURE TYPE PLANE STRESS

ACTIVE COORDINATE AXES X Y Z

EIGENVALUES

MODE	EIGENVALUE	FREQUENCY	PERIOD
1	4.198161E 04	1.030367E 01	9.705275E -02
2	4.798161E 04	1.088245E 01	9.188418E -02

EIGENVECTORS

MODE	EIGENVECTOR
1	1.000000 00 4.383221E -01
2	-6.026963E -01 1.000000 00

TOP

4. Eigenvectors Normalized with Respect to Mass

In this example, eigenvectors are calculated, for the frame of Figure 3, which are normalized with respect to mass. This is required if a subsequent NORMAL MODES dynamic response analysis is to be specified. Input and output are given below.

Example A.4.: Input

STRUDL 'VERIFY' '2 STORY 2 DOF FRAME'

TYPE PLANE FRAME

UNITS FEET

JOINTS COORDINATES

1	0.	0.	S
2	0.	12.	
3	0.	24.	
4	20.	24.	
5	20.	12.	
6	20.	0.	S
7	10.	12.	
8	10.	24.	

MEMBER INCIDENCES

1	1	2
2	2	3
3	6	5

4	5	4
5	3	8
6	8	4
7	2	7
8	7	5

UNITS INCHES

MEMBER PROPERTIES

1 TO 4 PRIS AX 11.8 IZ 517.

5 TO 8 PRIS AX 11.8 IZ 310.

CONSTANTS

E 30.E6 ALL

INERTIA OF JOINT 7 LINEAR X 4.5840

INERTIA OF JOINT 8 LINEAR X 3.3338

DYNAMIC DEGREES OF FREEDOM

JOINTS 7, 8 DISPL X

DYNAMIC ANALYSIS EIGENVALUE

NORMALIZE EIGENVECTORS OFF

LIST DYNAMIC EIGENVECTORS

FINISH

 RESULTS OF LATEST ANALYSES

PROBLEM - VERIFY TITLE - 2 STORY 2 DOF FRAME DYNAMICS

ACTIVE UNITS INCH LB RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

EIGENVECTORS

MODE 1

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.2129360E 00	0.353302E-02	0.0	0.0	0.743028E-02	0.0
3	0.4858847E-00	0.3348317E-02	0.0	0.0	0.290395E-02	0.0
4	0.4858847E 00	-0.3348317E-02	0.0	0.0	0.290395E-02	0.0
5	0.2129360E-00	-0.2353302E-02	0.0	0.0	0.1743028E-02	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.2136310E 00	-0.7573963E-17	0.0	0.0	0.8420977E-03	0.0
8	0.4870371E 00	0.1015418E-17	0.0	0.0	0.6033434E-03	0.0

MODE 2

JOINT	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.3998759E 00	0.3462136E-02	0.0	0.0	0.1544602E-03	0.0
3	-0.2437199E 00	-0.6825276E-02	0.0	0.0	0.4324086E-02	0.0
4	-0.2437199E 00	0.6825276E-02	0.0	0.0	0.4324086E-02	0.0
5	0.3998759E 00	0.3462136E-02	0.0	0.0	0.1544602E-03	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.4153494E 00	-0.1291016E-16	0.0	0.0	0.3395340E-04	0.0
8	-0.2505093E 00	0.3263873E-16	0.0	0.0	-0.2076727E-02	0.0

LTOP

B. Example Calculations - Dynamic Structural Response

1. Sinusoidal Joint Loading

In this example, the two story, two degree of freedom frame of Figure 3 has sinusoidally varying joint loads applied simultaneously in the horizontal direction to joints 7 and 8. Three loading functions are considered, as follows:

$$(1) F = 10.0 \text{ sine } (32.34t)$$

$$(2) F = 10.0 \text{ sine } (142.0t)$$

$$(3) F = 10.0 \text{ sine } (320.0t)$$

The first loading function is applied with a frequency of one-half the fundamental frequency of the frame. The frequency of the second loading function lies between the first and second natural frequencies of the frame and the third loading function is applied with a frequency well above the second natural frequency of the frame.

Maximum member forces and joint displacements, velocities and accelerations are calculated.

Input and computer output are given below.

Example B.1.: Computer Input and Output

```
STRUDL 'VERIFY' '2 STORY 2 DOF FRAME'
```

```
TYPE PLANE FRAME
```

```
UNITS FEET
```

JOINT COORDINATES

1	0.	0.	S
2	0.	12.	
3	0.	24.	
4	20.	24.	
5	20.	12.	
6	20.	0.	S
7	10.	12.	
8	10.	24.	

MEMBER INCIDENCES

1	1	2
2	2	3
3	6	5
4	5	4
5	3	8
6	8	4
7	2	7
8	7	5

UNITS INCHES

MEMBER PROPERTIES

1	TO	4	PRIS	AX	11.8	IZ	517.
5	TO	8	PRIS	AX	11.8	IZ	310.

CONSTANTS

E 30.E6 ALL

INERTIA OF JOINT 7 LINEAR X 4.5840
INERTIA OF JOINT 8 LINEAR X 3.3338
DYNAMIC DEGREES OF FREEDOM
JOINTS 7, 8 DISPL X
UNITS KIPS
DYNAMIC LOADING 1 'SINE JOINT LOADS, HALF FUNDAMENTAL'
JOINTS 7, 8 FOR X FUNCTION SINE AMPLI 10.0 FREQ 32.34
INTEGRATE FROM 0.0 TO 1.0 AT .01
DYNAMIC LOADING 3 'SINE JOINT LOADS, ABOVE 2nd'
JOINTS 7, 8 FOR X FUNCTION SINE AMPLI 10.0 FREQ 320.
INTEGRATE FROM 0.0 TO .10 AT .001
DYNAMIC ANALYSIS MODAL
LIST DYNAMIC DISPL VELO ACCEL MAX FORECS ALL
FINISH

PROBLEM - VERIFY TITLE - 2 STORY 2 DOF FRAME DYNAMICS

ACTIVE UNITS INCH KIP RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

 SINE JOINT LOADS, HALF FUNDAMENTAL

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR-Y	SHEAR-Z	TORSIONAL	BENDING-Y	BENDING-Z
1	1	MAXIMUM -16.4298553 0.8399992	16.4664001 0.4499996				1720.6887207 0.6499994
1	2	MAXIMUM 16.4298553 0.8399992	-16.4664001 0.4499996				651.2163086 0.4499996
2	2	MAXIMUM -6.8251829 0.8399992	9.2638502 0.8399992				514.9716797 0.8399992
12	3	MAXIMUM 6.8251829 0.8399992	-9.2638502 0.8399992				819.0219727 0.8399992
3	6	MAXIMUM 16.4298553 0.8399992	16.4664001 0.4499996				1720.6887207 0.6499994
3	5	MAXIMUM -16.4298553 0.8399992	-16.4664001 0.4499996				651.2163086 0.4499996
4	5	MAXIMUM 6.8251829 0.8399992	9.2638502 0.8399992				514.9716797 0.8399992
4	4	MAXIMUM -6.8251829 0.8399992	-9.2638502 0.8399992				819.0219727 0.8399992
5	3	MAXIMUM -9.2615070 0.8399992	-6.8251905 0.8399992				-819.0219727 0.8399992
5	8	MAXIMUM 9.2615070 0.8399992	6.8251905 0.8399992				-0.0009239 0.0699999
6	8	MAXIMUM 9.2615070 0.8399992	-6.8251753 0.8399992				-0.0007500 0.1299999
6	4	MAXIMUM -9.2615070 0.8399992	6.8251753 0.8399992				-819.0219727 0.8399992
7	2	MAXIMUM -7.5100260 0.4499996	-9.6047020 0.8399992				-1152.5627441 0.8399992
7	7	MAXIMUM 7.5100260 0.4499996	9.6047020 0.8399992				0.0009239 0.3299997
8	7	MAXIMUM 7.5100260 0.4499996	-9.6046782 0.8399992				0.0010625 0.4299992

RESULTANT JOINT DISPLACEMENTS= FREE JOINTS

JOINT	TIME	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.1000	0.0104823	0.0000618	0.0000618	0.0	0.0	0.0
	0.02000	0.00676685	0.00005440	0.00005440	0.0	0.0	0.0
	0.03000	0.01799390	0.00017737	0.00017737	0.0	0.0	0.0
	0.04000	0.03412737	0.00035328	0.00035328	0.0	0.0	0.0
	0.05000	0.05082936	0.00053027	0.00053027	0.0	0.0	0.0
	0.06000	0.06796746	0.00065040	0.00065040	0.0	0.0	0.0
	0.07000	0.0854883	0.0007436	0.0007436	0.0	0.0	0.0
	0.08000	0.10336804	0.000819828	0.000819828	0.0	0.0	0.0
	0.09000	0.12168044	0.000889944	0.000889944	0.0	0.0	0.0
	0.10000	0.1404675107	0.00095532	0.00095532	0.0	0.0	0.0
	0.11000	0.15977706	0.001019977	0.001019977	0.0	0.0	0.0
	0.12000	0.17950043	0.001081133	0.001081133	0.0	0.0	0.0
	0.13000	0.19962706	0.001139179	0.001139179	0.0	0.0	0.0
	0.14000	0.220156257	0.001194144	0.001194144	0.0	0.0	0.0
	0.15000	0.24111175	0.001246172	0.001246172	0.0	0.0	0.0
	0.16000	0.262508279	0.00129526	0.00129526	0.0	0.0	0.0
	0.17000	0.28438213	0.00134156	0.00134156	0.0	0.0	0.0
	0.18000	0.3067057155	0.00138517	0.00138517	0.0	0.0	0.0
	0.19000	0.32945198	0.00142616	0.00142616	0.0	0.0	0.0
	0.20000	0.35266966	0.00146466	0.00146466	0.0	0.0	0.0
	0.21000	0.376314992	0.001501758	0.001501758	0.0	0.0	0.0
	0.22000	0.400359173	0.001537308	0.001537308	0.0	0.0	0.0
	0.23000	0.42476491	0.001571336	0.001571336	0.0	0.0	0.0
	0.24000	0.449503643	0.001603887	0.001603887	0.0	0.0	0.0
	0.25000	0.474559420	0.001635002	0.001635002	0.0	0.0	0.0
	0.26000	0.499917539	0.001664725	0.001664725	0.0	0.0	0.0
	0.27000	0.525573258	0.001693112	0.001693112	0.0	0.0	0.0
	0.28000	0.551522558	0.001720208	0.001720208	0.0	0.0	0.0
	0.29000	0.577761380	0.001746053	0.001746053	0.0	0.0	0.0
	0.30000	0.604386808	0.001770708	0.001770708	0.0	0.0	0.0
	0.31000	0.631404971	0.001794214	0.001794214	0.0	0.0	0.0
	0.32000	0.658819643	0.001816636	0.001816636	0.0	0.0	0.0
	0.33000	0.686629000	0.001837925	0.001837925	0.0	0.0	0.0
	0.34000	0.714839420	0.001858136	0.001858136	0.0	0.0	0.0
	0.35000	0.743457258	0.001877318	0.001877318	0.0	0.0	0.0
	0.36000	0.772488008	0.001895513	0.001895513	0.0	0.0	0.0
	0.37000	0.80193808	0.001912785	0.001912785	0.0	0.0	0.0
	0.38000	0.831814971	0.001929185	0.001929185	0.0	0.0	0.0
	0.39000	0.862125258	0.001944764	0.001944764	0.0	0.0	0.0
	0.40000	0.892877558	0.001959574	0.001959574	0.0	0.0	0.0
	0.41000	0.924079420	0.001973668	0.001973668	0.0	0.0	0.0
	0.42000	0.955739668	0.001987094	0.001987094	0.0	0.0	0.0
	0.43000	0.987866808	0.001999915	0.001999915	0.0	0.0	0.0
	0.44000	1.020479420	0.002012185	0.002012185	0.0	0.0	0.0
	0.45000	1.053586808	0.002023964	0.002023964	0.0	0.0	0.0
	0.46000	1.087199420	0.002035294	0.002035294	0.0	0.0	0.0
	0.47000	1.121337558	0.002046136	0.002046136	0.0	0.0	0.0
	0.48000	1.156012258	0.002056536	0.002056536	0.0	0.0	0.0
	0.49000	1.19124330	0.002066544	0.002066544	0.0	0.0	0.0
	0.50000	1.227049420	0.002076118	0.002076118	0.0	0.0	0.0
	0.51000	1.263449971	0.002085308	0.002085308	0.0	0.0	0.0
	0.52000	1.300463352	0.002094164	0.002094164	0.0	0.0	0.0
	0.53000	1.338109420	0.002102645	0.002102645	0.0	0.0	0.0
	0.54000	1.376409420	0.002110806	0.002110806	0.0	0.0	0.0
	0.55000	1.415386808	0.002118699	0.002118699	0.0	0.0	0.0
	0.56000	1.455063352	0.002126274	0.002126274	0.0	0.0	0.0
	0.57000	1.495470971	0.002133585	0.002133585	0.0	0.0	0.0
	0.58000	1.536649420	0.002140585	0.002140585	0.0	0.0	0.0
	0.59000	1.578639420	0.002147327	0.002147327	0.0	0.0	0.0
	0.60000	1.621470971	0.002153764	0.002153764	0.0	0.0	0.0
	0.61000	1.665175258	0.002159953	0.002159953	0.0	0.0	0.0
	0.62000	1.709783352	0.002165844	0.002165844	0.0	0.0	0.0
	0.63000	1.755336808	0.002171485	0.002171485	0.0	0.0	0.0
	0.64000	1.801886808	0.002176825	0.002176825	0.0	0.0	0.0
	0.65000	1.849483352	0.002181914	0.002181914	0.0	0.0	0.0
	0.66000	1.898179420	0.002186708	0.002186708	0.0	0.0	0.0
	0.67000	1.947939420	0.002191254	0.002191254	0.0	0.0	0.0
	0.68000	1.998829420	0.002195604	0.002195604	0.0	0.0	0.0
	0.69000	2.050919420	0.002199708	0.002199708	0.0	0.0	0.0
	0.70000	2.104286808	0.002203614	0.002203614	0.0	0.0	0.0
	0.71000	2.158909420	0.002207274	0.002207274	0.0	0.0	0.0
	0.72000	2.214879420	0.002210736	0.002210736	0.0	0.0	0.0
	0.73000	2.272199420	0.002213953	0.002213953	0.0	0.0	0.0
	0.74000	2.330879420	0.002216974	0.002216974	0.0	0.0	0.0
	0.75000	2.390919420	0.002219854	0.002219854	0.0	0.0	0.0
	0.76000	2.452329420	0.002222544	0.002222544	0.0	0.0	0.0
	0.77000	2.515109420	0.002225094	0.002225094	0.0	0.0	0.0
	0.78000	2.579269420	0.002227464	0.002227464	0.0	0.0	0.0
	0.79000	2.644819420	0.002229614	0.002229614	0.0	0.0	0.0
	0.80000	2.711779420	0.002231594	0.002231594	0.0	0.0	0.0
	0.81000	2.780179420	0.002233364	0.002233364	0.0	0.0	0.0
	0.82000	2.849999420	0.002234974	0.002234974	0.0	0.0	0.0
	0.83000	2.921269420	0.002236374	0.002236374	0.0	0.0	0.0
	0.84000	2.993999420	0.002237614	0.002237614	0.0	0.0	0.0
	0.85000	3.068219420	0.002238644	0.002238644	0.0	0.0	0.0
	0.86000	3.143979420	0.002239414	0.002239414	0.0	0.0	0.0
	0.87000	3.221319420	0.002239974	0.002239974	0.0	0.0	0.0
	0.88000	3.300289420	0.002240274	0.002240274	0.0	0.0	0.0
	0.89000	3.380859420	0.002240364	0.002240364	0.0	0.0	0.0
	0.90000	3.463019420	0.002240194	0.002240194	0.0	0.0	0.0
	0.91000	3.546769420	0.002239714	0.002239714	0.0	0.0	0.0
	0.92000	3.632119420	0.002238974	0.002238974	0.0	0.0	0.0
	0.93000	3.719079420	0.002237924	0.002237924	0.0	0.0	0.0
	0.94000	3.807669420	0.002236514	0.002236514	0.0	0.0	0.0
	0.95000	3.897919420	0.002234794	0.002234794	0.0	0.0	0.0
	0.96000	3.989869420	0.002232714	0.002232714	0.0	0.0	0.0
	0.97000	4.083569420	0.002230314	0.002230314	0.0	0.0	0.0
	0.98000	4.179069420	0.002227544	0.002227544	0.0	0.0	0.0
	0.99000	4.276339420	0.002224364	0.002224364	0.0	0.0	0.0
	1.00000	4.375349420	0.002220734	0.002220734	0.0	0.0	0.0

RESULTANT JOINT VELOCITIES- FREE JOINTS

JOINT	TIME	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
-2	GLOBAL	0:0	0:0	0:0	0:0	0:0	0:0
		0:01000	0:0195017	0:0193210	-0:0	0:0	0:0194712
		0:02000	0:05019121	0:00839394	-0:0	0:0	0:00652357
		0:03000	0:09409599	0:01575838	-0:0	0:0	0:01156440
		0:04000	0:01717151	0:01850950	-0:0	0:0	0:01397794
		0:05000	0:04570780	0:01597566	-0:0	0:0	0:01183331
		0:06000	0:01889114	0:00680581	-0:0	0:0	0:00471336
		0:07000	0:08324518	0:00780851	-0:0	0:0	0:00570482
		0:08000	0:02580109	0:002142240	-0:0	0:0	0:01616241
		0:09000	0:02080078	0:003082898	-0:0	0:0	0:02327781
		0:10000	0:01201630	0:003328752	-0:0	0:0	0:02456528
		0:11000	0:047863159	0:0042613436	-0:0	0:0	0:011974189
		0:12000	0:01216202	0:0013347229	-0:0	0:0	0:01029775
		0:13000	0:018041145	0:0040298106	-0:0	0:0	0:009335902
		0:14000	0:01561810	0:011849091	-0:0	0:0	0:013593920
		0:15000	0:02644556	0:01707857	-0:0	0:0	0:01299280
		0:16000	0:0222200	0:01444081	-0:0	0:0	0:00817108
		0:17000	0:01855087	0:00021781	-0:0	0:0	0:003305840
		0:18000	0:018550803	0:00088934	-0:0	0:0	0:00355840
		0:19000	0:09545804	0:0054706	-0:0	0:0	0:0037314
		0:20000	0:03088432	0:012547049	-0:0	0:0	0:00350309
		0:21000	0:02235665	0:0114655	-0:0	0:0	0:0032731
		0:22000	0:0793960	0:01714655	-0:0	0:0	0:00345869
		0:23000	0:00066849	0:0191278	-0:0	0:0	0:0198960
		0:24000	0:09833403	0:016208668	-0:0	0:0	0:02096052
		0:25000	0:01919114	0:003288070	-0:0	0:0	0:02232194
		0:26000	0:051542018	0:003040608	-0:0	0:0	0:014552192
		0:27000	0:03954773	0:00490662	-0:0	0:0	0:02052352
		0:28000	0:07665514	0:00792058	-0:0	0:0	0:0207332
		0:29000	0:08806763	0:01866822	-0:0	0:0	0:0207332
		0:30000	0:08809979	0:01394857	-0:0	0:0	0:0207332
		0:31000	0:01392271	0:001760282	-0:0	0:0	0:01523296
		0:32000	0:08003900	0:00141617	-0:0	0:0	0:01222298
		0:33000	0:05541336	0:00064648	-0:0	0:0	0:00234194
		0:34000	0:02204498	0:00957976	-0:0	0:0	0:0222997
		0:35000	0:06220518	0:01609695	-0:0	0:0	0:01406175
		0:36000	0:07022519	0:04335300	-0:0	0:0	0:01106175
		0:37000	0:05247309	0:02371357	-0:0	0:0	0:01722052
		0:38000	0:05812836	0:003199811	-0:0	0:0	0:0175050
		0:39000	0:025933231	0:003208533	-0:0	0:0	0:0222309
		0:40000	0:061523496	0:01129513	-0:0	0:0	0:0222309
		0:41000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:42000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:43000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:44000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:45000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:46000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:47000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:48000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:49000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:50000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:51000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:52000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:53000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:54000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:55000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:56000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:57000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:58000	0:05993033	0:01129513	-0:0	0:0	0:0222309
		0:59000	0:05993033	0:003208533	-0:0	0:0	0:0222309
		0:60000	0:05993033	0:01129513	-0:0	0:0	0:0222309

RESULTANT JOINT ACCELERATIONS- FREE JOINTS

JOINT	TIME	X DISP	Y DISP	Z DISP	X ROT	Y ROT	Z ROT
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.1000	519.6728516	4.2070627	4.2070627	0.0	0.0	0.0
	0.2000	560.5664063	8.1363039	8.1363039	0.0	0.0	0.0
	0.3000	544.0002441	5.5988808	5.5988808	0.0	0.0	0.0
	0.4000	109.8215637	0.1654036	0.1654036	0.0	0.0	0.0
	0.5000	-678.3940430	-5.3861809	-5.3861809	0.0	0.0	0.0
	0.6000	-1066.5012207	-15.0476274	-15.0476274	0.0	0.0	0.0
	0.7000	-1207.7736816	-11.6537342	-11.6537342	0.0	0.0	0.0
	0.8000	-1473.6293993	-16.6687089	-16.6687089	0.0	0.0	0.0
	0.9000	-238.6789091	-2.9261951	-2.9261951	0.0	0.0	0.0
	1.0000	841.9077148	13.5886860	13.5886860	0.0	0.0	0.0
	1.1000	1243.0478516	19.9601192	19.9601192	0.0	0.0	0.0
	1.2000	162.7629395	9.8167269	9.8167269	0.0	0.0	0.0
	1.3000	306.9750777	11.6554493	11.6554493	0.0	0.0	0.0
	1.4000	-686.9544333	-9.8000363	-9.8000363	0.0	0.0	0.0
	1.5000	-467.3998632	-7.1752256	-7.1752256	0.0	0.0	0.0
	1.6000	-264.2186441	-3.2027740	-3.2027740	0.0	0.0	0.0
	1.7000	594.0245102	5.7148905	5.7148905	0.0	0.0	0.0
	1.8000	986.1297602	13.3330255	13.3330255	0.0	0.0	0.0
	1.9000	276.1951036	3.4785744	3.4785744	0.0	0.0	0.0
	2.0000	1016.9522219	19.1862980	19.1862980	0.0	0.0	0.0
	2.1000	-1223.2349890	-14.5490287	-14.5490287	0.0	0.0	0.0
	2.2000	-48.2556890	-1.0955365	-1.0955365	0.0	0.0	0.0
	2.3000	1104.4349037	13.0956247	13.0956247	0.0	0.0	0.0
	2.4000	1048.2756478	15.8006028	15.8006028	0.0	0.0	0.0
	2.5000	46.8775940	-2.5129843	-2.5129843	0.0	0.0	0.0
	2.6000	-589.4997559	-6.1005497	-6.1005497	0.0	0.0	0.0
	2.7000	-270.4977489	-3.6215153	-3.6215153	0.0	0.0	0.0
	2.8000	459.5567520	1.9734980	1.9734980	0.0	0.0	0.0
	2.9000	755.5844727	5.5580015	5.5580015	0.0	0.0	0.0
	3.0000	387.0974493	3.2803160	3.2803160	0.0	0.0	0.0
	3.1000	-594.2314493	-8.0982094	-8.0982094	0.0	0.0	0.0
	3.2000	-1273.4606202	-12.8750600	-12.8750600	0.0	0.0	0.0
	3.3000	1398.8736080	12.4735533	12.4735533	0.0	0.0	0.0
	3.4000	396.0037388	3.4316733	3.4316733	0.0	0.0	0.0
	3.5000	1220.0279785	12.6702594	12.6702594	0.0	0.0	0.0
	3.6000	77.1709247	1.8093729	1.8093729	0.0	0.0	0.0
	3.7000	-65.0052144	-1.5318252	-1.5318252	0.0	0.0	0.0
	3.8000	559.521494	3.5285152	3.5285152	0.0	0.0	0.0
	3.9000	859.5567527	6.1005497	6.1005497	0.0	0.0	0.0
	4.0000	387.0974493	3.2803160	3.2803160	0.0	0.0	0.0
	4.1000	-594.2314493	-8.0982094	-8.0982094	0.0	0.0	0.0
	4.2000	-1273.4606202	-12.8750600	-12.8750600	0.0	0.0	0.0
	4.3000	1398.8736080	12.4735533	12.4735533	0.0	0.0	0.0
	4.4000	396.0037388	3.4316733	3.4316733	0.0	0.0	0.0
	4.5000	1220.0279785	12.6702594	12.6702594	0.0	0.0	0.0
	4.6000	77.1709247	1.8093729	1.8093729	0.0	0.0	0.0
	4.7000	-65.0052144	-1.5318252	-1.5318252	0.0	0.0	0.0
	4.8000	559.521494	3.5285152	3.5285152	0.0	0.0	0.0
	4.9000	859.5567527	6.1005497	6.1005497	0.0	0.0	0.0
	5.0000	387.0974493	3.2803160	3.2803160	0.0	0.0	0.0
	5.1000	-594.2314493	-8.0982094	-8.0982094	0.0	0.0	0.0
	5.2000	-1273.4606202	-12.8750600	-12.8750600	0.0	0.0	0.0
	5.3000	1398.8736080	12.4735533	12.4735533	0.0	0.0	0.0
	5.4000	396.0037388	3.4316733	3.4316733	0.0	0.0	0.0
	5.5000	1220.0279785	12.6702594	12.6702594	0.0	0.0	0.0
	5.6000	77.1709247	1.8093729	1.8093729	0.0	0.0	0.0
	5.7000	-65.0052144	-1.5318252	-1.5318252	0.0	0.0	0.0
	5.8000	559.521494	3.5285152	3.5285152	0.0	0.0	0.0
	5.9000	859.5567527	6.1005497	6.1005497	0.0	0.0	0.0
	6.0000	387.0974493	3.2803160	3.2803160	0.0	0.0	0.0

LOADING 2 2 SINE JOINT LOADS, BET FUND AND 2ND

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR-Y	SHEAR-Z	TORSIONAL	MOMENT-BENDING-Y	MOMENT-BENDING-Z
1	1	MAXIMUM -7.3588190 0.1199999	5.3262177 0.5099999				565.4145508 1.0000000
1	2	MAXIMUM 7.3588190 0.1199999	-5.3262177 0.5099999				222.7431541 0.5099999
2	2	MAXIMUM -3.4775648 0.1199999	5.5234251 0.6099994				378.5449212 0.6099994
2	3	MAXIMUM 3.4775648 0.1199999	-5.5234251 0.6099994				417.3085937 0.1199999
3	6	MAXIMUM 7.3588190 0.1199999	5.3262177 0.5099999				555.4145508 1.0000000
3	5	MAXIMUM -7.3588190 0.1199999	-5.3262177 0.5099999				222.7431541 0.5099999
4	5	MAXIMUM 3.4775648 0.1199999	5.5234251 0.6099994				378.5449212 0.6099994
4	4	MAXIMUM -3.4775648 0.1199999	-5.5234251 0.6099994				417.3085937 0.1199999
5	3	MAXIMUM -5.5234604 0.6099994	3.4775715 0.1199999				-417.3085937 0.1199999
5	8	MAXIMUM 5.5234604 0.6099994	-3.4775715 0.1199999				-0.0002165 0.8299994
6	8	MAXIMUM 5.5234604 0.6099994	-3.4775753 0.1199999				-0.0002500 0.1299999
6	4	MAXIMUM -5.5234604 0.6099994	3.4775753 0.1199999				-417.3088379 0.1199999
7	2	MAXIMUM 3.4734173 0.4699996	-3.8850555 0.8499992				466.2065430 0.8499992
7	7	MAXIMUM -3.4734173 0.4699996	3.8850555 0.8499992				0.0002310 0.8099992
8	7	MAXIMUM -3.4734173 0.4699996	3.8850613 0.8499992				-0.0002500 0.1299999
8	5	MAXIMUM 3.4734173 0.4699996	-3.8850613 0.8499992				456.2070313 0.8499992

2. Sinusoidal Joint Loading - Normal Modes Input

This example uses the frame of Figure 3 and the loading conditions are identical to the previous example except the NORMAL MODES feature is used to determine the structural responses. Eigenvectors normalized with respect to mass are required as part of the input in this example and were calculated in Example A.4. Input and computer output are given below.

Example B.2.: Input

```

STRU DL 'VERIFY' '2 STORY 2 DOF NORMAL MODES'

NORMAL MODES

MODE 1  4187.6    .4870  .2136
MODE 2  47937.0  -.2505  .4153

DYNAMIC LOADING 1 'SINE JOINT LOADS, HALF FUNDAMENTAL'
ROW 1 FUNCTION SINE AMPLITUDE 10000.  FREQ 32.34
ROW 2 FUNCTION SINE AMPLITUDE 10000.  FREQ 32.34
INTEGRATE FROM 0.0 TO 1.0 AT .01

DYNAMIC LOADING 2 'SINE JOINT LOADS, BET FUND AND 2ND'
ROW 1 FUNCTION SINE AMPLITUDE 10000.  FREQ 142.
Row 2 FUNCTION SINE AMPLITUDE 10000.  FREQ 142.
INTEGRATE FROM 0.0 TO 1.0 AT 0.1

DYNAMIC LOADING 3 'SINE JOINT LOADS, ABOVE 2ND'
ROW 1 FUNCTION SINE AMPLITUDE 100000.  FREQ 320.

```

ROW 2 FUNCTION SINE AMPLITUDE 10000. FREQ 320.

INTEGRATE FROM 0.0 TO 1.0 AT 0.1

PRINT DYNAMIC DATA

DYNAMIC ANALYSIS MODAL

FINISH

 PROBLEM DATA FROM INTERNAL STORAGE

JOB ID VERIFY JOB TITLE 2 STORY FRAME 2 DOF NORMAL MODES
 ACTIVE UNITS LENGTH INCH WEIGHT LB ANGLE RAD TEMPERATURE DEG TIME SEC

***** DYNAMIC STRUCTURAL DATA *****
 NORMAL MODES
 MODE EIGENVALUE / EIGENVECTORS

1 4187.59786 0.487000 0.213600
 2 47937.00000 -0.250500 0.415300
 ***** DYNAMIC LOADING DATA *****

LOADING 1 SINE JOINT LOADS HALF FUNDAMENTAL STATUS ACTIVE

ROW	LOADS	TIME	LOAD	TIME	LOAD	TIME	LOAD
1	FUNCTION1 SIN	AMPLITUDE1	1.0000E 04	FREQUENCY1	3.2340E 01	PHASE ANGLE1	0.0
2	FUNCTION1 SIN	AMPLITUDE1	1.0000E 04	FREQUENCY1	3.2340E 01	PHASE ANGLE1	0.0

INTEGRATION PERIODS
 INITIAL 0.0
 FINAL 1.00000
 INCREMENT 0.01000

LOADING 2 SINE JOINT LOADS BET FUND AND 2ND STATUS ACTIVE

ROW	LOADS	TIME	LOAD	TIME	LOAD	TIME	LOAD
1	FUNCTION1 SIN	AMPLITUDE1	1.0000E 04	FREQUENCY1	1.4200E 02	PHASE ANGLE1	0.0
2	FUNCTION1 SIN	AMPLITUDE1	1.0000E 04	FREQUENCY1	1.4200E 02	PHASE ANGLE1	0.0

INTEGRATION PERIODS
 INITIAL 0.0
 FINAL 1.00000
 INCREMENT 0.01000

TIME	FORCE	DISPLACEMENT	VELOCITY	ACCELERATION
0.0	0.0	0.0	0.0	0.0
0.1	1.77919E	0.597826E-02	0.802444E	0.13599E
0.2	0.26355E	1.84628E-01	1.796147E	0.568832E
0.3	0.49984E	7.45147E-01	3.240010E	1.182976E
0.4	0.618262E	1.15870E	3.85828E	0.162933E
0.5	0.69328E	1.35166E	3.44979E	0.319230E
0.6	0.700E	1.35166E	1.600513E	0.278598E
0.7	0.264301E	1.04193E	4.65018E	0.295149E
0.8	0.289470E	1.98959E	6.88020E	0.25712E
0.9	0.72248E	1.31355E	6.48229E	0.164877E
1.0	0.736248E	1.25418E	5.88653E	0.275553E
1.1	0.736248E	1.24266E	3.68950E	0.921514E
1.2	0.736248E	1.06556E	0.82582E	0.022935E
1.3	0.951605E	1.75486E	4.48534E	0.453494E
1.4	0.711023E	2.17250E	5.98621E	0.023652E
1.5	0.711023E	2.60210E	1.52882E	0.130717E
1.6	1.86611E	1.61405E	1.83865E	0.33369E
1.7	0.0	0.0	0.0	0.0

0.0	0.0	0.0	0.0	0.0
0.1	1.93850E	0.697797E	7.87797E	0.176E
0.2	0.26355E	1.84628E	3.24001E	0.56883E
0.3	0.49984E	1.15870E	3.85828E	0.16293E
0.4	0.61826E	1.35166E	3.44979E	0.31923E
0.5	0.69328E	1.35166E	1.60051E	0.27859E
0.6	0.700E	1.04193E	4.65018E	0.29514E
0.7	0.26430E	1.98959E	6.88020E	0.25712E
0.8	0.28947E	1.31355E	6.48229E	0.16487E
0.9	0.72248E	1.25418E	5.88653E	0.27555E
1.0	0.73624E	1.24266E	3.68950E	0.92151E
1.1	0.73624E	1.06556E	0.82582E	0.02293E
1.2	0.95160E	1.75486E	4.48534E	0.45349E
1.3	0.71102E	2.17250E	5.98621E	0.02365E
1.4	0.71102E	2.60210E	1.52882E	0.13071E
1.5	1.86611E	1.61405E	1.83865E	0.33369E
1.6	0.0	0.0	0.0	0.0

D.O.F.	TIME	FORCE	DISPLACEMENT	VELOCITY	ACCELERATION
2	0:0000	0:00000000	0:00000000	0:00000000	0:00000000
	0:0100	3:177919E 03	1:061084E -02	3:0012874E 00	0:239949E 02
	0:0200	6:0263355E 03	6:823802E -02	8:545555E 00	5:587842E 02
	0:0300	8:249984E 03	1:808679E -01	1:397880E 01	5:463835E 02
	0:0400	9:689328E 03	3:413328E -01	1:7181E 01	1:80374E 02
	0:0500	9:689328E 03	5:103376E -01	1:485501E 01	1:842209E 02
	0:0600	9:689328E 03	6:105655E -01	1:83782E 01	1:842209E 02
	0:0700	9:689328E 03	6:492879E -01	1:83782E 01	1:842209E 02
	0:0800	9:689328E 03	6:928799E -01	1:83782E 01	1:842209E 02
	0:0900	9:689328E 03	7:438799E -01	1:83782E 01	1:842209E 02
	0:1000	9:689328E 03	8:039999E -01	1:83782E 01	1:842209E 02
	0:1100	9:689328E 03	8:736715E -01	1:83782E 01	1:842209E 02
	0:1200	9:689328E 03	9:5248703E -01	1:83782E 01	1:842209E 02
	0:1300	9:689328E 03	1:03309E -01	1:83782E 01	1:842209E 02
	0:1400	9:689328E 03	1:1845661E -01	1:83782E 01	1:842209E 02
	0:1500	9:689328E 03	1:455677E -01	1:83782E 01	1:842209E 02
	0:1600	9:689328E 03	1:700996E -01	1:83782E 01	1:842209E 02
	0:1700	9:689328E 03	1:500996E -01	1:83782E 01	1:842209E 02
	0:1800	9:689328E 03	1:335883E -01	1:83782E 01	1:842209E 02
	0:1900	9:689328E 03	1:177243E -01	1:83782E 01	1:842209E 02
	0:2000	9:689328E 03	1:266272E -01	1:83782E 01	1:842209E 02
	0:2100	9:689328E 03	1:711779E -01	1:83782E 01	1:842209E 02
	0:2200	9:689328E 03	1:432799E -01	1:83782E 01	1:842209E 02
	0:2300	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2400	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2500	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2600	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2700	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2800	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:2900	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3000	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3100	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3200	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3300	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3400	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3500	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3600	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3700	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3800	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:3900	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4000	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4100	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4200	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4300	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4400	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4500	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4600	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4700	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4800	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:4900	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5000	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5100	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5200	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5300	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5400	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5500	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5600	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5700	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5800	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5900	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02
	0:5900	9:689328E 03	1:25199E -01	1:83782E 01	1:842209E 02

3. El Centro Earthquake - Stored Accelerations

In this example, the two story, two degree of freedom frame of Figure 3 is loaded by the horizontal acceleration history of the El Centro earthquake through use of the SUPPORT ACCELERATIONS command. Structural responses are calculated which include internal member forces, and joint displacements, velocities and accelerations. The input and computer output follow.

Example B.3.: Input

```
STRUDL 'VERIFY' '2 STORY 2 DOF FRAME'
```

```
TYPE PLANE FRAME
```

```
UNITS FEE
```

```
JOINT COORDINATES
```

```
1    0.    0.    S
```

```
2    0.   12.
```

```
3    0.   24.
```

```
4   20.   24.
```

```
5   20.   12.
```

```
6   20.    0.    S
```

```
7   10.   12.
```

```
8   10.   24.
```

```
MEMBER INCIDENCES
```

```
1    1    2
```

2	2	3
3	6	5
4	5	4
5	3	8
6	8	4
7	2	7
8	7	5

UNITS INCHES

MEMBER PROPERTIES

1 TO 4 PRIS AX 11.8 IZ 517.

5 TO 8 PRIS AX 11.8 IZ 310.

CONSTANTS

E 30.E6 A11

INERTIA OF JOINT 7 LINEAR X 4.5840

INERTIA OF JOINT 8 LINEAR X 3.3338

DYNAMIC DEGREES OF FREEDOM

JOINTS 7, 8 DISPL X

UNITS KIPS

DYNAMIC LOADING 1 'EL CENTRO SUP ACCEL'

TRANSLATION X FILE 'EL CENTRO'

INTEGRATE FROM 0.0 TO 6.0 AT .10

DYNAMIC ANALYSIS MODAL

LIST DYNAMIC DISPL VELO ACCEL MAX FORCES ALL

FINISH

 RESULTS OF LATEST ANALYSES

PROBLEM - VERIFY TITLE - EL CENTRO RESPONSE, 2 DOF FRAME

ACTIVE UNITS INCH KIP CYC DEGF SEC
 ACTIVE STRUCTURE TYPE PLANE FRAME
 ACTIVE COORDINATE AXES X Y

LOADING - 1 EL CENTRO SUP ACCEL
 =====

MEMBER	JOINT	AXIAL	SHEAR-Y	SHEAR-Z	TORSIONAL	BENDING-Y	BENDING-Z
1	1	MAXIMUM TIME	-1.1796932 1.9999943	1.3858643 1.9999943			140.1832886 1.9999943
1	2	MAXIMUM TIME	1.1796932 1.9999943	-1.3858643 1.9999943			57.3811188 1.9999943
2	2	MAXIMUM TIME	-0.4606909 1.9999943	0.5707079 1.9999943			26.8991699 1.9999943
2	3	MAXIMUM TIME	0.4606909 1.9999943	-0.5707079 1.9999943			55.2827454 1.9999943
3	6	MAXIMUM TIME	1.1796932 1.9999943	1.3858643 1.9999943			140.1832886 1.9999943
3	5	MAXIMUM TIME	-1.1796932 1.9999943	-1.3858643 1.9999943			59.3811188 1.9999943
4	5	MAXIMUM TIME	0.4606909 1.9999943	0.5707079 1.9999943			25.8991699 1.9999943
4	4	MAXIMUM TIME	-0.4606909 1.9999943	-0.5707079 1.9999943			55.2827454 1.9999943
5	3	MAXIMUM TIME	-0.5707558 1.9999943	-0.4606913 1.9999943			-55.2829132 1.9999943
5	8	MAXIMUM TIME	0.5707558 1.9999943	0.4606913 1.9999943			0.0000577 1.6999960
6	8	MAXIMUM TIME	0.5707558 1.9999943	-0.4606901 1.9999943			0.0000391 1.9999943
6	4	MAXIMUM TIME	-0.5707558 1.9999943	0.4606901 1.9999943			-55.2828522 1.9999943
7	2	MAXIMUM TIME	-0.8151535 1.9999943	-0.7190033 1.9999943			-95.2003650 1.9999943

RESULTANT JOINT DISPLACEMENTS- FREE JOINTS

JOINT	TIME	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.10000	-0.0022399	-0.0000219	-0.0000027	0.0	0.0	0.0
	0.20000	-0.0014555	-0.0000142	-0.0000018	0.0	0.0	0.0
	0.30000	-0.0009254	-0.0000091	-0.0000011	0.0	0.0	0.0
	0.40000	-0.0011686	-0.0000113	-0.0000014	0.0	0.0	0.0
	0.50000	-0.0021971	-0.0000216	-0.0000027	0.0	0.0	0.0
	0.60000	-0.0057099	-0.0000557	-0.0000069	0.0	0.0	0.0
	0.70000	-0.0089571	-0.0000876	-0.0000109	0.0	0.0	0.0
	0.80000	-0.0056734	-0.0000552	-0.0000076	0.0	0.0	0.0
	0.90000	-0.0021631	-0.0000156	-0.0000024	0.0	0.0	0.0
	1.00000	-0.0008212	-0.0000079	-0.0000029	0.0	0.0	0.0
	1.20000	-0.0020090	-0.0000129	-0.0000040	0.0	0.0	0.0
	1.40000	-0.0032651	-0.0000208	-0.0000061	0.0	0.0	0.0
	1.60000	-0.0019852	-0.0000148	-0.0000044	0.0	0.0	0.0
	1.70000	-0.0034904	-0.0000219	-0.0000061	0.0	0.0	0.0
	1.80000	-0.0239239	-0.0000337	-0.0000049	0.0	0.0	0.0
	1.89999	-0.0492499	-0.0000716	-0.0000097	0.0	0.0	0.0
	1.99999	-0.0199958	-0.0000189	-0.0000016	0.0	0.0	0.0
	2.09999	-0.0064786	-0.0000342	-0.0000047	0.0	0.0	0.0
	2.19999	-0.0064786	-0.0000342	-0.0000047	0.0	0.0	0.0
	2.29999	-0.0052221	-0.0000233	-0.0000032	0.0	0.0	0.0
	2.39999	-0.0022449	-0.0000120	-0.0000016	0.0	0.0	0.0
	2.49999	-0.0016567	-0.0000051	-0.0000002	0.0	0.0	0.0
	2.59999	-0.0016567	-0.0000051	-0.0000002	0.0	0.0	0.0
	2.69999	-0.0033363	-0.0000090	-0.0000004	0.0	0.0	0.0
	2.79999	-0.0051535	-0.0000150	-0.0000007	0.0	0.0	0.0
	2.89999	-0.0049831	-0.0000142	-0.0000007	0.0	0.0	0.0
	2.99999	-0.0024668	-0.0000073	-0.0000003	0.0	0.0	0.0
	3.09999	-0.0008318	-0.0000015	-0.0000000	0.0	0.0	0.0
	3.19999	-0.0020312	-0.0000021	-0.0000002	0.0	0.0	0.0
	3.29999	-0.0031712	-0.0000032	-0.0000003	0.0	0.0	0.0
	3.39999	-0.0000345	-0.0000000	-0.0000000	0.0	0.0	0.0
	3.49999	-0.0028183	-0.0000020	-0.0000001	0.0	0.0	0.0
	3.59999	-0.0013387	-0.0000004	-0.0000000	0.0	0.0	0.0
	3.69999	-0.0002541	-0.0000001	-0.0000000	0.0	0.0	0.0
	3.79999	-0.0014948	-0.0000003	-0.0000000	0.0	0.0	0.0
	3.89999	-0.0020297	-0.0000003	-0.0000000	0.0	0.0	0.0
	3.99999	-0.0020512	-0.0000003	-0.0000000	0.0	0.0	0.0
	4.09999	-0.0061153	-0.0000006	-0.0000000	0.0	0.0	0.0
	4.19999	-0.0020104	-0.0000001	-0.0000000	0.0	0.0	0.0
	4.29999	-0.0080619	-0.0000008	-0.0000000	0.0	0.0	0.0
	4.39999	-0.0000196	-0.0000000	-0.0000000	0.0	0.0	0.0
	4.49999	-0.0019644	-0.0000000	-0.0000000	0.0	0.0	0.0

RESULTANT JOINT VELOCITIES- FREE JOINTS

JOINT	GLOBAL	TIME /	X DISP.	DISPLACEMENT	Z DISP.	X ROT.	Y ROT.	Z ROT.
2	0.0	0.0	0.0044955	0.0000124	0.0000124	0.0000000	0.0000000	0.0000000
	0.10000	0.0	0.0011533	-0.00000416	-0.00000416	0.0000000	0.0000000	0.0000000
	0.20000	0.0	0.0038271	-0.00000286	-0.00000286	0.0000000	0.0000000	0.0000000
	0.30000	0.0	0.0036428	-0.00001075	-0.00001075	0.0000000	0.0000000	0.0000000
	0.40000	0.0	0.0028373	-0.00000629	-0.00000629	0.0000000	0.0000000	0.0000000
	0.50000	0.0	0.0078389	-0.00000893	-0.00000893	0.0000000	0.0000000	0.0000000
	0.60000	0.0	0.0217664	-0.00000972	-0.00000972	0.0000000	0.0000000	0.0000000
	0.70000	0.0	0.0156602	0.00002969	0.00002969	0.0000000	0.0000000	0.0000000
	0.80000	0.0	0.0118988	0.00000544	0.00000544	0.0000000	0.0000000	0.0000000
	0.90000	0.0	0.0428974	-0.00001793	-0.00001793	0.0000000	0.0000000	0.0000000
	1.00000	0.0	0.0274059	0.00005290	0.00005290	0.0000000	0.0000000	0.0000000
	1.10000	0.0	0.0630746	-0.00001814	-0.00001814	0.0000000	0.0000000	0.0000000
	1.20000	0.0	0.0475173	-0.00000923	-0.00000923	0.0000000	0.0000000	0.0000000
	1.30000	0.0	0.0118963	-0.00000564	-0.00000564	0.0000000	0.0000000	0.0000000
	1.40000	0.0	0.0405614	-0.00000585	-0.00000585	0.0000000	0.0000000	0.0000000
	1.50000	0.0	0.0504149	0.00000760	0.00000760	0.0000000	0.0000000	0.0000000
	1.60000	0.0	0.0018884	0.00000248	0.00000248	0.0000000	0.0000000	0.0000000
	1.70000	0.0	0.0373905	-0.00000795	-0.00000795	0.0000000	0.0000000	0.0000000
	1.80000	0.0	0.0158356	-0.00001872	-0.00001872	0.0000000	0.0000000	0.0000000
	1.90000	0.0	0.0184070	-0.00005007	-0.00005007	0.0000000	0.0000000	0.0000000
	2.00000	0.0	0.0788070	-0.00005327	-0.00005327	0.0000000	0.0000000	0.0000000
	2.10000	0.0	0.0425184	-0.00000387	-0.00000387	0.0000000	0.0000000	0.0000000
	2.20000	0.0	0.128153	-0.00001045	-0.00001045	0.0000000	0.0000000	0.0000000
	2.30000	0.0	0.0622791	-0.00000987	-0.00000987	0.0000000	0.0000000	0.0000000
	2.40000	0.0	0.0533316	-0.00005277	-0.00005277	0.0000000	0.0000000	0.0000000
	2.50000	0.0	0.0149651	-0.00002445	-0.00002445	0.0000000	0.0000000	0.0000000
	2.60000	0.0	0.0732222	-0.00001539	-0.00001539	0.0000000	0.0000000	0.0000000
	2.70000	0.0	0.093360	0.00002319	0.00002319	0.0000000	0.0000000	0.0000000
	2.80000	0.0	0.0339977	-0.00000164	-0.00000164	0.0000000	0.0000000	0.0000000
	2.90000	0.0	0.002702	0.000002047	0.000002047	0.0000000	0.0000000	0.0000000
	3.00000	0.0	0.001708	0.00001645	0.00001645	0.0000000	0.0000000	0.0000000
	3.10000	0.0	0.0415093	0.00005399	0.00005399	0.0000000	0.0000000	0.0000000
	3.20000	0.0	0.0790405	0.0012177	0.0012177	0.0000000	0.0000000	0.0000000
	3.30000	0.0	0.0274008	-0.00000686	-0.00000686	0.0000000	0.0000000	0.0000000
	3.40000	0.0	0.0702995	-0.00001966	-0.00001966	0.0000000	0.0000000	0.0000000
	3.50000	0.0	0.1502445	-0.00002569	-0.00002569	0.0000000	0.0000000	0.0000000
	3.60000	0.0	0.2093067	-0.000020929	-0.000020929	0.0000000	0.0000000	0.0000000
	3.70000	0.0	0.2034236	-0.000017790	-0.000017790	0.0000000	0.0000000	0.0000000
	3.80000	0.0	0.1095595	-0.000015572	-0.000015572	0.0000000	0.0000000	0.0000000
	3.90000	0.0	0.1272952	-0.00004900	-0.00004900	0.0000000	0.0000000	0.0000000
	4.00000	0.0	0.1596860	-0.00005504	-0.00005504	0.0000000	0.0000000	0.0000000
	4.10000	0.0	0.1539747	-0.00002084	-0.00002084	0.0000000	0.0000000	0.0000000
	4.20000	0.0	0.0651903	-0.000016399	-0.000016399	0.0000000	0.0000000	0.0000000
	4.30000	0.0	0.1901170	0.000006611	0.000006611	0.0000000	0.0000000	0.0000000

4. El Centro Earthquake - Response Spectrum

For this example, response spectra for the El Centro earthquake are referenced as SUPPORT ACCELERATIONS for the two story frame of Figure 3. The accelerations versus frequency response spectra for the El Centro earthquake were obtained from the Structural Engineering Handbook (Gaylord 1968). Internal member forces and joint displacements, velocities and accelerations are calculated. The input and computer output follow. Note that results are comparable to the results obtained in the previous example.

Example B.4.: Input

```

STRUDL 'VERIFY' 'EL CENTRO RES SPEC'
UNITS CYCLES
STORE RESPONSE SPECTRA ACCEL VS FREQ 'ELCENRS'
DAMPING 0.0 FACTOR 386.4
.231 .3 .33 .4 .297 .5 .396 .6 .479 .7 .528 .8 .66 .9
.825 1.0 1.32 1.5 1.32 2.0 2.15 2.5 1.42 3.0 2.15 4.0
2.31 5.0 2.90 6.0 2.48 7.0 1.39 8.0 1.16 9.0 .999 10.0
.999 10.3 .9824 15.0 .9324 20.0 .8991 25. .8658 30.0
.8325 34.85
DAMPING .05 FACTOR 386.4
.165 .30 .198 .40 .165 .50 .198 .60 .231 .70 .297 .80
.396 .90 .495 1.0 .528 1.5 .825 2.0 .825 2.5 .825 3.0

```

.957 4.0 .924 5.0 .891 6.0 .792 7.0 .66 8.0

.627 9.0 .528 10.0 .512 10.3 .429 15.0

.396 20.0 .363 25.0 .347 30.0 .3333 34.85

TYPE PLANE FRAME

UNITS FEET

JOINT COORDINATES

1 0. 0. S

2 0. 12.

3 0. 24.

4 20. 24.

5 20. 12.

6 20. 0. S

7 10. 12.

8 10. 241.

MEMBER INCIDENCES

1 1 2

2 2 3

3 6 5

4 5 4

5 3 8

6 8 4

7 2 7

8 7 5

UNITS INCHES

MEMBER PROPERTIES

1 TO 4 PRIS AX 11.8 IZ 517.

5 TO 8 PRIS AX 11.8 IZ 310.

CONSTANTS

E 30.E6 ALL

INERTIA OF JOINT 7 LINEAR X 4.5840

INERTIA OF JOINT 8 LINEAR X 3.3338

DYNAMIC DEGREES OF FREEDOM

JOINTS 7, 8 DISPL X

UNITS KIPS

DYNAMIC LOADING 1 'EL CENTRO RES SPEC'

SUPPORT ACCELERATIONS

TRANSLATION X FILE 'ELCENRS'

INTEGRATE FROM 0.0 TO 6.0 AT .10

DYNAMIC ANALYSIS MODAL

LIST DYNAMIC DISPL VELO ACCEL MAX FORCES ALL

FINISH

 RESULTS OF LATEST ANALYSES

PROBLEM - VERIFICA TITILE - STR EXAMPLE

ACTIVE UNITS INCH KIP RAD DEGF SEC

ACTIVE STRUCTURE TYPE PLANE FRAME

ACTIVE COORDINATE AXES X Y

LOADING - 2 EL CENTRO RES SPEC

MEMBER FORCES

MEMBER	JOINT	RESPONSE TYPE	AXIAL	FORCE-Y SHEAR	SHEAR-Z	TORSIONAL	MOMENT BENDING-Y	BENDING-Z
1	1	RMS ABS SUM	1.3894567 1.4491644	1.3205624 1.4914675				39.9181152 152.3128510
1	2	RMS ABS SUM	1.3894567 1.4491644	1.3205624 1.4914675				50.8911285 62.4584961
2	2	RMS ABS SUM	0.5899072 0.6462211	0.8282670 0.9593056				48.9499664 50.5935364
2	3	RMS ABS SUM	0.5899072 0.6462211	0.8282670 0.9593056				70.7886910 77.5464172
3	6	RMS ABS SUM	1.3894567 1.4491644	1.3205624 1.4914675				39.9181152 152.3128510
3	5	RMS ABS SUM	1.3894567 1.4491644	1.3205624 1.4914675				50.8911285 62.4584961
4	5	RMS ABS SUM	0.5899072 0.6462211	0.8282670 0.9593056				48.9499664 50.5935364
4	4	RMS ABS SUM	0.5899072 0.6462211	0.8282670 0.9593056				70.7886910 77.5464172
5	3	RMS ABS SUM	0.8282319 0.9592697	0.5899074 0.6462213				70.7886910 77.5464172
5	8	RMS ABS SUM	0.8282319 0.9592697	0.5899074 0.6462213				0.0000289 0.0000298
6	8	RMS ABS SUM	0.8282319 0.9592697	0.5899064 0.6462204				0.0000625 0.0000625
6	4	RMS ABS SUM	0.8282319 0.9592697	0.5899064 0.6462204				70.7886910 77.5464172

JOINT	RESULTANT JOINT DISPLACEMENTS- SUPPORTS			DISPLACEMENT			ROTATION		
	RESPONSE TYPE	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.		
1	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		
6	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		

JOINT	RESULTANT JOINT DISPLACEMENTS- FREE JOINTS			DISPLACEMENT			ROTATION		
	RESPONSE TYPE	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.		
2	GLOBAL RMS	0.0911729	0.0003652	0.0000566			0.0000566		
	GLOBAL ABS SUM	0.0539607	0.0005895	0.0000667			0.0000667		
3	GLOBAL RMS	0.1165976	0.0008049	0.0000495			0.0000495		
	GLOBAL ABS SUM	0.1183327	0.0008524	0.0000542			0.0000542		
4	GLOBAL RMS	0.1165976	0.0008049	0.0000495			0.0000495		
	GLOBAL ABS SUM	0.1183327	0.0008524	0.0000542			0.0000542		
5	GLOBAL RMS	0.0511729	0.0003652	0.0000566			0.0000566		
	GLOBAL ABS SUM	0.0539607	0.0005895	0.0000667			0.0000667		
7	GLOBAL RMS	0.0911729	0.0003652	0.0000566			0.0000566		
	GLOBAL ABS SUM	0.0539607	0.0005895	0.0000667			0.0000667		
8	GLOBAL RMS	0.1165976	0.0008049	0.0000495			0.0000495		
	GLOBAL ABS SUM	0.1183327	0.0008524	0.0000542			0.0000542		

JOINT	RESULTANT JOINT VELOCITIES- SUPPORTS			DISPLACEMENT			ROTATION		
	RESPONSE TYPE	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.		
1	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		
6	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		

JOINT	RESULTANT JOINT VELOCITIES- FREE JOINTS			DISPLACEMENT			ROTATION		
	RESPONSE TYPE	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.		
2	GLOBAL RMS	3.3653946	0.0369423	0.0043076			0.0043076		
	GLOBAL ABS SUM	3.9342699	0.0419771	0.0043360			0.0043360		
3	GLOBAL RMS	7.8570934	0.0530832	0.0033570			0.0033570		
	GLOBAL ABS SUM	7.9271421	0.0627085	0.0042598			0.0042598		
4	GLOBAL RMS	7.5540934	0.0530832	0.0033570			0.0033570		
	GLOBAL ABS SUM	7.9271421	0.0627085	0.0042598			0.0042598		
5	GLOBAL RMS	3.3653946	0.0369423	0.0043076			0.0043076		
	GLOBAL ABS SUM	3.9342699	0.0419771	0.0043360			0.0043360		
7	GLOBAL RMS	3.3806009	0.0000000	0.0020910			0.0020910		
	GLOBAL ABS SUM	3.9683556	0.0000000	0.0020910			0.0020910		
8	GLOBAL RMS	7.5723098	0.0000000	0.0015768			0.0015768		
	GLOBAL ABS SUM	7.9556913	0.0000000	0.0020101			0.0020101		

JOINT	RESULTANT JOINT ACCELERATIONS- SUPPORTS			DISPLACEMENT			ROTATION		
	RESPONSE TYPE	X DISP.	Y DISP.	Z DISP.	X ROT.	Y ROT.	Z ROT.		
1	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		
6	GLOBAL RMS	0.0	0.0	0.0			0.0		
	GLOBAL ABS SUM	0.0	0.0	0.0			0.0		

JOINT	RESULTANT JOINT ACCELERATIONS	FREE JOINTS RESPONSE	DISPLACEMENT	ROTATION	Z ROT.
TYPE	X DISP	Y DISP	X ROT	Y ROT	Z ROT
2	GLOBAL RMS	254.3262177	2.6473227		0.2798578
3	GLOBAL ABS SUM	351.4504395	3.5550032		0.2871926
	GLOBAL RMS SUM	495.3508301	4.1020031		0.3139714
4	GLOBAL ABS SUM	572.0124512	5.4711769		0.4429894
	GLOBAL RMS SUM	495.3508301	4.1020031		0.3139714
5	GLOBAL ABS SUM	572.0124512	5.4711769		0.4429894
	GLOBAL RMS SUM	254.3262177	2.6473227		0.2798578
7	GLOBAL ABS SUM	351.4504395	3.5550032		0.2871926
	GLOBAL RMS SUM	257.8217773	0.0000000		0.1346786
8	GLOBAL ABS SUM	496.8911133	0.0000000		0.1398239
	GLOBAL RMS SUM	575.5031738	0.0000000		0.1490811
LTOP					
FINISH					
GOOD-BYE					

V. COMPARATIVE RESULTS OF STRUDL EXAMPLES

A. Example A.1.

In the STRUDL calculation of eigenvalues and eigenvectors for the frame in Example A.1. (see Figure 2) the following assumptions were made: (1) The inertia (mass) of the frame was concentrated at the six joints. That is, half the inertia of member B1 plus half the inertia of member C1 was assumed to be concentrated at joint 1. STRUDL calculated these inertia values. This assumption results from use of the STRUDL command INERTIA OF JOINTS LUMPED (see Section III.A. of this report). (2) All 12 degrees of freedom of the frame were considered in the analysis. These 12 degrees of freedom consisted of translation in the X and Y directions and rotation about the Z axis for each of joints 1, 2, 3 and 4. All degrees of freedom are considered in any STRUDL dynamic analysis unless the user specifies the degrees of freedom by use of the DYNAMIC DEGREES OF FREEDOM command (see Section III.A. of this report).

The result of this assumption was that the frame of Example A.1. has 12 modes of vibration and 12 associated eigenvalues. Results then printed out by STRUDL in this example were the 12 eigenvalues and eigenvectors for the 12 modes. STRUDL results shown in this report are all 12 eigenvalues plus eigenvectors for the first two modes only.

B. Example A.2.

The frame in Example A.2. is the same as the frame of Example A.1. in terms of the geometry, overall dimensions and member properties. However, the structural model used in the STRUDL analysis was different (see Figure 3). In the STRUDL calculation of eigenvalues and eigenvectors for the frame in Example A.2. the assumptions were made that (1) the inertia of the frame was concentrated at joints 7 and 8 only. In this case, half the inertia of members 2 and 4 plus all the inertia of members 5 and 6 was assumed to be concentrated at joint number 8. Calculation of these inertia values was carried out manually. This assumption results from use of the STRUDL command which specifies INERTIA OF JOINTS (see Section III.A. of this report). (2) only two degrees of freedom of the frame were considered in the analysis. These two degrees of freedom were translation in the X direction at each of joints 7 and 8. These degrees of freedom were specified by use of the DYNAMIC DEGREES OF FREEDOM command (see section III.A. of this report).

The result of these two assumptions was that the frame of Example A.2. had two modes of vibration and two associated eigenvalues.

C. Comparison of Results from Examples A.1. and A.2.

The frequencies for Examples A.1. and A.2. are compared in Table 1, below.

TABLE 1
FREQUENCIES
(cycles/second)

Mode Number	Example A.1.	Example A.2.
1	9.99	10.3
2	30.3	34.8

D. Example B.1.

Table 2 below summarizes the maximum internal moments and axial forces in member 1 at joint 1 for the three sinusoidal loading conditions of Example B.1.

TABLE 2
INTERNAL MEMBER FORCES

Sinusoidal Joint Loads	Bending Moment (ft. kips)	Axial Force (kips)
Applied at half the fundamental frequency	1720	16.4
Applied at frequency between fundamental and 2nd	565	7.36
Applied at frequency above 2nd	333	2.3

E. Example B.2.

The dynamic response results printed out by STRUDL in Example B.2. were external forces, displacements, velocities and accelerations for the two degrees of freedom of the structure. Degree of freedom number 1 (DOF 1) refers to joint 8 and degree of freedom number 2 refers to joint 7 of the frame in Figure 3. It should be emphasized that in the NORMAL MODES analysis the force results printed out were external applied forces at the two degrees of freedom (joints 7 and 8). Internal member forces are not available in a NORMAL MODES analysis.

If the results desired by the user are external forces, displacements, velocities and accelerations at the degrees of freedom, then the use of the NORMAL MODES feature results in a computer cost savings. Comparative costs for the Central Florida Regional Data Center computer are \$23.00 when the structure is input by geometry and connectivity, versus \$11.00 for the NORMAL MODES input.

F. Comparison of Results from Examples B.3. and B.4.

Table 3 below compares the maximum internal member forces for Examples B.3. and B.4.

TABLE 3
MAX INTERNAL MEMBER FORCES
(Member 1, Joint 1)

E1 Centro Loading	Bending Moment (inch kips)	Axial Force (kips)
Support Accelerations	140	1.18
Response Spectra	140	1.39

It is seen in Table 3 that the results are comparable for Examples B.3. and B.4. The response spectra values were obtained from the Structural Engineering Handbook (Gaylord 1968, p. 3-5). Results for the response spectra loading condition are thus independent of results for the support accelerations loading condition. Since results are comparable, it is concluded that the E1 Centro earthquake support accelerations stored in STRUDL are correct.

VI. CONCLUDING REMARKS

In conclusion, this paper has presented a detailed examination of the structural dynamic analysis capabilities of the ICES STRUDL II computer program at the Central Florida Regional Data Center. The objective of the paper has been to provide a beginning user with detailed documentation.

The beginning user should first review the "Flow Chart of STRUDL Dynamic Analysis Commands." This flow chart will enable the user to determine which commands are required and a command sequence for his particular dynamics problem.

Documentation of correct commands and examples of commands is provided in section III. The beginning user should review this entire section before attempting to use the program. The subtleties and pitfalls involved in use of the commands are presented in this section. Also presented in this section are "Rules for Use of the STRUDL Dynamics Program," which gives the user a checklist for avoiding trouble.

Section IV of the report presents the actual computer command input and resulting computer output for a number of plane frame example problems. The various STRUDL features are illustrated here and provide the user with solutions which may be useful to him as examples of particular types of problems.

LIST OF REFERENCES

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