RELIABILITY OF FLOORS UNDER IMPACT VIBRATION

by

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ABSTRACT

Floor vibration is a serviceability limit state problem as opposed to limit state of collapse. People find excessive vibrations annoying and it leads to unacceptable floor performance. Improvements in design techniques and use of higher strength materials have made floors lighter and more sensitive to vibrations. The existing code criteria for limiting floor deflection are not satisfactory as they do not relate to human perception of vibrations.

A finite element computer program is developed for a rational analysis of floor vibrations due to human footfall impact. The approach followed in the solution is to use a Fourier series expansion of displacement functions along the span and a finite element approximation in the transverse direction. A time step analysis is followed to obtain the floor's dynamic response at any point on the floor due to footfall impact elsewhere. A sensitivity analysis is done to study the effect of various floor parameters on floor performance.

A reliability study of floor performance as affected by variability of joist stiffness is made by simulation. Floors simulated by randomly selecting joists from a population are analyzed and vibration response ratings are obtained by relating the response to human perception criteria. The probability of people rating the floor as of a certain performance level is predicted. Based on the reliability analysis, allowable spans and allowable deflections for a

certain level of floor performance and a target reliability are proposed.

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1. INTRODUCTION

1.1 THE PROBLEM

Floor vibration is an important serviceability limit state in floor design as people find excessive vibrations annoying. Vibrations caused by impacts due to human footfall is a common source of these vibrations. More efficient design methods and use of higher strength materials tend to make the floors lighter and more sensitive to vibrations. The existing code criteria of limiting static floor deflection are generally not satisfactory because they are not related to the vibration of the floor which the person feels. Hence there exists a need for a systematic study of the floor vibrations caused by footfall impacts and to establish a design criterion for acceptable floor performance. We need to focus our attention on the following aspects of the problem:

- What is the peak displacement and frequency of the vibrations which a person senses as footfall impact is applied to the floor by another person;
- How do various floor parameters affect the floor's dynamic response;
- How to classify the floor's response as satisfactory or disturbing as perceived by human beings;
- What design criteria to employ to ensure acceptable floor performance;

1.2 BACKGROUND AND PREVIOUS RESEARCH

Floor structures have traditionally been designed with respect to static load carrying capacity. The stiffness requirement has usually been expressed in terms of midspan deflection given as a fraction of actual span length. A more rational analysis of the performance of floor systems has been made possible with the development of the finite element method. Two excellent works which employ this sophisticated technique to analyze timber floors are quoted here.

The first one by Thompson, Goodman and Vanderbilt {13} describes a finite element method for the analysis of layered wood systems. The method includes the effects of slip between layers due to fastener deformations, orthotropic material properties and gaps in layers. For the purposes of the finite element analysis, the floor is idealized as a set of crossing beams. The beams in the direction of the joists consist of the joist plus the composite flange of one or more layers of sheathing, equal in width to the joist spacing. The beams in the perpendicular direction consist of sheathing strips of one or more layers of arbitrary width. The T-beams and sheathing strips are subdivided into finite elements and their deformations are matched at points of intersection. The torsional stiffness of T-beams and sheathing is neglected. Based upon the above described model, a computer program FEAFL0 {14} was developed by Thompson et al. which can

analyze wood floors subjected to any pattern of loading perpendicular to the face of the sheathing.

The second and more recent paper is by Foschi {7} where a combined Fourier series and finite element analysis of wood floors is discussed. The method includes the lateral and torsional deformation of joists as degrees of freedom. For the purposes of analysis, the floor is idealized as consisting of T-beam finite elements. Each element consists of the joists and the sheathing strip equal in width to the spacing of the joists. Along the direction of the span of the joists a Fourier series approximation is employed. Thus the floor needs to be broken up into finite elements only in the transverse direction, making the model suitable for a computer with small core memory. Based on the above described model a computer program FAP (Floor Analysis Program) was developed and efficiently implemented in a PDP 11/60 minicomputer. The FAP program does a static analysis of a floor system. As will be described in this thesis, this program has been modified to carry out a dynamic analysis of floors.

Human response to vibrations is very subjective and difficult to generalize. A substantial amount of experimental research has been done in this area and the pertinent contributions are quoted here. One of the early works is by Reiher and Meister {12}. In their work, human subjects were subjected to steady state vertical vibrations and were asked to classify vibrations in one of the

following categories: (1) Slightly Perceptible; (2) Distinctly Perceptible; (3) Strongly Perceptible; (4) Disturbing; and (5) Very Disturbing. Plots of peak displacement versus frequency were made and the above mentioned regions identified. However, it was found by Allen and Rainer {1} that transient vibrations caused by footsteps are less annoying than continuous vibrations. Ohlsson {8} experimentally evaluated the human footfall loading. He studied the human response to floor vibrations and suggested design criteria based upon modal parameters like eigenfrequencies, modal masses and damping. In an another paper published by Allen and Rainer {2} on the vibration of long span floors, a heel impact test was used for evaluating floor performance. They presented an annoyance criterion for floor vibration in terms of floor acceleration and damping. They concluded that damping is effective in reducing annoying walking vibrations. Polensek {10} has studied the human response to vibration of wood-joist floor systems. He used a rating scale more or less on the same lines as Reiher and Meister and investigated the vibration caused by an impact of a 70 pound steel weight dropped onto floor centroid. Plots of maximum deflection versus frequency were made and smooth curves represented by mathematical equations were predicted. Atherton, Polensek and Corder {3} found that amplitude was the best indicator of human response, but recommended that a variable containing amplitude, damping and frequency would be more appropriate for predicting human

response to floor vibrations. Wiss and Parmelee {15} studied experimentally the human response to transient vertical vibrations in terms of their frequency, maximum displacement and damping. They assumed approximately the same rating scale as used by Reiher and Meister but assigned numerical values to the ratings to incorporate those into the analysis. For each rating value plots of the product of frequency and amplitude (FA) versus damping coefficient (D) were made on a log-log plot. A regression analysis was also carried out on the experimental data and a mathematical equation predicting rating as a function of amplitude, frequency and damping was suggested. In this thesis, these plots and equations are used, as will be described fully in subsequent chapters.

1.3 OBJECTIVE AND CONTENT OF THE THESIS

The aim of the work presented in this thesis is to develop a rational analytical method for analyzing floor vibrations due to impact. It was found by Onysko {9} that the present deflection criterion based on deflection caused by uniform loading does not adequately identify "good" from "poor" floor performance. An attempt is made here to establish a design criterion for satisfactory floor performance as perceived by human beings.

The specific problem on which we focus our attention in this work is shown in Fig. (1.1), a floor in static equilibrium under dead and live loads. The live load could

be people occupying the floor. We are interested in the vibration felt by a person(identified hereafter as "receiver") at point 1 of the floor when some other person(identified hereafter as "impacter") applies a footfall impact at point 2 of the floor. Stated otherwise, we wish to estimate the floor's dynamic response(displacement, velocity and acceleration) at point 1 due to impact at point 2. A finite element computer program is developed here for this purpose. This is a modified version of the Floor Analysis Program (FAP) as developed by Foschi [7]. This program does a time step analysis and is capable of predicting the dynamic response at any point on the floor due to an impact at some other point. The program is also used for a sensitivity analysis of the effect of

Fig. 1.1. Problem of interest

various floor parameters on floor vibration response. A multiple linear regression analysis is also done and a prediction equation for estimation of peak displacement in terms of maximum static displacement is suggested.

To predict floor performance determined by human perception of vibration, Wiss and Parmelee's relation between rating, frequency, amplitude and damping is assumed. The effect of variability in modulus of elasticity for a population of joists on the floor's response is studied by simulation and the distribution of the response ratings is established for the population of simulated floors. The results are used to estimate the reliability that the floor would fall into a particular rating category. Finally, a design criterion is established for obtaining allowable spans corresponding to a target reliability.

2. THEORETICAL FORMULATION

2.1 THE MODEL

The type of floor considered is shown in Fig. (2.1). The floor cover (sheathing) is assumed fastened (nailed) to the wood joists to produce an assembly capable of composite action and behaving under load as a stiffened plate. The floor cover may have gaps across the span. However, in this work no gaps are considered. Although the program developed here would be suitable for wood floors, it can also be used for concrete or steel floors by making minor modifications.

Fig. 2.1. Floor Assembly

In general, it is assumed that the cover has different elastic properties in the directions parallel and perpendicular to the joists and is considered as an orthotropic plate for the purposes of the analysis. The

floor is modelled as consisting of T-beam finite elements in the Y-direction as shown in Fig. (2.1). The nodes considered for each finite element are shown in Fig. (2.2). The deformations of the plate in the Y-direction are approximated by a finite element approach and matched at nodes 1 and 3 as shown in Fig. (2.2). In the longitudinal direction (X-direction) a Fourier Series approximation is employed.

Fig. 2.2. Nodes for T-beam Finite Element

Using the model, the deflections of the plate and the joists can be expressed as:

Plate Displacements(middle surface):

$$\text{Vertical Displacement: } w(x, y) = \sum_{n=1}^N F_{1n}(y) \sin\left(\frac{n\pi x}{L}\right) \quad (2.1a)$$

(z-direction)

$$\text{Axial Displacement : } u(x, y) = \sum_{n=1}^N F_{2n}(y) \cos\left(\frac{n\pi x}{L}\right) \quad (2.1b)$$

(x-direction)

$$\text{Lateral Displacement : } v(x, y) = \sum_{n=1}^N F_{3n}(y) \sin\left(\frac{n\pi x}{L}\right) \quad (2.1c)$$

(y-direction)

where, N is the number of terms in the Fourier Series considered to approximate the displacement.

Since $w=v=0$ at $x=0$ & $x=L$, the assumed functions imply simply

supported boundary conditions at ends. The functions $F_{1n}(y)$, $F_{2n}(y)$ and $F_{3n}(y)$ are determined from a finite element polynomial approximation in Y-direction. These functions are expressed in terms of the nodal degrees of freedom at points 1, 2, 3 and 4 shown in Fig. (2.2).

Joist Displacements:

The displacement functions for joists are expressed as follows:

$$\text{Vertical Displacement: } W(x) = \sum_{n=1}^N W_n \sin\left(\frac{n\pi x}{L}\right) \quad (2.2a)$$

(z-direction)

$$\text{Axial Displacement : } U(x) = \sum_{n=1}^N U_n \cos\left(\frac{n\pi x}{L}\right) \quad (2.2b)$$

(x-direction)

$$\text{Lateral Displacement : } V(x) = \sum_{n=1}^N V_n \sin\left(\frac{n\pi x}{L}\right) \quad (2.2c)$$

(y-direction)

$$\text{Rotation : } \theta(x) = \sum_{n=1}^N \theta_n \sin\left(\frac{n\pi x}{L}\right) \quad (2.2d)$$

where W_n , U_n , V_n and θ_n are joist degrees of freedom as shown in Fig. (2.3).

Fig. 2.3. Joist degrees of freedom

For each element as shown in Fig. (2.2), a total of 19 degrees of freedom are identified associated with each

n(term in Fourier series). The elemental nodal degree of freedom vector is expressed by Eq. (2.3).

$$\{\delta_n\} = \begin{bmatrix} w_{1n} \\ w'_{1n} \cdot s \\ u_{1n} \\ u'_{1n} \cdot s \\ v_{1n} \\ v'_{1n} \cdot s \\ u_{2n} \\ v_{2n} \\ w'_{2n} \cdot s \\ w_n \\ U_n \\ V_n \\ \theta_n \cdot s \\ w_{3n} \\ w'_{3n} \cdot s \\ u_{3n} \\ u'_{3n} \cdot s \\ v_{3n} \\ v'_{3n} \cdot s \end{bmatrix} \quad (2.3)$$

There are six degrees of freedom each at nodes 1 and 3, three at node 2 and four at node 4. For example, $w'_{1n} \cdot s$ = the component denoting the derivative of $w(x,y)$ with respect to $y(')$ at node 1, multiplied by the joist spacing "s", to make it dimensionally uniform.

Using the shape functions shown in Appendix I, and the nondimensional variable $\xi=2y/s$, the functions $F_{1n}(y)$, $F_{2n}(y)$ and $F_{3n}(y)$ can be written in terms of $\{\delta_n\}$:

$$F_{1n}(\xi) = \{M_0(\xi)\}^T \{\delta_n\} \quad (2.4a)$$

$$F_{2n}(\xi) = \{M_3(\xi)\}^T \{\delta_n\} \quad (2.4b)$$

$$F_{3n}(\xi) = \{M_5(\xi)\}^T \{\delta_n\} \quad (2.4c)$$

Furthermore, these equations permit us to obtain the following derivatives:

$$\frac{dF_{1n}(\xi)}{d\xi} = \{M_1(\xi)\}^T \{\delta_n\} \quad (2.5a)$$

$$\frac{d^2F_{1n}(\xi)}{d\xi^2} = \{M_2(\xi)\}^T \{\delta_n\} \quad (2.5b)$$

$$\frac{dF_{2n}(\xi)}{d\xi} = \{M_4(\xi)\}^T \{\delta_n\} \quad (2.5c)$$

$$\frac{dF_{3n}(\xi)}{d\xi} = \{M_6(\xi)\}^T \{\delta_n\} \quad (2.5d)$$

Thus with the displacement functions defined, the strain energy, kinetic energy and the dissipative energy can be computed and system matrices can be derived as explained in next section.

2.2 FORMULATION OF THE EQUATIONS OF MOTION

In order to formulate the equations of motion for the floor system, the **Variational Approach** is employed. This approach makes use of scalar energy quantities in a variational form. This process avoids establishing the vectorial equations of equilibrium which becomes very complex here. Moreover, as opposed to virtual work analysis no direct use of the inertial or elastic forces acting on the system is made. The effects of these forces are represented instead by the variations of the kinetic and potential energy of the system. The most generally applicable variational concept is **Hamilton's Principle**, which states that the variation of the kinetic and potential energy plus the variation of the work done by the nonconservative forces considered during any time interval t_1 to t_2 must equal zero. Mathematically, the principle is expressed as:

$$\int_{t_1}^{t_2} \delta(T-V)dt + \int_{t_1}^{t_2} \delta W_{nc} dt = 0 \quad (2.6)$$

where: T =total kinetic energy of the system

V =potential energy of the system, including
both strain energy and potential of any
conservative external forces.

W_{nc} =work done by nonconservative forces
acting on system, including damping and
any arbitrary external loads.

δ =variation taken during indicated time interval.

For the floor system we are dealing with, the kinetic energy can be expressed in terms of the generalized coordinates and their first time derivatives, and the potential energy can be expressed in terms of the generalized coordinates alone. In addition, the virtual work which is performed by the nonconservative forces as they act through the virtual displacements caused by an arbitrary set of variations in the generalized coordinates can be expressed as a linear function of those variations. In mathematical terms, we can write

$$T = T(q_1, q_2, \dots, q_n, \dot{q}_1, \dot{q}_2, \dots, \dot{q}_n) \quad (2.7a)$$

$$V = V(q_1, q_2, \dots, q_n) \quad (2.7b)$$

$$\delta W_{nc} = Q_1 \delta q_1 + Q_2 \delta q_2 + \dots + Q_n \delta q_n \quad (2.7c)$$

where the coefficients $Q_1, Q_2, \dots, Q_n$ are the generalized forcing functions corresponding to the generalized coordinates $q_1, q_2, \dots, q_n$ respectively.

Introducing Eq. (2.7) into Hamilton's Principle (Eq. 2.6) and carrying out the mathematics leads to the well known Lagrange's Equation Of Motion which is expressed as

$$\frac{\partial}{\partial t} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i \quad (2.8)$$

In the above equation Q_i includes contribution from external forces as well as damping forces ie.

$$Q_i = Q_{ie} + Q_{id}$$

The Q_{id} part of Q_i can be computed by using Raleigh's Dissipative Function (D) and is expressed as

$$Q_{id} = - \frac{\partial D}{\partial \dot{q}_i} \quad (2.9)$$

Using Eq. (2.9) we get the following convenient form of Lagrange's equation of motion:

$$\frac{\partial}{\partial t} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} + \frac{\partial D}{\partial \dot{q}_i} = Q_{ie} \quad (2.10)$$

where: Q_{ie} = external generalized forces acting on the system.

$D = W_d/2$, W_d being the work done by dissipative forces per unit time.

For the floor system, which is modelled by finite elements, nodal degrees of freedom as given by Eq. (2.3) replace the generalized coordinates q_i and the nodal forces replace the generalized forces Q_i . On substituting the kinetic energy, potential energy and dissipative energy of the structure into Eq. (2.10) we directly obtain the equation of motion of the system expressed as:

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = \{R\} \quad (2.11)$$

where: $[M]$ =global mass matrix;

$[C]$ =global damping matrix;

$[K]$ =global stiffness matrix;

$\{R\}$ =global nodal force vector;

$\{X\}$ =global nodal displacement vector;

$\{\dot{X}\}$ =global nodal velocity vector; "'' denoting the differentiation with respect to time;

$\{\ddot{X}\}$ =global nodal acceleration vector;

The system matrices and vectors as defined above are obtained by assembling the matrices and vectors of each finite element, as shown in detail in the following sections.

2.2.1 DERIVATION OF STIFFNESS MATRIX

The stiffness matrix is obtained from the total strain energy of the system. In order to obtain the total strain energy, we have to consider contributions from the various components of the floor system ie. the plate, joists and the connectors between the joists and the plate.

Strain Energy in the Plate: As the floor is being modelled by finite elements, we consider here strain energy in the flange of one T-beam element. This will lead to the stiffness matrix of one finite element. The total system stiffness matrix can be obtained by assembling all the element stiffness matrices.

Using small deflection orthotropic plate theory, the strain energy of the flange per unit area can be expressed as:

$$\begin{aligned}
\Delta U_f = & \frac{K_x}{2} \left(\frac{\partial^2 w}{\partial x^2} \right)^2 + \frac{K_y}{2} \left(\frac{\partial^2 w}{\partial y^2} \right)^2 + K_\nu \frac{\partial^2 w}{\partial x^2} \frac{\partial^2 w}{\partial y^2} \\
& + 2K_G \left(\frac{\partial^2 w}{\partial x \partial y} \right)^2 + \frac{D_x}{2} \left(\frac{\partial u}{\partial x} \right)^2 + \frac{D_y}{2} \left(\frac{\partial v}{\partial y} \right)^2 \\
& + D_\nu \frac{\partial u}{\partial x} \frac{\partial v}{\partial y} + \frac{D_G}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2
\end{aligned} \tag{2.12}$$

where:

$$\begin{aligned}
K_x &= \text{flexural stiffness in x-direction} \\
&= \frac{E_x d^3}{12(1-\nu_{xy}\nu_{yx})}
\end{aligned}$$

$$K_y = \text{flexural stiffness in y-direction} = K_x (E_y/E_x)$$

$$K_\nu = \text{coefficient associated with Poisson's ratio} = \nu_{xy} K_x$$

$$K_G = \text{torsional stiffness} = Gd^3/12$$

$$\begin{aligned}
D_x &= \text{axial stiffness in x-direction} \\
&= \frac{E_x d}{(1-\nu_{xy}\nu_{yx})}
\end{aligned}$$

$$D_y = \text{axial stiffness in y-direction} = D_x (E_y/E_x)$$

$$D_\nu = \text{coefficient associated with Poisson's ratio} = \nu_{xy} D_x$$

$$D_G = \text{in plane shear stiffness} = Gd$$

and E_x = modulus of elasticity in x-direction; E_y = modulus of elasticity in y-direction; ν_{xy} = Poisson's ratio, strain in x-direction when stress is applied in

y-direction; ν_{yx} = Poisson's ratio, strain in y-direction when stress is applied in x-direction; and G = shear modulus in x-y plane.

The total strain energy in the flange can be obtained by integrating over the area as shown in Fig. (2.4) Thus, the flange strain energy is expressed as:

$$U_f = \int_{-s/2}^{s/2} \int_0^L \Delta U_f \, dx dy \quad (2.13)$$

On substituting the expressions for displacements as given by Eq. (2.1) into Eq. (2.12) and integrating over span length, we obtain for each term

$$\int_0^L \frac{K_x}{2} \left(\frac{\partial^2 w}{\partial x^2} \right)^2 dx = \frac{K_x}{2} \sum_{n=1}^N F_{1n}^2(y) \frac{n^4 \pi^4}{2L^3} \quad (2.14a)$$

$$\int_0^L \frac{K_y}{2} \left(\frac{\partial^2 w}{\partial y^2} \right)^2 dx = \frac{K_y}{2} \sum_{n=1}^N (F_{1n}''(y))^2 \left(\frac{L}{2} \right) \quad (2.14b)$$

Fig. 2.4. Flange Area of Finite Element

$$\int_0^L K_\nu \frac{\partial^2 w}{\partial x^2} \frac{\partial^2 w}{\partial y^2} dx = -K_\nu \sum_{n=1}^N F_{1n}(y) F_{1n}''(y) \frac{n^2 \pi^2}{2L} \quad (2.14c)$$

$$2K_G \int_0^L \left(\frac{\partial^2 w}{\partial x \partial y} \right)^2 dx = 2K_G \sum_{n=1}^N (F_{1n}'(y))^2 \frac{n^2 \pi^2}{2L} \quad (2.14d)$$

$$\int_0^L \frac{D_x}{2} \left(\frac{\partial u}{\partial x} \right)^2 dx = \frac{D_x}{2} \sum_{n=1}^N (F_{2n}(y))^2 \frac{n^2 \pi^2}{2L} \quad (2.14e)$$

$$\int_0^L \frac{D_y}{2} \left(\frac{\partial v}{\partial y} \right)^2 dx = \frac{D_y}{2} \sum_{n=1}^N (F_{3n}'(y))^2 \left(\frac{L}{2} \right) \quad (2.14f)$$

$$\int_0^L D_\nu \left(\frac{\partial u}{\partial x} \right) \left(\frac{\partial v}{\partial y} \right) dx = -D_\nu \sum_{n=1}^N F_{2n}(y) F_{3n}'(y) \frac{n\pi}{2} \quad (2.14g)$$

$$\int_0^L \frac{D_G}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2 dx = \frac{D_G}{2} \sum_{n=1}^N [F_{2n}'(y) + \frac{n\pi}{L} F_{3n}(y)]^2 \frac{L}{2} \quad (2.14h)$$

In order to obtain the strain energy in the flange of one element we substitute the expressions for functions $F_{1n}(y)$, $F_{2n}(y)$ and $F_{3n}(y)$ and their derivatives as given by Eq. (2.4) and (2.5) into Eq. (2.14), integrate over joist spacing, and we get

$$U_{f1} = \sum_{n=1}^N \frac{K_x}{2} \frac{n^4 \pi^4}{4L^3} \frac{1}{s-1} \int \{\delta_n\}^T \{M_0(\xi)\} \{M_0(\xi)\}^T \{\delta_n\} d\xi \quad (2.15a)$$

$$U_{f2} = \sum_{n=1}^N \frac{K_y}{2} \frac{4L}{s^3-1} \int \{\delta_n\}^T \{M_2(\xi)\} \{M_2(\xi)\}^T \{\delta_n\} d\xi \quad (2.15b)$$

$$U_{f3} = \sum_{n=1}^N \left(-\frac{K_\nu}{2} \right) \frac{2n^2 \pi^2}{Ls} \int \{\delta_n\}^T \{M_0(\xi)\} \{M_2(\xi)\}^T \{\delta_n\} d\xi \quad (2.15c)$$

$$U_{f4} = \sum_{n=1}^N 2K_G \frac{n^2 \pi^2}{Ls} \int \{\delta_n\}^T \{M_1(\xi)\} \{M_1(\xi)\}^T \{\delta_n\} d\xi \quad (2.15d)$$

$$U_{f5} = \sum_{n=1}^N \frac{D_x}{2} \frac{n^2 \pi^2 s}{4L} \int \{\delta_n\}^T \{M_3(\xi)\} \{M_3(\xi)\}^T \{\delta_n\} d\xi$$

(2.15e)

$$U_{f6} = \sum_{n=1}^N \frac{D}{2} \frac{L}{S} \int_{-1}^1 \{\delta_n\}^T \{M_6(\xi)\} \{M_6(\xi)\}^T \{\delta_n\} d\xi$$

(2.15f)

$$U_{f7} = \sum_{n=1}^N (-D \nu \frac{n\pi}{2}) \int_{-1}^1 \{\delta_n\}^T \{M_3(\xi)\} \{M_6(\xi)\}^T \{\delta_n\} d\xi$$

(2.15g)

$$U_{f8} = \sum_{n=1}^N \frac{D}{12} \frac{L}{S} \int_{-1}^1 \{\delta_n\}^T \left(\frac{2}{S} \{M_4(\xi)\} + \frac{n\pi}{L} \{M_5(\xi)\} \right) \left(\frac{2}{S} \{M_4(\xi)\}^T + \frac{n\pi}{L} \{M_5(\xi)\}^T \right) \{\delta_n\} d\xi$$

(2.15h)

Thus strain energy in the flange of one element is:

$$U_f = U_{f1} + U_{f2} + U_{f3} + U_{f4} + U_{f5} + U_{f6} + U_{f7} + U_{f8} \quad (2.16)$$

Strain Energy in the Joist: Strain energy in the joist consists of two flexural components (one being the bending in vertical plane and other lateral bending), an axial component and a torsional component. The strain energy is expressed as

$$U_j = \frac{EI_y}{2} \int_0^L \left(\frac{d^2W}{dx^2} \right)^2 dx + \frac{EI_z}{2} \int_0^L \left(\frac{d^2V}{dx^2} \right)^2 dx + \frac{EA}{2} \int_0^L \left(\frac{dU}{dx} \right)^2 dx + \frac{GI_t}{2} \int_0^L \left(\frac{d\theta}{dx} \right)^2 dx \quad (2.17)$$

where: $I_y = (BH^3)/12$; $I_z = (HB^3)/12$;

$A = BH$;

$I_t = \beta(H/B)HB^3$;

and "B" being the joist width, "H" the joist depth and " β " the torsional constant.

Using the expressions for $W(x)$, $U(x)$, $V(x)$ and $\theta(x)$ as given by Eq. (2.2) we obtain for strain energy in the joist as:

$$U_j = \frac{EI_y}{2} \sum_{n=1}^N W_n^2 \frac{n^4 \pi^4}{2L^3} + \frac{EI_z}{2} \sum_{n=1}^N V_n^2 \frac{n^4 \pi^4}{2L^3} + \frac{EA}{2} \sum_{n=1}^N U_n^2 \frac{n^2 \pi^2}{2L} + \frac{GI_t}{2} \sum_{n=1}^N \theta_n^2 \frac{n^2 \pi^2}{2L} \quad (2.18)$$

Strain Energy in the Connectors: It is assumed here, that plate is connected to the joists by uniformly spaced nails along the centreline of the top surface of the joist. The model assumes three types of slips between the plate and the joist which can be expressed as:

$$\text{Slip parallel to the joist} = \Delta u = \left[u_0 - \frac{d}{2} \left(\frac{dw}{dx} \right) \right] - \left[U + \frac{H}{2} \left(\frac{dw}{dx} \right) \right] \quad (2.19a)$$

$$\text{Slip perpendicular to the joist} = \Delta v = \left[v_0 - \frac{d}{2} \left(\frac{\partial w_0}{\partial y} \right) \right] - \left[V + \frac{H}{2} \theta \right] \quad (2.19b)$$

$$\text{Rotational slip} = \phi = \frac{\partial w_0}{\partial y} - \theta \quad (2.19c)$$

where d =the cover thickness; and the displacements u_0 , v_0 and w_0 correspond to the point in the plate's middle plane directly over the joist, as shown in Fig. (2.1). In the above Eq. (2.19) it has been assumed that the

vertical displacement of the plate, w_0 , and the displacement, W , of the joist are identical. If we assume that K_{nx} , K_{ny} represent the stiffness for the slips in x and y -direction respectively, and $K_{n\theta}$ represents the stiffness for the rotational slip, converting the discrete nailing pattern into a continuous connector, the strain energy can be expressed as:

$$U_c = \frac{K_{nx}}{2e} \int_0^L (\Delta u)^2 dx + \frac{K_{ny}}{2e} \int_0^L (\Delta v)^2 dx + \frac{K_{n\theta}}{2e} \int_0^L \phi^2 dx \quad (2.20)$$

where e is the nail spacing.

On substituting the expressions for plate and joist displacements from Eq. (2.1) and (2.2) we obtain:

$$U_c = \sum_{n=1}^N \left\{ \frac{L}{2} \frac{K_{nx}}{2e} \left[F_{2n}(\xi=0) - U_n - W_n \frac{n\pi}{2L} (H+d) \right]^2 + \frac{L}{2} \frac{K_{ny}}{2e} \left[F_{3n}(\xi=0) - V_n - \theta_n \left(\frac{H}{2} + \frac{d}{2} \right) \right]^2 + \frac{L}{2} \frac{K_{n\theta}}{2e} \left[w'_{2n} - \theta_n \right]^2 \right\} \quad (2.21)$$

Now we can express scalar nodal degrees of freedom in the above Eq. (2.21) in terms of the vector $\{\delta_n\}$ as given in the Eq. (2.3). We define the following (19×1) vectors:

$\{e_7\}^T = (0 \ 0 \ \dots 1 \dots 0 \ 0)$, the seventh element is unity.

$\{e_8\}^T = (0 \ 0 \ \dots 1 \dots 0 \ 0)$, the eighth element is unity.

Similarly vectors $\{e_1\}, \{e_2\}, \dots, \{e_{13}\}$ are defined.

Thus we get strain energy in the connectors as:

$$\begin{aligned}
 U_c = \sum_{n=1}^N \{ & \frac{L}{2} \frac{K_{nx}}{2e} \{\delta_n\}^T \begin{bmatrix} e_7 - e_{11} - e_{10} \frac{n\pi}{2L} (H+d) \\ e_7 - e_{11} - e_{10} \frac{n\pi}{2L} (H+d) \end{bmatrix}^T \{\delta_n\} \\
 & + \frac{L}{2} \frac{K_{ny}}{2e} \{\delta_n\}^T \begin{bmatrix} e_8 - e_{12} - e_{13} \frac{H}{2s} - e_9 \frac{d}{2s} \\ e_8 - e_{12} - e_{13} \frac{H}{2s} - e_9 \frac{d}{2s} \end{bmatrix}^T \{\delta_n\} \\
 & + \frac{L}{2} \frac{K_{n\theta}}{2e} \{\delta_n\}^T \begin{bmatrix} \frac{e_9}{s} - \frac{e_{13}}{s} \end{bmatrix} \begin{bmatrix} \frac{e_9}{s} - \frac{e_{13}}{s} \end{bmatrix}^T \{\delta_n\} \} \\
 & \quad \quad \quad (2.22)
 \end{aligned}$$

The Total strain energy in one T-beam element is given by

$$U(n) = U_f(n) + U_j(n) + U_c(n) \quad (2.23)$$

On taking the first variation of $U(n)$ with respect to $\{\delta_n\}$ we get expression of the form $[K_{ne}]\{\delta_n\}$ in which $[K_{ne}]$ is the element stiffness matrix of size (19×19) . The global stiffness matrix is obtained by assembling the stiffness matrices of each element. By considering the variation of U w.r.t different $\{\delta_n\}$ global stiffness matrix can be obtained for each term in the Fourier series.

2.2.2 DERIVATION OF MASS MATRIX

A consistent mass matrix is obtained from the total kinetic energy of the system. The total kinetic energy consists of contributions from the plate and the joists. Kinetic energy in Plate: The velocity components of any plate particle can be expressed as:

$$\dot{u}_p = \dot{u} - z \left(\frac{\partial \dot{w}}{\partial x} \right) \quad (2.24a)$$

$$\dot{v}_p = \dot{v} - z \left(\frac{\partial \dot{w}}{\partial y} \right) \quad (2.24b)$$

$$\dot{w}_p = \dot{w} \quad (2.24c)$$

where $\dot{u}_p, \dot{v}_p$ and $\dot{w}_p$ are the velocity components at any point z below the middle surface of the plate. Thus the kinetic energy of the plate is given by

$$T_p = \frac{\rho_p}{2} \int_V (\dot{u}_p^2 + \dot{v}_p^2 + \dot{w}_p^2) dV \quad (2.25)$$

in which ρ_p is the mass density of the plate. On substituting the expressions given by Eq. (2.24) we obtain

$$\begin{aligned} T_p = & \rho_p \frac{d}{2} \int_{-s/2}^{s/2} \int_0^L (\dot{u}^2 + \dot{v}^2 + \dot{w}^2) dx dy \\ & + \frac{\rho_p}{2} \frac{d^3}{12} \int_{-s/2}^{s/2} \int_0^L \left[\left(\frac{\partial \dot{w}}{\partial x} \right)^2 + \left(\frac{\partial \dot{w}}{\partial y} \right)^2 \right] dx dy \end{aligned} \quad (2.26)$$

in which d is the plate thickness, s is the joist spacing and L is the span of the floor.

Now using Eq. (2.1), (2.4) and (2.5) we obtain:

$$\begin{aligned}
 T_p = \sum_{n=1}^N \{ & \frac{\rho_p}{2} h \frac{L}{2} \frac{s}{2} \int_{-1}^1 \{\dot{\delta}_n\}^T \{M_3(\xi)\} \{M_3(\xi)\}^T \{\dot{\delta}_n\} d\xi \\
 & + \frac{\rho_p}{2} h \frac{L}{2} \frac{s}{2} \int_{-1}^1 \{\dot{\delta}_n\}^T \{M_5(\xi)\} \{M_5(\xi)\}^T \{\dot{\delta}_n\} d\xi \\
 & + \frac{\rho_p}{2} h \frac{L}{2} \frac{s}{2} \int_{-1}^1 \{\dot{\delta}_n\}^T \{M_0(\xi)\} \{M_0(\xi)\}^T \{\dot{\delta}_n\} d\xi \\
 & + \frac{\rho_p}{2} \frac{d^3}{12} \frac{L}{2} \frac{n^2 \pi^2}{L^2} \frac{s}{2} \int_{-1}^1 \{\dot{\delta}_n\}^T \{M_0(\xi)\} \{M_0(\xi)\}^T \{\dot{\delta}_n\} d\xi \\
 & + \frac{\rho_p}{2} \frac{d^3}{12} \frac{L}{2} \frac{4}{s^2} \frac{s}{2} \int_{-1}^1 \{\dot{\delta}_n\}^T \{M_1(\xi)\} \{M_1(\xi)\}^T \{\dot{\delta}_n\} d\xi \} \\
 & \quad (2.27)
 \end{aligned}$$

Kinetic Energy in the Joist: The velocity components of any joist particle as shown in Fig. (2.5) can be expressed as:

$$\dot{u}_b = \dot{U} - z \frac{d\dot{W}}{dx} - y \frac{d\dot{V}}{dx} \quad (2.28a)$$

$$\dot{v}_b = \dot{V} + \dot{\theta} r \cos \alpha = \dot{V} - \dot{\theta} z \quad (2.28b)$$

$$\dot{w}_b = \dot{W} + \dot{\theta} r \sin \alpha = \dot{W} + \dot{\theta} y \quad (2.28c)$$

Thus the kinetic energy of the joist is given by

$$T_j = \frac{\rho_j}{2} \int_V (\dot{u}_b^2 + \dot{v}_b^2 + \dot{w}_b^2) dV \quad (2.29)$$

in which ρ_j is the mass density of the joist. Using Eq.

Fig. 2.5. Velocity Components of Joist Particle

(2.2) and (2.28) we obtain

$$\begin{aligned}
 T_j = & \frac{\rho_j}{2} BH \frac{L}{2} \sum_{n=1}^N (\dot{U}_n^2 + \dot{V}_n^2 + \dot{W}_n^2) \\
 & + \frac{\rho_j}{2} \frac{BH^3}{12} \frac{L}{2} \sum_{n=1}^N (\frac{n^2 \pi^2}{L^2} \dot{W}_n^2 + \dot{\theta}_n^2) \\
 & + \frac{\rho_j}{2} \frac{HB^3}{12} \frac{L}{2} \sum_{n=1}^N (\frac{n^2 \pi^2}{L^2} \dot{V}_n^2 + \dot{\theta}_n^2) \quad (2.30)
 \end{aligned}$$

Using the vectors $\{e_1\}$, $\{e_2\}$ $\{e_{13}\}$ as defined

before the kinetic energy in the joist can be expressed as:

$$\begin{aligned}
 T_j = & \frac{\rho_j}{2} BH \frac{L}{2} \sum_{n=1}^N \{ (\{\dot{\delta}_n\}^T e_{11} e_{11}^T \{\dot{\delta}_n\}) \\
 & + (\{\dot{\delta}_n\}^T e_{12} e_{12}^T \{\dot{\delta}_n\}) \\
 & + (\{\dot{\delta}_n\}^T e_{10} e_{10}^T \{\dot{\delta}_n\}) \} \\
 & + \frac{\rho_j}{2} \frac{BH^3}{12} \frac{L}{2} \sum_{n=1}^N \{ \frac{n^2 \pi^2}{L^2} (\{\dot{\delta}_n\}^T e_{10} e_{10}^T \{\dot{\delta}_n\}) \\
 & + (\{\dot{\delta}_n\}^T e_{13} e_{13}^T \{\dot{\delta}_n\}) \} \\
 & + \frac{\rho_j}{2} \frac{HB^3}{12} \frac{L}{2} \sum_{n=1}^N \{ \frac{n^2 \pi^2}{L^2} (\{\dot{\delta}_n\}^T e_{12} e_{12}^T \{\dot{\delta}_n\}) \\
 & + (\{\dot{\delta}_n\}^T e_{13} e_{13}^T \{\dot{\delta}_n\}) \} \quad (2.31)
 \end{aligned}$$

The total kinetic energy in one T-beam element is given by:

$$T(n) = T_p + T_j \quad (2.32)$$

The kinetic energy is only a function of $\{\dot{\delta}_n\}$ and therefore the term $\frac{\partial T}{\partial q_i}$ in Eq. (2.10) vanishes and the term $\frac{\partial}{\partial t} \left(\frac{\partial T}{\partial \dot{q}_i} \right)$ yields an expression of the form $[M_{ne}] \{\ddot{\delta}_n\}$

in which $[M_{ne}]$ is the element mass matrix of size (19x19). The global mass matrix is obtained by assembling mass matrices of all the elements. By taking the variation of "T" with respect to different $\{\dot{\delta}_n\}$, mass matrix for each term in the Fourier Series can be obtained.

2.2.3 DERIVATION OF DAMPING MATRIX

The damping matrix is obtained from the Raleigh's dissipative function. As Raleigh's dissipative function is defined as half the work done by the dissipative forces per unit time, we need to compute the work done by the dissipative forces. We define the following damping coefficients:

C_p = plate damping coefficient having units of force per unit velocity per unit volume.

C_b = joist damping coefficient having units of force per unit velocity per unit volume.

C_{nx} = damping coefficient for slip at the connectors parallel to the joist having units of force per unit velocity.

C_{ny} = damping coefficient for slip at the connectors perpendicular to the joist having units of force per unit velocity.

$C_{n\theta}$ = damping coefficient for rotational slip at the connectors having units of force per unit angular velocity.

Now we can express the Raleigh's dissipative function as:

$$D = D_p + D_b + D_c \quad (2.34)$$

where:

$$\begin{aligned} D_p &= \text{dissipative energy in the plate} \\ &= \frac{C_p}{2} \int_V (\dot{u}_p^2 + \dot{v}_p^2 + \dot{w}_p^2) dV \end{aligned} \quad (2.35a)$$

$$\begin{aligned}
D_b &= \text{dissipative energy in the joist} \\
&= \frac{C_b}{2} \int_V (\dot{u}_b^2 + \dot{v}_b^2 + \dot{w}_b^2) dV
\end{aligned} \tag{2.35b}$$

$$\begin{aligned}
D_c &= \text{dissipative energy in the connectors} \\
&= \frac{C_{nx}}{2e} \int_0^L (\Delta\dot{u})^2 dx + \frac{C_{ny}}{2e} \int_0^L (\Delta\dot{v})^2 dx + \frac{C_{n\theta}}{2e} \int_0^L \dot{\phi}^2 dx
\end{aligned} \tag{2.35c}$$

in which $\dot{u}_p$, $\dot{v}_p$ and $\dot{w}_p$ are velocities of any plate particle; $\dot{u}_b$, $\dot{v}_b$ and $\dot{w}_b$ are velocities of any joist particle; and $\Delta\dot{u}$, $\Delta\dot{v}$ and $\dot{\phi}$ are slip velocities.

The Eqs. (2.35a) and (2.35b) as above are similar to Eqs. (2.25) and (2.29) except that C_p replaces ρ_p and C_b replaces ρ_j .

Hence the dissipative energy in the plate (C_p) can be expressed by Eq. (2.27) if ρ_p is replaced by C_p and the dissipative energy in the joist (C_b) can be expressed by Eq. (2.31) if ρ_j is replaced by C_b . The Eq. (2.35c) is very similar to Eq. (2.20) except that stiffness coefficients have been replaced by the damping coefficients and slip velocities are substituted for slips. Thus dissipative energy associated with the slips (D_c) between the cover and the joists can be expressed by Eq. (2.22) if K_{nx} , K_{ny} and $K_{n\theta}$ are replaced by C_{nx} , C_{ny} and $C_{n\theta}$ respectively and $\{\delta_n\}$ replaced by $\{\dot{\delta}_n\}$.

On taking the variation of the total dissipative energy in one element (D) with respect to $\{\dot{\delta}_n\}$ as given by the term $\frac{\partial D}{\partial \dot{q}_i}$ in Eq. (2.10) we obtain an expression of

the type $[C_{ne}]\{\dot{\delta}_n\}$ in which $[C_{ne}]$ is the element damping matrix of size (19x19). The global damping matrix is obtained by assembling the damping matrices of all the elements. By taking the variation of D w.r.t. different $\{\dot{\delta}_n\}$ damping matrix for each term in the Fourier series can be obtained.

2.2.4 DERIVATION OF A CONSISTENT LOAD VECTOR

A consistent load vector is derived from the load potential. The load potential per joist corresponding to the applied load function $p(x,y)$ is given by

$$U_L = \int_{-s/2}^{s/2} \int_0^L p(x,y) \cdot w(x,y) \, dx dy$$

Applying the principle of virtual work and using Eq. (2.1) we get

$$\sum_{n=1}^N \{\delta_n\}^T \{R_n\} = \int_{-s/2}^{s/2} \int_0^L p(x,y) \sum_{n=1}^N F_{1n}(y) \sin\left(\frac{n\pi x}{L}\right) \, dx dy$$

Since $\{\delta_n\}$ is an arbitrary virtual displacement equality holds for each n and $\{R_n\}$ can be obtained. For example for uniformly distributed load $p(x,y)=p$ we get

$$\{\delta_n\}^T \{R_n\} = \int_{-1}^1 \int_0^L p \{M_0(\xi)\}^T \{\delta_n\} \sin\left(\frac{n\pi x}{L}\right) \, dx d\xi$$

$$\text{or } \{R_n\} = \int_{-1}^1 \int_0^L p \{M_0(\xi)\} \sin\left(\frac{n\pi x}{L}\right) \, dx d\xi \quad (2.36)$$

The global consistent load vector can be obtained by combining all the element load vectors $\{R_n\}$ of size (19×1) .

Now we have all the matrices and vectors in Eq. (2.11) and we can formulate the complete equation of motion of the floor system. However, we yet have to include the effect of the people standing on the floor. This is done in the next section.

2.2.5 DYNAMIC EFFECTS OF PEOPLE ON FLOOR

Researchers have proposed various models with spring-dashpot combinations to study the mechanical behaviour of the human body. The International Organisation for Standardization has presented a two degree of freedom model in the standard ISO:5982. The model including the proposed parameter values is shown in Fig. (2.6a). The biodynamic modelling working group (ISO/TC 108/SC 4/WG 5) has proposed a draft addendum to ISO:5982 which includes an improved and more complex model of human being. Here, for simplicity we will consider just a single degree of freedom spring-dashpot

model as shown in Fig. (2.6b).

Fig. 2.6. Human Being Model

The numerical values for the spring constant and damping coefficient have been chosen as the average of the corresponding values in the model shown in Fig. (2.6a). In some of the future discussions, the people on the floor would be referred to just as masses on the floor. Now consider the floor with people on it as shown in Fig. (2.7). The degrees of freedom of the masses are shown by y_i , $i=1,2,\dots,n$. The kinetic energy, potential energy and the dissipative energy of floor system including the masses can be expressed as

$$T = \frac{1}{2} \{\dot{X}\}^T [M] \{\dot{X}\} + \sum_{i=1}^N \frac{1}{2} m_i \dot{y}_i^2 \quad (2.37)$$

$$V = \frac{1}{2}\{\dot{\mathbf{x}}\}^T [\mathbf{K}]\{\mathbf{x}\} + \sum_{i=1}^N \left[\frac{1}{2}k_i (y_i - w_i)^2 \right] - \sum_{n=1}^N m_i g y_i \quad (2.38)$$

$$D = \frac{1}{2}\{\dot{\mathbf{x}}\}^T [\mathbf{C}]\{\dot{\mathbf{x}}\} + \sum_{i=1}^N \left[\frac{1}{2}c_i (\dot{y}_i - \dot{w}_i)^2 \right] \quad (2.39)$$

in which, $[\mathbf{M}]$, $[\mathbf{K}]$ and $[\mathbf{C}]$ are respectively the global mass, stiffness and damping matrices of the floor. The vectors $\{\mathbf{x}\}$ and $\{\dot{\mathbf{x}}\}$ are the global displacement and velocity vectors for the floor and w_i denotes the vertical deflection of the floor at the location of mass m_i .

Now from Eqs. (2.1a) and (2.4a) we have

Fig. 2.7. Floor with people

$$\begin{aligned}
 w &= \sum_{i=1}^N \{M_0(\xi)\}^T \{X_n\} \sin\left(\frac{n\pi x}{L}\right) \\
 &= \langle \{M_0(\xi)\}^T \sin\left(\frac{\pi x}{L}\right) \quad \{M_0(\xi)\}^T \sin\left(\frac{2\pi x}{L}\right) \dots \dots \dots \\
 &\quad \dots \dots \dots \{M_0(\xi)\}^T \sin\left(\frac{n\pi x}{L}\right) \rangle \{X\}
 \end{aligned}$$

in which $\{X\}^T = \{(X_1) (X_2) \dots (X_n)\}$ and vector $\{M_0(\xi)\}^T$ has been extended to the global size. For example in case of two finite elements total global d.o.f. are $(2 \times 13 + 6 = 32)$. Each of $(X_1), (X_2), \dots, (X_n)$ will have 32 components. The shape function $\{M_0(\xi)\}$ relates to the nodal degree of freedom of only one element and gives the variation of displacement over that element. Hence if the displacement under first element is desired, the first 19 components of the extended $\{M_0(\xi)\}$ vector corresponding to the degrees of freedom of first element should be the usual shape function $\{M_0(\xi)\}$. Other components of the extended $\{M_0(\xi)\}$ vector will be zero. Thus depending on the element number under which deflection is desired, the extended vector would change. Thus we can express w_i as

$$w_i = \{L_i\}^T \{X\} \quad (2.40)$$

On substituting Eq. (2.40) into Eqs. (2.37), (2.38) and (2.39) we obtain

$$T = \frac{1}{2} \{\dot{X}\}^T [M] \{\dot{X}\} + \sum_{i=1}^N \frac{1}{2} m_i \dot{y}_i^2 \quad (2.41)$$

$$V = \frac{1}{2}\{\dot{\mathbf{x}}\}^T [\mathbf{K}]\{\dot{\mathbf{x}}\} + \sum_{i=1}^N \left[\frac{1}{2}k_i (y_i - \{\mathbf{L}_i\}^T \{\mathbf{x}\})^2 \right] - \sum_{i=1}^N m_i g y_i \quad (2.42)$$

$$D = \frac{1}{2}\{\dot{\mathbf{x}}\}^T [\mathbf{C}]\{\dot{\mathbf{x}}\} + \sum_{i=1}^N \left[\frac{1}{2}c_i (\dot{y}_i - \{\mathbf{L}_i\}^T \{\dot{\mathbf{x}}\})^2 \right] \quad (2.43)$$

2.2.6 FINAL EQUATIONS OF MOTION

Finally by using the Lagrange's equation of motion as given by Eq. (2.10) and substituting for T, V and D from Eqs.(2.41), (2.42) and (2.43), we obtain:

$$m_i \ddot{y}_i + c_i \dot{y}_i - c_i \{\mathbf{L}_i\}^T \{\dot{\mathbf{x}}\} + k_i y_i - k_i \{\mathbf{L}_i\}^T \{\mathbf{x}\} = m_i g \quad (2.44)$$

$$\begin{aligned} [\mathbf{M}]\{\ddot{\mathbf{x}}\} - \sum_{i=1}^N [c_i \{\mathbf{L}_i\}] \dot{y}_i + \left[\sum_{i=1}^N c_i \{\mathbf{L}_i\} \{\mathbf{L}_i\}^T + [\mathbf{C}] \right] \{\dot{\mathbf{x}}\} \\ - \sum_{i=1}^N [k_i \{\mathbf{L}_i\}] y_i + \left[\sum_{i=1}^N k_i \{\mathbf{L}_i\} \{\mathbf{L}_i\}^T + [\mathbf{K}] \right] \{\mathbf{x}\} = \{\mathbf{R}\} \end{aligned} \quad (2.45)$$

2.3 SOLUTION OF THE EQUATIONS OF MOTION

The dynamic equations of equilibrium as given by Eqs. (2.44) & (2.45) are a set of second order linear differential equations. A numerical step by step direct integration method is employed to obtain the solution. In this procedure, dynamic equilibrium is satisfied only at

discrete time points within the total interval of the solution. A variation of displacement, velocity and acceleration within each time interval is assumed and this defines the accuracy, stability and the cost of the solution procedure. Of the many available numerical integration methods, an unconditionally stable implicit direct integration method is used here.

Wilson θ Method: This method is an extension of the linear acceleration method. In this method acceleration is assumed to have a linear variation from time t to $(t+\theta\Delta t)$, where $\theta \geq 1.0$. When $\theta=1$, this method reverts back to the linear acceleration method but for $\theta > 1.37$ it becomes unconditionally stable. Usually a value of $\theta=1.4$ is used. The algorithm is derived here.

By looking at Fig. (2.8) we can write the linear acceleration assumption as

Fig. 2.8. Linear Acceleration Variation

$$\ddot{x}_{t+\tau} = \ddot{x}_t + \frac{\tau}{\theta\Delta t} (\ddot{x}_{t+\theta\Delta t} - \ddot{x}_t) \quad (2.46)$$

on integration:

$$\dot{x}_{t+\tau} = \dot{x}_t + \ddot{x}_t \tau + \frac{\tau^2}{2\theta\Delta t} (\ddot{x}_{t+\theta\Delta t} - \ddot{x}_t) \quad (2.47)$$

once again on integration:

$$x_{t+\tau} = x_t + \dot{x}_t \tau + \ddot{x}_t \frac{\tau^2}{2} + \frac{\tau^3}{6\theta\Delta t} (\ddot{x}_{t+\theta\Delta t} - \ddot{x}_t) \quad (2.48)$$

Now from Eqs. (2.47) and (2.48), at time $(t+\theta\Delta t)$ or $\tau=\theta\Delta t$ we get

$$\dot{x}_{t+\theta\Delta t} = \dot{x}_t + \frac{\theta\Delta t}{2} (\ddot{x}_{t+\theta\Delta t} + \ddot{x}_t) \quad (2.49)$$

$$x_{t+\theta\Delta t} = x_t + \dot{x}_t \theta\Delta t + \frac{\theta^2\Delta t^2}{6} (\ddot{x}_{t+\theta\Delta t} + 2\ddot{x}_t) \quad (2.50)$$

From Eqs. (2.49) and (2.50) we solve for $\dot{x}_{t+\theta\Delta t}$ and $\ddot{x}_{t+\theta\Delta t}$ and we get

$$\ddot{x}_{t+\theta\Delta t} = \frac{6}{\theta^2\Delta t^2} (x_{t+\theta\Delta t} - x_t) - \frac{6}{\theta\Delta t} \dot{x}_t - 2\ddot{x}_t \quad (2.51)$$

$$\dot{x}_{t+\theta\Delta t} = \frac{3}{\theta\Delta t} (x_{t+\theta\Delta t} - x_t) - 2\dot{x}_t - \frac{\theta\Delta t}{2} \ddot{x}_t \quad (2.52)$$

In order to obtain the response at time $(t+\Delta t)$, equilibrium is considered at time $(t+\theta\Delta t)$ ie.

$$[M]\{\ddot{x}_{t+\theta\Delta t}\} + [C]\{\dot{x}_{t+\theta\Delta t}\} + [K]\{x_{t+\theta\Delta t}\} = \{R_{t+\theta\Delta t}\} \quad (2.53)$$

in which $R_{t+\theta\Delta t} = R_t + \theta(R_{t+\Delta t} - R_t)$ is linearly projected load vector. On substituting Eqs. (2.51) and (2.52) into (2.53) we obtain

$$\begin{aligned} & \left[\frac{6}{\theta^2 \Delta t^2} [M] + \frac{3}{\theta \Delta t} [C] + [K] \right] x_{t+\theta\Delta t} \\ &= \{R_{t+\theta\Delta t} + \left(\frac{6}{\theta^2 \Delta t^2} [M] + \frac{3}{\theta \Delta t} [C] \right) x_t \\ &+ \left(\frac{6}{\theta \Delta t} [M] + 2[C] \right) \dot{x}_t \\ &+ \left(2[M] + \frac{\theta \Delta t}{2} [C] \right) \ddot{x}_t \} \end{aligned} \quad (2.54)$$

The coefficient matrix on the left hand side of Eq. (2.54) is called the effective stiffness matrix and the vector on the right hand side is called the effective load vector. This equation can be solved for $x_{t+\theta\Delta t}$. Then from Eq. (2.51) $\ddot{x}_{t+\theta\Delta t}$ is obtained. Finally, Eqs. (2.46), (2.47) and (2.48) are used to obtain response at time $(t+\Delta t)$ by using $\tau=\Delta t$. The solution at time $(t+\Delta t)$ is given by

$$\ddot{x}_{t+\Delta t} = \frac{6}{\theta^3 \Delta t^2} (x_{t+\theta\Delta t} - x_t) - \frac{6}{\theta^2 \Delta t} \dot{x}_t + \left(1 - \frac{3}{\theta}\right) \ddot{x}_t \quad (2.55)$$

$$\dot{x}_{t+\Delta t} = \dot{x}_t + \frac{\Delta t}{2} (\ddot{x}_{t+\Delta t} + \ddot{x}_t) \quad (2.56)$$

$$x_{t+\Delta t} = x_t + \Delta t \cdot \dot{x}_t + \frac{\Delta t^2}{6} (\ddot{x}_{t+\Delta t} + 2\ddot{x}_t) \quad (2.57)$$

Thus, by using this stepwise procedure, solution at any time $(t+\Delta t)$ can be obtained if the response at time t is known. We need to know the displacement, velocity and the acceleration vectors at the beginning to start this marching procedure. The displacement and velocity vectors are known from the initial conditions of the problem and the initial acceleration vector is computed from Eq. (2.11) This method can be easily programmed. Even though this method is unconditionally stable, the accuracy of the solution depends on the characteristics of the dynamic loading and the size of the time step.

3. THE COMPUTER PROGRAM

3.1 PROGRAM FEATURES

The computer program performs a dynamic analysis of the floors with equidistant stiffeners in one direction. The program evaluates the response of the floor subjected to impact loading. The sources of impact loading could be dropping of heavy objects, human activity such as dancing, jumping or walking. In this work, the program has been applied to evaluate the floor response as a result of single human footfall impact. This type of impact occurs when a person with his heels raised approximately 2in.(5cm) relaxes and allows his heels to impact the floor. Since the human being has been modelled as a spring-dashpot system, the footfall impact is simulated by giving an initial velocity (computed from considerations of free fall under gravity) to the mass. For example, for an heel impact of 2inches, the initial velocity would be $\sqrt{2 \times 386.4 \times 2} = 39.31$ inches per second.

The program performs a time step analysis and gives information about the displacement, velocity and acceleration at any time, $t > 0$ and at any point on the floor. The program provides the option to randomly select the modulus of elasticity of the joists and to carry out simulations to evaluate the system variability produced by variability in the population of joists. The program considers damping and the damping matrix has been derived from energy considerations as explained in the second

chapter. The mass matrix used in the program is a consistent mass matrix derived from energy considerations as explained in the second chapter and not a lumped mass matrix. The dimension statements in the program impose the following limitations:

1. The number of joists in the floor are limited to 10.
2. The number of the Fourier series terms that can be considered for solution are limited to 3.
3. The number of persons or the masses that can be considered to occupy the floor are limited to 5.
4. The number of floor points at which response can be evaluated are limited to 10.

These limitations can be easily overcome by changing the dimension statements for the different matrices and vectors.

3.2 PROGRAM STRUCTURE

The program consists of a number of subroutines which read and print the structure and load data, carry out numerical integration, assemble mass, stiffness and damping matrices, solve system of equations of dynamic equilibrium and generate results. These subroutines combined with the main program where they are called produce the complete program. A brief discussion of the main subroutines and the operations they carry out is presented here.

Subroutine GENMTX: This subroutine evaluates the integrals as shown in Eq. (2.15) required in the development of the stiffness, mass and the damping matrices. The routine

computes the integrals numerically using the six point Gauss Quadrature rule.

Subroutine DATA & PRINT: The subroutine DATA reads in all the input for the structure, such as material properties, sizes and dimensions, boundary conditions etc. and the loading data. Then subroutine PRINT prints out the read data which serves as a check on the read data.

Subroutine ASMBLY: This routine assembles the global floor stiffness, mass and the damping matrices. It also assembles the global load vector. This routine calls a subroutine STFMAS which computes the element stiffness, mass and the damping matrices ie. STIFF, DMASS and DAMP respectively of size (19×19) and the element load vector VECTR. This routine assembles the element matrices. The global matrices are symmetric and thus only the lower triangular parts of the matrices are stored into one dimensional vectors. This is repeated for each n (term in Fourier Series) and all the vectors are stored in GSTIF, GMASS and GDAMP. Since there are 19 degrees of freedom per element and 12 are shared with the adjoining elements (6 at point 1 and 6 at point 2 of Fig. 2.2), the global degrees of freedom would be $(13NJT+6)$, where NJT are the number of joists. The global matrices would be banded matrices with a band width of 19. Thus, each of the vectors in the matrices GSTIF, GMASS and GDAMP would have $19(13NJT+6)$ components. By assembling the element load vectors VECTR the global vector FORCE1 of size $(13NJT+6)$ associated with each n is obtained. This routine also

imposes the boundary conditions on the stiffness, mass and the damping matrices once they are formed. To do this the rows and columns of the matrices corresponding to the restrained degrees of freedom are made zero. Also the element in the load vector corresponding to the restrained degree of freedom is made zero. This routine also calls a subroutine DECMP which carries out a Cholesky decomposition of the global mass matrix and stores it into matrix DCPMAS.

Subroutine AXLRTN: This routine computes the initial acceleration vector ie. the acceleration induced in the floor system at the instant of impact. The initial displacement vector of the floor system at the instant of impact is taken as zero as the floor is considered to be in static equilibrium prior to impact. The routine computes the initial acceleration vector directly from the equation of motion given by Eq. (2.11).

Subroutine EFMAT: This routine computes the effective stiffness matrix of Eq. (2.54). The effective stiffness matrix depends not only on the basic stiffness, mass and the damping matrices but also on the value of θ and the size of the time step. This routine also carries out a Cholesky decomposition of the effective stiffness matrix by calling a subroutine DECMP. This is needed when solving for the unknown displacement vector. This decomposed effective stiffness matrix is stored in EFSTIF.

Subroutine EFLOAD: This routine computes the effective load vector of Eq. (2.54). This also like effective stiffness

matrix depends on the basic stiffness, mass and the damping matrices and on θ and the time step size.

Subroutine SOLVE: This routine solves for the vector $\{X_{t+\theta\Delta t}\}$ in Eq. (2.54) and computes the displacement, velocity and the acceleration vectors at time $(t+\Delta t)$ given by Eqs. (2.55), (2.56) and (2.57). An iterative procedure is employed to obtain the solution. Schematically, Eq. (2.54) can be written as

$$\begin{bmatrix} S(1,1) & S(1,k) & S(1,N) \\ S(k,1) & S(k,k) & S(k,N) \\ S(N,1) & S(N,k) & S(N,N) \end{bmatrix} \begin{bmatrix} X_1 \\ X_k \\ X_N \end{bmatrix} = \begin{bmatrix} R_1 \\ R_k \\ R_N \end{bmatrix}$$

in which $S(k,k)=[S(k,k)]$ is a global matrix of size $(13NJT+6) \times (13NJT+6)$; $X_k=\{X_k\}$ is a global vector of size $(13NJT+6)$ and N is the no of terms in the Fourier Series. Now the solution for each vector $\{X_k\}$ can be written as

$$\{X_k\}^i = [S(k,k)]^{-1} \left\{ \{R_k\} - \sum_{\substack{n=1 \\ n \neq k}}^N [S(k,n)] \{R_n\}^{i-1} \right\} \quad (3.1)$$

$i=(1,2,\dots)$

in which i denotes the iteration number. For the starting vector following approximation is used

$$\{X_k\}^0 = [S(k,k)]^{-1} \{R_k\} \quad (3.2)$$

The iterations are stopped when

$$\left| \{X_k\}^i - \{X_k\}^{i-1} \right| < \epsilon \left| \{X_k\}^{i-1} \right| \quad (3.3)$$

for $k=1,2,\dots,N$ and ϵ a small number (e.g., 0.001).

In the above equations the terms associated with the masses have not been included for simplicity. The solution for y_i (degrees of freedom associated with the masses) is obtained by using the same iterative procedure. In the above described procedure only $(13NJT+6)$ equations need be solved at each step of the iteration. The convergence is usually obtained within 5 iterations.

Subroutine RESULT: The solution vectors which are obtained by routine SOLVE are the complete solution vectors giving information about all the deformations associated with each degree of freedom. However, we are only interested in the vertical out of plane deformation of the floor. This subroutine picks up the relevant components of the solution vector and prints out the vertical displacement, velocity and the acceleration of the floor.

Appendix II includes the "User's Manual" and illustrative input/output files. A comprehensive listing of the computer program is provided in Appendix III.

4. HUMAN PERCEPTION OF VIBRATIONS

4.1 HUMAN DISCOMFORT CRITERION

Depending on the floor configuration, a person may find vibrations caused by footfall impacts during normal walking objectionable. Wiss and Parmelee [15] conducted an experimental study of human response to transient vertical vibrations in terms of their frequency, maximum displacement and damping. The wave-form which was used for these vibrations is shown in Fig. (4.1). The vibrations lasted not more than 5 seconds and the damping rate varied between 0.01 to 0.20 of critical damping.

During the course of Wiss & Parmelee's study, several persons were subjected to vibrations of various combinations of frequency, peak amplitude and damping and were asked to

Fig. 4.1. Vibration Signal used by Wiss & Parmelee

classify each of the vibrations according to the following classification: (1)imperceptible; (2)barely perceptible; (3)distinctly perceptible; (4)strongly perceptible; and (5)severe. A total of 40 subjects were tested. Numerical values were assigned to each rating as follows:

<u>Rating(R)</u>	<u>Classification</u>
1	Imperceptible
2	Barely Perceptible
3	Distinctly Perceptible
4	Strongly Perceptible
5	Severe

Since ratings 1 and 5 are unbounded at the lower and upper regions respectively, it is hard to establish the true mean line for these ratings and thus these are not considered in the analysis. For ratings $R = 2, 3$ and 4 , and damping coefficients larger than 0.01 multiple regression analysis were performed and a relationship between the three variables R , FA and D was obtained. The prediction equation is given by

$$R = 5.08 \left(\frac{FA}{D^{0.217}} \right)^{0.265} \quad (4.1)$$

where: F =frequency, in cycles per second

A =peak displacement in inches

D =damping ratio

R=response rating

In their study Wiss and Parmelee also suggested some alternate mathematical models by performing somewhat different statistical analyses. The prediction equations from two such models are

$$R = 2.624 \left(\frac{FA}{D^{0.0463}} \right)^{0.1445} \quad (4.2)$$

$$R = 3.830 \left(\frac{FA}{D^{0.311}} \right)^{0.155} \quad (4.3)$$

Plot of product of frequency & amplitude (FA) vs. damping (D) for response ratings R=2,3 & 4 and based upon Eqs. (4.1) is shown in Fig. (4.2).

Fig. 4.2. Wiss & Parmelee's model curves

The plot illustrates that vibrations of a particular

frequency and amplitude are progressively less perceptible as damping is increased. Also note that for a given rating the product of frequency and amplitude may be approximately twice as much when damping is increased from 0.02 to 0.20 of critical.

Now look at a typical floor response to footfall impact as shown in Fig. 4.3.

Fig. 4.3. Typical floor response to footfall impact

The floor vibration has a damping rate of 0.15 of critical. It dies much earlier than 5 seconds and thus has characteristics similar to the wave-form used by Wiss & Parmelee. Hence in this work Eq. (4.1) has been used as a criterion for classifying human response to floor vibrations.

4.2 HUMAN PERCEPTION AND FLOOR RELIABILITY

Limit states methods of design are being introduced into design recommendations by various codes. This probability based approach is more realistic as the variability of several design parameters is taken into account rather than assuming them to be deterministic. Foschi {6} has presented an interesting discussion on this design concept.

Floor vibrations and human perception of annoying motion is a "serviceability limit state". That is, it refers to performance acceptance rather than to catastrophic failure. Having a means of classifying human response to floor vibrations, we can use reliability theory to predict the probability that floors would be classified into a particular rating category by people.

Suppose we are interested in knowing the probability that people would rate the floors as having a response rating of R_0 or less. We define the following function:

$$G = R_0 - R \quad (4.4)$$

in which R is the rating given to each floor by people. The distribution of ratings is obtained for a population of simulated floors considering the variability in the modulus of elasticity of the joists. Now $G > 0$ for $R < R_0$; $G = 0$ for $R = R_0$; and $G < 0$ for $R > R_0$. Thus, positive values of G imply that the floors would qualify to be in a specified category or in others words would survive the test and negative values of G imply that floor would fail the test. Hence, G can be

interpreted as a Failure Function. Study of the $\text{Prob}(G < 0)$ thus leads to an estimate of the Probability of Failure, P_f with respect to the particular limit state of exceeding the desired rating R_0 . The probability of failure can be related to the Reliability Index, β which facilitates the understanding and the determination of the probability of failure. The reliability index, β can be written as:

$$\beta = \bar{G} / \sigma_G \quad (4.5)$$

Reliability index, β is a measure of the number of standard deviations (σ_G), $\bar{G}$ is from the failure event $G=0$. The probability of failure, P_f is given by the area of the shaded region in Fig. (4.4).

Fig. 4.4. Reliability index and Probability of failure

If G has a normal distribution the probability of failure can be directly determined from the normal tables as:

$$P_f = \Phi(-\beta) \quad (4.6)$$

in which Φ is the cumulative distribution for the standardized normal probability function.

Thus, reliability index and the probability of failure can be determined without any difficulty if G is a linear combination of normally distributed variables. If the variables are non-normal or G is a non-linear function, the Eq. (4.6) would give only an approximate value of P_f . However, the error can be minimized if the basic variables are transformed into a set of normal variables before computing the reliability index. Rackwitz Fiessler Algorithm [11] does this transformation. This is an iterative procedure to locate the most likely failure point and gives an estimate of the reliability index which can be related to the normal tables to get P_f . If the variables $x_1, x_2, \dots, x_n$ are dependent on one another, they should be uncorrelated before using the Rackwitz Fiessler Algorithm. A computer program has been written based on this algorithm and is quite simple to use.

5. RESULTS AND DISCUSSIONS

5.1 NUMERICAL CONVERGENCE

Since a Fourier series approximation is employed along the floor span (x-direction), the efficiency of the analysis depends on the number of Fourier series terms (n) needed for convergence of the solution. The floor considered consists of nine joists supported on all four sides (the usual boundary conditions of simple supports at joist ends plus restraint on the vertical deflection of the first and the last joist). The convergence was tested by analyzing the floor response to impact for two values of " n ". Only the

Fig. 5.1. Effect of " n " on Floor response

first term in the Fourier series was considered for one case and first three terms were considered for the other case. The results are shown in Fig. (5.1). The convergence is apparent and the results suggest that using only the first term in the Fourier series is satisfactory. This was expected as the floor was excited by a single point impact on its centroid.

5.2 SENSITIVITY ANALYSIS

A sensitivity analysis was done to study the effect of various floor parameters on the floor response. A reference floor with typical parameter values as shown in table (5.1) was chosen.

Parameter	Symbol	Reference value	Range
Joist spacing	S	16in	12-20
Receiver's weight	W_R	200lb	140-200
Impacter's weight	W_I	200lb	140-200
Mass damping	RC	6lb.s/in	3-12
Span	RL	144in	96-192
Joist MOE	E	$1.55(10^6)$ psi	1.2-1.8
Floor damping	CP	6lb.s/in	3-12
Joist depth	H	7.25in	7.25-11.25
Nail spacing	ENL	8in	0.5-16
Nail stiffness	KN	6800lb/in	10^3-10^5

Table 5.1. Reference Floor

The ranges of parameter values studied are also shown in table 5.1. In addition the reference floor had a plate thickness of 5/8in and was supported on all four sides. To study the effect of a particular parameter, the value of that parameter was varied around the reference value while keeping other parameters unchanged and the response analyzed. The effect of these parameters on the floor response are illustrated by figures (5.2) to (5.9). Following is a brief discussion of the plots.

Figures (5.2) and (5.3) show the effect of floor damping and mass damping. While the influence of mass damping is significant, the effect of floor damping is negligible. It cannot be concluded from here that floor damping is unimportant since, values of CP were assumed arbitrarily. However, these plots clearly illustrate that in considering total system damping mass damping cannot be ignored.

Figures (5.4) and (5.5) illustrate that as span is reduced or joist depth is increased, the floor becomes stiffer, thereby reducing the peak displacement and increasing the frequency of vibrations. The initial kink observed in the curves for stiffer floors is due to the fact that the acceleration variation at the instant of impact is much more irregular for stiffer floors than for relatively flexible floors. Since we are assuming a linear acceleration variation within the time step, it means that the size of the time step in the beginning is too big for stiffer

floors.

Fig. (5.6) illustrates that joist spacing has very little influence on floor response. As joist spacing is increased, the flexibility of the floor increases due to which the response tends to go up but at the same time the distance between the impactor and the receiver increases due to which the response tends to drop. Thus the combined effect is that the response remains practically unchanged.

Fig. (5.7) illustrates that as nail spacing is decreased, the relative movement between the plate and the joist is reduced, thereby making the floor stiffer and thus a lower peak displacement is observed.

Fig. (5.8) illustrates that the worst impact condition is when there is a heavy impactor and a light receiver. This impact condition is used for all the analysis.

Fig. (5.9) illustrates the effect of torsional and lateral restraint on the joists. It is observed that torsional restraint is quite effective in reducing the peak displacement.

Fig.5.2. Effect of floor damping on response

Fig.5.3. Effect of mass damping on response

Fig.5.4. Effect of span on response

Fig.5.5. Effect of joist depth on response

Fig.5.6. Effect of joist spacing on response

Fig.5.7. Effect of nail spacing on response

Fig.5.8. Effect of weight of people on response

Fig.5.9. Effect of torsional restraint on response

Regression Analysis:

A multiple linear regression analysis was done to come up with expressions for the peak displacement and the frequency of vibrations sensed by the receiver in terms of the floor parameters. An equation of the following form was proposed.

$$\begin{aligned} X_p/\delta = & A_0 + A_1(S/16) + A_2(W_R/200) + A_3(W_I/200) \\ & + A_4(RC/6) + A_5(RK/400) + A_6(RL/144) \\ & + A_7(E/1.55) + A_8(CP/6) + A_9(H/7.25) \\ & + A_{10}(ENL/8) + A_{11}(KN/6800) \end{aligned} \quad (5.1)$$

subject to constraint

$$(X_p/\delta)_0 = A_0 + A_1 + A_2 + \dots + A_{11} \quad (5.2)$$

in which: $A_0, A_1, \dots, A_{11}$ are the coefficients to be determined by regression. X_p is the peak floor displacement at the receiver's point made nondimensional by dividing it by the static deflection, $\delta = W_I L^3 / 48EI$. Note that instead of using the absolute floor parameters their ratios to the reference values are used. Values of the floor parameters used in Eq. (5.1) should be of the same units as the reference values. The constraint in Eq. (5.2) ensures that the regression equation is satisfied for the reference floor. $(X_p/\delta)_0$ corresponds to the reference floor. This relation will be applicable for the range of parameters listed in table (5.1).

In order to briefly explain how the coefficients were obtained, the floor parameter ratios are denoted by x and (X_p/δ) by y and the problem is expressed as a minimization

problem.

$$\text{Minimize: } \sum_{i=1}^k d_i^2 = \sum_{i=1}^k [(A_0 + A_1 x_1 + \dots + A_n x_n)_i - y_i]^2 \quad (5.3)$$

in which $k > n$.

$$\text{Constraint: } A_0 + A_1 + \dots + A_n = y_0 \quad (5.4)$$

Using Lagrange's multiplier Eqs. (5.3) and (5.4) can be expressed as:

$$\begin{aligned} \text{Minimize: } \epsilon = \sum_{i=1}^k [(A_0 + A_1 x_1 + \dots + A_n x_n)_i - y_i]^2 \\ + \lambda (A_0 + A_1 + \dots + A_n - y_0) \end{aligned} \quad (5.5)$$

$\frac{\partial \epsilon}{\partial a_i}$ ($i=1, 2, \dots, n$), leads to a system of equations which allow us to determine the coefficients $A_0, A_1, \dots, A_n$. Finally, these coefficients can be substituted into Eq. (5.1) to get the equation for x_p/δ . Similarly, a relation for the frequency ratio, f/f_0 , is obtained in which:

$f_0 = \frac{\pi}{2L^2} \sqrt{\frac{EI}{\rho A}}$, the frequency of a simply supported beam.

The Regression Equations:

For a floor of nine beams and supported on all four sides the following equations are obtained for a footfall drop of 2 inches:

$$\begin{aligned} x_p/\delta = & 0.4800 - 0.0278(S/16) - 0.0600(W_R/200) \\ & - 0.1870(W_I/200) - 0.0192(RC/6) + 0.1920(RK/400) \\ & - 0.0897(RL/144) + 0.1370(E/1.55) - 0.0144(CP/6) \\ & + 0.0816(H/7.25) + 0.1270(ENL/8) - 0.0144(KN/6800) \end{aligned}$$

(5.6)

$$\begin{aligned}
 f/f_0 = & 0.0785 + 0.00017(S/16) - 0.0167(W_R/200) \\
 & - 0.0600(W_I/200) - 0.0024(RC/6) + 0.0488(RK/400) \\
 & + 0.2490(RL/144) - 0.0662(E/1.55) - 0.0004(CP/6) \\
 & - 0.0888(H/7.25) - 0.0010(ENL/8) + 0.00015(KN/6800)
 \end{aligned}
 \tag{5.7}$$

The regression analysis for 2 in. footfall drop was repeated for floor having additional constraints on torsional and lateral degrees of freedom of the joists. The equations for this case are as follows:

$$\begin{aligned}
 X_P/\delta = & 0.0802 + 0.1450(S/16) - 0.0100(W_R/200) \\
 & - 0.0934(W_I/200) + 0.0096(RC/6) + 0.0972(RK/400) \\
 & - 0.4320(RL/144) + 0.1510(E/1.55) - 0.0064(CP/6) \\
 & + 0.2950(H/7.25) + 0.0365(ENL/8) - 0.00407(KN/6800)
 \end{aligned}
 \tag{5.8}$$

$$\begin{aligned}
 f/f_0 = & 0.0911 - 0.00098(S/16) - 0.0200(W_R/200) \\
 & - 0.0966(W_I/200) - 0.0076(RC/6) + 0.0648(RK/400) \\
 & + 0.2950(RL/144) - 0.0796(E/1.55) - 0.0000(CP/6) \\
 & - 0.0978(H/7.25) - 0.0029(ENL/8) + 0.00044(KN/6800)
 \end{aligned}
 \tag{5.9}$$

To see the performance of the regression equations, a floor with following parameters different from those of the reference floor was selected.

$$RL = 168 \text{ in}$$

$$S = 20 \text{ in}$$

$$E = 1.75(10^6) \text{ psi}$$

$$CP=101b.s/in$$

$$W_R=1401b$$

$$ENL=2in$$

This floor was analyzed with and without torsional restraints. Actual computer results are compared with those obtained from the regression equations and are shown in table (5.2).

Floor	Computer	Regression	Computer	Regression
1	2.77mm	3.09mm	4.17Hz	3.92Hz
2	1.48mm	1.35mm	4.17Hz	4.20Hz
Notes: Floor 1 is without torsional restraints on joists. Floor 2 is with torsional restraint on joists.				

Table 5.2. Performance of Regression Equations.

We observe fairly good agreement between the computed values and those obtained from the regression equations. Hence, for the range of parameters studied, regression equations can be used to approximately determine the peak displacement and frequency. Damping rate can be assumed 0.15 of the critical for the parameter range considered and thus the floor rating can be estimated by using Eq. (4.1).

5.3 RELIABILITY ANALYSIS AND DESIGN CRITERION

The results of a study of timber floor behaviour as influenced by the variability of joist stiffnesses are presented here. Foschi [7] reports tests on Douglas-Fir lumber (No. 2 grade & better). The moduli of elasticity of

the joists obey the following 3 parameter Weibull distribution:

$$E = E_0 + m[-\ln(1-p)]^{1/k} \quad (5.10)$$

in which:

$$E_0 = 0.7718 \times 10^6 \text{ psi}$$

$$m = 0.8777 \times 10^6 \text{ psi}$$

$$k = 2.7198$$

p = uniform random number; $0 \leq p \leq 1$

Four types of floors as shown in table (5.3) were analyzed. The floors have different joist types and boundary conditions. Other floor parameters were the same as in the reference floor.

Floor type	Joist type	B in	H in	Torsional restraint†
A	2x8	1.5	7.25	No
B	2x8	1.5	7.25	Yes
C	2x10	1.5	9.25	No
D	2x12	1.5	11.25	No
†In addition to supports on all four sides.				

Table 5.3. Floor types analyzed

For each floor type, three spans (8ft, 12ft and 16ft) were considered. For each span, 300 floors were simulated and they were analyzed for 1in & 2in footfall drops. This yielded the floor response rating files for the two footfall drops each containing 300 values. The reliability indices (β) were determined, with respect to three different

reference ratings ($R_0=2, 3$ and 4) and two footfall drops (1in and 2in), using the Rackwitz Fiessler algorithm. Then, for each floor type smooth curves, β vs. L were plotted as shown in Fig. (5.10) to (5.13).

The β vs. L plots show higher reliability for 1in footfall drop, which means that for a lower impact there is a higher reliability of not exceeding a certain reference rating. Also for a particular reference rating, as floor span is increased, the reliability index drops, which means that the floors of longer span have a lower reliability of not exceeding a certain reference rating. For target reliabilities of 2 (corresponds to a probability of failure of approximately $20/1000$) and 3 (probability of failure $1/1000$) and a reference rating of 3 (distinctly perceptible vibrations) allowable spans are obtained for each floor type and are listed in table 5.4.

Fig. 5.10. Plot for floor type A

Fig. 5.11. Plot for floor type B

Fig. 5.12. Plot for floor type C

Fig. 5.13. Plot for floor type D

Drop	$\beta=2$		$\beta=3$	
	1in.	2in.	1in.	2in.
Floor A	8.2	7.7	7.4	6.9
Floor B	8.8	7.9	7.6	6.9
Floor C	10.3	9.3	9.5	8.6
Floor D	13.8	12.2	13.5	11.7

Table 5.4. Allowable spans in ft. for $R_0=3$ with receiver and impactor on adjacent joists.

To explain what is implied by an allowable span of 8.2ft for floor type A, it means that if floor type A is restricted to a span of 8.2ft, then for a footfall drop of 1in, the reliability index for not exceeding a response rating of 3 is 2 or, in other words, there are only 20 out of 1000 chances that the vibrations would be distinctly perceptible or more severe.

To develop a design criterion in terms of allowable static deflections, deflections of single joists loaded by a 1KN concentrated load at its centre and with allowable spans given in table 5.4 are computed and listed in table 5.5.

Drop	$\beta=2$		$\beta=3$	
	1in.	2in.	1in.	2in.
Floor A	1.366	1.1308	1.0037	0.8137
Floor B	1.688	1.2212	1.0873	0.8137
Floor C	1.3032	0.9593	1.0225	0.7586
Floor D	1.7422	1.2038	1.6311	1.0618

Table 5.5. Allowable deflection in mm for $R_0=3$ with receiver and impactor on adjacent joists.

The modulus of elasticity for computing the deflection is taken as $1.55(10^6)$ psi which is the mean of the distribution of E-values considered. Note that tables 5.4 and 5.5 are for the case when the receiver and the impactor are on the adjacent joists. The analysis was repeated for the case when the receiver was on the same joist as the impactor and 2 feet away from him as shown in Fig. 5.14.

Fig. 5.14. Receiver and impactor on same joist

The results of the analysis are shown in tables 5.6 and 5.7.

	$\beta=2$		$\beta=3$	
Drop	1in.	2in.	1in.	2in.
Floor A	5.75	5.4	5.4	5.1
Floor B	6.5	5.85	5.8	5.3
Floor C	7.55	6.7	6.75	6.1
Floor D	8.5	7.85	7.6	7.15

Table 5.6. Allowable spans in ft. for $R_0=3$ with receiver and impacter on same joists.

	$\beta=2$		$\beta=3$	
Drop	1in.	2in.	1in.	2in.
Floor A	0.528	0.437	0.437	0.368
Floor B	0.763	0.556	0.542	0.413
Floor C	0.576	0.402	0.411	0.304
Floor D	0.457	0.360	0.326	0.272

Table 5.7. Allowable deflection in mm for $R_0=3$ with receiver and impacter on same joists.

On looking at tables 5.5 and 5.7 we note that the case when the receiver and impacter are on the same joist is more severe. However, it is very unlikely in real practice that the receiver and impacter would be just 2 feet apart. At greater distances, the receiving point would be close to the support and the vibrations much less. On this basis, the case of receiver and impacter on adjacent joists governs and

we base our design criterion on table 5.5.

Design Criterion:

- If the deflection of a joist loaded by 1KN concentrated load at its centre is limited to approximately 1.0mm then, for the floor made with these joists, the reliability index for not exceeding a response rating of 3 is 2 or, in other words, there would be only 20 out of 1000 chances that the vibrations would be distinctly perceptible or more severe, under footfalls of upto 2 inches.
- If the deflection of a joist loaded by 1KN concentrated load at its centre is limited to approximately 0.8mm then, for the floor made with these joists, the reliability index for not exceeding a response rating of 3 is 3 or, in other words, there would be only 1 out of 1000 chances that the vibrations would be distinctly perceptible or more severe, under footfalls of upto 2 inches.

It is interesting to compare this design criterion to the limiting deflection values imposed by the codes of different countries as listed in table 5.8.

Country	Load	Deflection	E(MPa)
Canada	1.9KN/m ²	L/360	8400
Norway	1KN	0.9mm	10800
Sweden	1KN	1.5mm	11700
Denmark	1KN	0.9mm	12600
UK	DL+1.5KN/mm ²	L/333	6900
Germany	DL+2KN/mm ²	L/300	10000
Finland	DL+1.5KN/mm ²	L/300	7000

Table 5.8. Deflection provisions in different Countries.

We observe that our proposed design criterion agrees quite closely with those used in Scandinavia, particularly Norway and Denmark. Our study suggests that Swedish deflection provisions correspond to a somewhat lower β . It is also worthwhile to compare our design criterion with the one used in Canada. For this we compute the deflections of the isolated joists with spans as listed in table 5.4 and loaded by a uniformly distributed load of 1.9KN/m²(40lb/ft²). These are listed in table 5.9 as a fraction of the span length.

Drop	$\beta=2$		$\beta=3$	
	1in.	2in.	1in.	2in.
Floor A	L/1339	L/1617	L/1822	L/2248
Floor B	L/1083	L/1498	L/1682	L/2248
Floor C	L/1403	L/1906	L/1789	L/2411
Floor D	L/1050	L/1519	L/1121	L/1722

Table 5.9. Allowable deflection based on distributed load
with receiver and impactor on adjacent joists.

We observe that the deflection limits imposed by our design criterion are considerably less than the L/360 limit imposed by the Canadian code. This means that L/360 and 1.9KN/m² are unsatisfactory as a means of designing for the limit state of floor vibrations.

6. CONCLUSIONS

A rational analytical study of the floor vibration problem can be made using the computer program developed in this work. Since a time step method of analysis is employed, complete variation of floor displacement, velocity and the acceleration can be traced.

A reliability based design criterion related to human perception of vibration was proposed. Our design criterion gives an indication of the amount of risk undertaken in design and thus enables the designer to reach a judgment on the limiting value of deflection in a case where he may be required to undertake a greater or a lesser risk. The design criterion proposed here agrees well with the one used in Norway, Denmark and Sweden, where the static deflection produced by a concentrated load of 1KN at midspan of a joist is required not to exceed an absolute maximum independent of span length. This maximum is approximately 1mm. The study clearly shows that the Canadian code criterion for limiting static deflections under a uniformly distributed load is unsatisfactory for the limit state of floor vibrations.

As a proposal for future research, floor vibration response resulting from a walking person, which comprises of a sequence footfall impacts, should be studied. Further, some experimental work needs to be done in the area of floor system damping, to improve the input assumptions for the program.

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APPENDIX I

Shape Functions:

Vector $\{M_0\}$

$$M_0(1) = \xi^2 - 5/4\xi^3 - 1/2\xi^4 + 3/4\xi^5$$

$$M_0(2) = (\xi^2 - \xi^3 - \xi^4 + \xi^5)/8.0$$

$$M_0(10) = 1.0 - 2.0\xi^2 + \xi^4$$

$$M_0(9) = (\xi - 2.0\xi^3 + \xi^5)/2.0$$

$$M_0(14) = \xi^2 + 5/4\xi^3 - 1/2\xi^4 - 3/4\xi^5$$

$$M_0(15) = (-\xi^2 - \xi^3 + \xi^4 + \xi^5)/8.0$$

All other components, $M_0(k)=0.0$, $k=1,2,\dots,19$.

Vector $\{M_3\}$

$$M_3(3) = 1/4(-3\xi + 4\xi^2 + \xi^3 - 2\xi^4)$$

$$M_3(4) = (-\xi + \xi^2 + \xi^3 - \xi^4)/8.0$$

$$M_3(7) = 1.0 - 2.0\xi^2 + \xi^4$$

$$M_3(16) = 1/4(3\xi + 4\xi^2 - \xi^3 - \xi^4)$$

$$M_3(17) = (-\xi - \xi^2 + \xi^3 + \xi^4)/8.0$$

All other components, $M_3(k)=0.0$, $k=1,2,\dots,19$.

Vector $\{M_5\}$

$$M_5(5)=M_3(3); M_5(6)=M_3(4); M_5(8)=M_3(7);$$

$$M_5(18)=M_3(16); M_5(19)=M_3(17)$$

All other components, $M_5(k)=0.0$, $k=1,2,\dots,19$.

Vectors $\{M_1\}$, $\{M_2\}$, $\{M_4\}$ and $\{M_6\}$

$$M_1(k) = \frac{dM_0(k)}{d\xi}; \quad M_2(k) = \frac{d^2M_0(k)}{d\xi^2};$$

$$M_4(k) = \frac{dM_3(k)}{d\xi}; \quad M_6(k) = \frac{dM_5(k)}{d\xi};$$

in which: $k=1,2,\dots,19$.

APPENDIX II

USER'S MANUAL

DYNAMIC FLOOR ANALYSIS PROGRAM

INPUT: All data to be entered in free format.

1. NFLOR, NM, NJT, ISYM, NPROP, INPTE, TOL

where:

NFLOR = Number of floors to be analyzed.

NM = Maximum order of sine/cosine terms in the Fourier series. There can be a maximum of three terms, so that for symmetrical problems along the joists, NM can be upto 5 (three terms will be of order 1, 3 and 5). For non-symmetrical problem NM is equal to maximum order of sine/cosine terms eg. NM=3 means terms with order 1, 2 and 3.

NJT = Number of joists in the floor.

ISYM = 0, for non-symmetrical problem along the joists; and equal to 1, for symmetrical problem along the joists.

NPROP = 1, if all joists have uniform properties; and equal to 0, if joists have different properties.

INPTE = 1, if doing simulation; and equal to 2, if not a simulation problem. If doing simulation use NFLOR=1, execution for the whole sample controlled by variable "NREPL" as given in item 4. When not doing simulation and analyzing more than one floor, subroutine "UPDATE"

should be rewritten to suit specific requirements. As illustrated in the program listing, subroutine UPDATE is so written that 20 floors can be analyzed, each having only certain parameters different from a reference floor. The parameter values for the reference floor are reset each time UPDATE is called.

TOL = Tolerance to stop iterations while solving the system of equations. The value for TOL may be taken as 0.001.

2. THETA, NTMZON

where:

THETA = Parameter for Wilson- θ time step method of solution. Its value is taken as 1.4 for unconditional stability.

NTMZON = Number of time zones.

3. TIME(I,J), J=1,3; I=1,NTMZON

where:

TIME(I,1) = Starting time of time zone.

TIME(I,2) = Ending time of time zone.

TIME(I,3) = Incremental step for the time zone.

If, INPTE=2 (not a simulation problem), go to 7.

4. NREPL,SEED

where:

NREPL = Sample size for simulation.

SEED = Random number initializer.

5. EMIN, EMAX

where:

EMIN = Minimum value of modulus of elasticity of joist.

EMAX = Maximum value of modulus of elasticity of joist.

6. E0, EM, EK

where:

E0, EM and EK = Weibull distribution parameters.

7. S, RL, D

where:

S = Joist spacing

RL = Joist span

D = Cover or plate thickness

8. RKX, RKY, RKV, RKG, RHOC

where:

RKX = Bending stiffness of the cover in the x-direction, parallel to the joists. For plywood, this is usually perpendicular to the face grain.

RKY = Bending stiffness of the cover in the y-direction, perpendicular to the joists. For plywood this is usually parallel to the face grain.

RKV, RKG = Parameters for plate bending, connected

respectively to Poisson's effect and torsion.

RHOC = Mass density of the plate.

9. DX, DY, DV, DG

DX = In-plane (axial) stiffness of the cover in the x-direction.

DY = In-plane (axial) stiffness of the cover in the y-direction.

DV, DG = In-plane (axial) stiffness, related respectively to Poisson's effect and in-plane shear.

If NPROP=0, non-uniform properties; go to 12.

10. BJT, HJT, RHOJT, CBT

where:

BJT = Width of joists.

HJT = Depth of joists.

RHOJT = Mass density of the joists.

CBT = Damping co-efficient for the joists, per unit volume of the joist; units of force/velocity/volume.

If INPTE=1, simulation case, go to 14.

11. EJT

where:

EJT = Modulus of elasticity of the joist.

Go to 14.

12. For each joist, input consecutively,

BJ(I), I = 1,NJT (width of joists)

HJ(I), I = 1,NJT (depth of joists)

If INPTE=1, go to 13.

YMOD(I), I = 1,NJT (E-value of joists)

13. CB(I), I = 1,NJT (damping coefficient of joists)

14. BETA, ALPHA, REG

where:

BETA = Torsion constant, function of ratio, HJT/BJT.

ALPHA = Shear deflection constant for rectangular cross-sections.

REG = Ratio of Young's modulus of joist to shear modulus (E/G).

15. ENL, XIN, RKPAL, RKPER, RKROT, NDISCR

where:

ENL = Nail spacing along the joists.

XIN = Distance between the support and the first nail along the joist.

RKPAL, RKPER = Nail load-slip moduli, respectively in directions parallel and perpendicular to the joist.

RKROT = Stiffness for relative rotation of the plate and the joist.

NDISCR = 0, if actual nailing pattern is transformed into an equivalent continuous connector for analysis and equal to 1, if nails are treated as discrete.

16. CP, CNPAL, CNPER, CNROT

where:

CP = Damping co-efficient for the plate, per unit volume of the flange of one T-beam element; units force/velocity/volume.

CNPAL, CNPER = Damping co-efficient for nail slip parallel and perpendicular to the joists respectively; units force/velocity.

CNROT = Damping co-efficient for rotational slip; units force/angular velocity.

17. NGAPS

where:

NGAPS = Number of gaps present in the cover.

If NGAPS=0, go to 20.

18. NGT

where:

NGT = 0, if gaps are as entered in 19 and equal to 1, if gaps are adjusted automatically, to the nailing pattern.

19. For each gap, enter: GAPX(I), GAP(I)

where:

GAPX(I) = x-co-ordinate of the beginning of gap.

GAP(I) = Width of the gap.

20. NLOAD, NLU, PLOAD

where:

NLOAD = Number of loaded areas; NLOAD=0 for uniformly distributed load.

NLU = For NLOAD=0, NLU=1, means that even outer flanges of outside joists are loaded and NLU=0 means they are unloaded. For NLOAD≠0, NLU=1, means all joists have same load distribution and NLU=0, means otherwise.

PLOAD = Magnitude of the uniformly distributed load.

21. NDRMAS

where:

NDRMAS = Number of people or masses on the floor.

22. For each mass, enter consecutively,

RM(I), I = 1, NDRMAS (magnitude of the mass)

RC(I), I = 1, NDRMAS (damping co-efficient of the mass)

RK(I), I = 1, NDRMAS (stiffness of the mass)

VEL(I), I = 1, NDRMAS (initial impact velocity of the mass)

NJDR(I), I = 1, NDRMAS (floor element no. on which mass is located)

RXO(I), RYO(I), I = 1, NDRMAS (x/y co-ordinates of the mass)

TIMIMP(I), I = 1, NDRMAS (time for which mass is on the floor)

RFORC(I), I = 1, NDRMAS (Weight of the mass)

If NLOAD=0, go to 25.

23. For each loaded area, enter:

NLJO(I), STORE(I,5), I = 1, NLOAD

where:

NLOAD(I) = Number of joist loaded.

STORE(I,5) = Magnitude of the load, uniformly distributed over the loaded area.

24. STORE(I,1), STORE(I,2), STORE(I,3), STORE(I,4)

where:

STORE(I,1) to STORE(I,4) = Co-ordinates of the loaded area, X1, X2, Y1, Y2 respectively as shown in fig. (A.1). X1 and X2 are the global co-ordinates, while Y1 and Y2 are local to the joist element.

25. GRVITY

where:

GRVITY = Acceleration due to gravity.

26. NBC

where:

NBC = Number of boundary conditions imposed.

Fig. A.1. Loading area coordinates

If NBC=0, go to 28.

27. For each boundary condition, (I=1,NBC) enter:

IBC(I,1), IBC(I,2)

where:

IBC(I,1) = Joist no. where boundary condition exists.

IBC(I,2) = Boundary condition code number. It is equal to the sequence number of the displacement component in the vector $\{\delta_n\}$ as given by Eq. (2.3) in chapter 2 eg., if the vertical displacement of the joist (w_n) is

restricted, the code is 10.

28. NPNTS

where:

NPNTS = Number of points on floor where response is desired.

29. For each point, (I=1,NPNTS), enter:

NDEFJT(I), DEFM(I,1), DEFM(I,2)

where:

NDEFJT(I) = Joist number on which point is located.

DEFM(I,1), DEFM(I,2) = x/y co-ordinates of the point.

30. SCALE(1), SCALE(2), SCALE(3)

where:

SCALE(1) = Conversion factor for time in seconds to milliseconds.

SCALE(2) = Conversion factor for displacement in inches to mm.

SCALE(3) = Conversion factor for lb/in to KN/mm.

NOTE: The program works with any set of consistent units.

Execution Command:

a)Simulation case:

\$Run objectprog 1=-1 2=-2 3=-3 4=-4 5=-5 6=-6 7=-7 8=-8 9=-9

b) Other than simulation problem:

\$Run objectprog 1=-1 2=-2 3=-3 4=-4 5=-5 6=-6 7=-7 8=-8

in which:

1. File attached to unit 1 is the input file to the program.
2. File attached to unit 2 contains the comprehensive output.
3. Files attached to units 3, 4 and 5 contain the summary of displacements, velocities and accelerations respectively at each time step.
4. File attached to unit 6 lists the number of iterations used to solve the system of equations at each time step.
5. File attached to unit 7 contains the force imparted to the floor by the impacting mass.
6. File attached to unit 8 lists the first two peak displacements and the time of their occurrence.
7. File attached to unit 9 lists the moduli of elasticity of the joists used for simulation.

Sample Input/Output:

The following pages illustrate the input/output files produced by the program. Input file A is for the simulation case and input file B is for normal problem. The output files correspond to the simulation problem.

Output file "-2", lists the section and material properties. Also the displacements, velocities and the

accelerations with appropriate headings are listed. Output files "-3", "-4" and "-5" summarize the displacements, velocities and accelerations respectively. Only file "-3" is illustrated here, others are similar. The first column is the time in milliseconds, second the floor displacement at receiver's point in mm, third the displacement of the floor at impactor's point in mm, fourth the displacement of the receiving mass in mm and the fifth is the displacement of the impacting mass in mm. The forces in file "-7" are in KN. Peak displacements in output file "-8" can be verified from file "-3".

Input file B

```

1 1.1.9.1.1.2.1.0E-3.
2 1.4.6.
3 0.0.0.001.0.00025.
4 0.001.0.01.0.0005.
5 0.01.0.02.0.001.
6 0.02.0.04.0.002.
7 0.04.0.20.0.005.
8 0.2.0.5.0.01.
9 0.0.144.0.0.825.
10 8000.28000.500.1800.5.0E-5.
11 340000.430000.18000.500000.
12 1.5.7.25.5.0E-5.3.83E-3.
13 0.2893.1.20.17.0.
14 8.0.0.0.8800.100000.0.
15 4.17E-3.3.8.0.5.0.5.0.
16 0.
17 0.1.0.0.
18 0.
19 0.1.0.0.
20 0.282.0.518.
21 8.0.5.0.
22 400.0.400.0.
23 0.0.38.31.
24 8.5.
25 72.0.72.0.
26 0.0.0.0.
27 0.0.200.0.
28 388.4.
29 1.7.
30 1.10.
31 1.11.
32 8.7.
33 8.10.
34 8.11.
35 2.
36 8.72.0.0.0.
37 8.72.0.0.0.
38 1000.0.25.4.1.758E-4.

```

Input file A

```

1 1.1.9.1.1.2.1.0E-3.
2 1.4.6.
3 0.0.0.001.0.00025.
4 0.001.0.01.0.0005.
5 0.01.0.02.0.001.
6 0.02.0.04.0.002.
7 0.04.0.20.0.005.
8 0.2.0.5.0.01.
9 0.0.144.0.0.825.
10 8000.28000.500.1800.5.0E-5.
11 340000.430000.18000.500000.
12 1.5.7.25.5.0E-5.3.83E-3.
13 0.2893.1.20.17.0.
14 8.0.0.0.8800.100000.0.
15 4.17E-3.3.8.0.5.0.5.0.
16 0.
17 0.1.0.0.
18 0.
19 0.1.0.0.
20 0.282.0.518.
21 8.0.5.0.
22 400.0.400.0.
23 0.0.38.31.
24 8.5.
25 72.0.72.0.
26 0.0.0.0.
27 0.0.200.0.
28 388.4.
29 1.7.
30 1.10.
31 1.11.
32 8.7.
33 8.10.
34 8.11.
35 2.
36 8.72.0.0.0.
37 8.72.0.0.0.
38 1000.0.25.4.1.758E-4.

```

```

1
2 DYNAMIC ANALYSIS OF FLOOR FOR IMPACT LOADING
3
4
5 NUMBER OF FLOORS = 1          NO OF ELEMENTS = 9
6      N = 1                    NO OF CAPS = 0
7
8
9 NO OF TIME ZONES = 6          THETA = 1.40
10 ZONE 1 START=0.0             END=0.00100    INCREMENT=0.00025
11 ZONE 2 START=0.00100        END=0.01000    INCREMENT=0.00050
12 ZONE 3 START=0.01000        END=0.02000    INCREMENT=0.00100
13 ZONE 4 START=0.02000        END=0.04000    INCREMENT=0.00200
14 ZONE 5 START=0.04000        END=0.20000    INCREMENT=0.00500
15 ZONE 6 START=0.20000        END=0.50000    INCREMENT=0.01000
16
17 PROPERTIES AND DIMENSIONS FOR FLANGE
18 S = 0.180000E+02            L = 0.144000E+03            D = 0.825000E+00
19 K(X) = 0.900000E+04          K(Y) = 0.280000E+05          K(Z) = 0.180000E+04
20 D(X) = 0.340000E+06          D(Y) = 0.470000E+06          D(Z) = 0.800000E+05
21 CP = 0.417000E-02            RHO = 0.800000E-04
22
23 PROPERTIES FOR CONNECTORS
24 STIFFNESS PARALLEL TO JOIST = 0.800000E+04    STIFFNESS PERPENDICULAR TO JOIST = 0.800000E+04
25 ROTATIONAL STIFFNESS FLANGE/JOIST = 0.100000E+06
26 DAMPING COEFFICIENTS
27 CNPAL = 0.800000E+01          CNPR = 0.800000E+01          CNROT = 0.800000E+01
28 SPACING BETWEEN CONNECTORS = 0.800000E+01
29
30
31 CONSTANTS FOR JOISTS
32
33 BETA = 0.288300E+00
34 ALPHA = 0.120000E+01
35 E/G = 0.170000E+02
36
37
38
39
40 LOADING
41 JOIST      X1      X2      Y1      Y2      LOAD
42 1          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
43 2          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
44 3          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
45 4          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
46 5          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
47 6          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
48 7          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
49 8          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
50 9          0.0      0.144000E+03    -0.800000E+01    0.800000E+01    0.0
51
52 NO OF MASSES ON FLOOR = 2
53
54 MASS NO = 1
55 M = 0.382000E+00            C = 0.800000E+01            K = 0.400000E+03
56 MASS ON JOIST NO = 6
57 COORDINATES X = 0.720000E+02    Y = 0.0
58 INITIAL VELOCITY = 0.0          CONTACT TIME = 0.500000E+00
59
60 MASS NO = 2
61 M = 0.818000E+00            C = 0.800000E+01            K = 0.400000E+03
62 MASS ON JOIST NO = 5
63 COORDINATES X = 0.720000E+02    Y = 0.0
64 INITIAL VELOCITY = 0.383100E+02    CONTACT TIME = 0.500000E+00
65 JOIST PROPERTIES
66 E = 0.180318E+07    G = 0.106088E+06    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
67 E = 0.159968E+07    G = 0.940881E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
68 E = 0.122381E+07    G = 0.719887E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
69 E = 0.132400E+07    G = 0.784708E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
70 E = 0.117750E+07    G = 0.852848E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
71 E = 0.120470E+07    G = 0.787470E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
72 E = 0.154562E+07    G = 0.809187E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
73 E = 0.138153E+07    G = 0.812866E+05    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
74 E = 0.178446E+07    G = 0.105203E+06    RHO = 0.800000E-04    C = 0.383000E-02    B = 1.500    H = 7.250
75 NO OF BOUNDARY CONDITIONS = 6
76 B.C. ON JOIST NO = 1          B.C. CODE NO = 7
77 B.C. ON JOIST NO = 1          B.C. CODE NO = 10
78 B.C. ON JOIST NO = 1          B.C. CODE NO = 11
79 B.C. ON JOIST NO = 9          B.C. CODE NO = 7
80 B.C. ON JOIST NO = 9          B.C. CODE NO = 10
81 B.C. ON JOIST NO = 9          B.C. CODE NO = 11
82
83 NO OF REPLICATIONS FOR SIMULATION = 1
84 EMIN = 0.0                    EMAX = 0.500000E+07
85
86
87 WEIBULL DISTRIBUTION PARAMETERS
88 EO = 0.770000E+06            EM = 0.800000E+06            EK = 0.270000E+01
89
90
91 SOLUTION AT START
92
93
94 SOLN AT FLOOR POINT 1
95 DISPLACEMENT                VELOCITY                ACCELERATION
96 0.0                          0.0                    -0.414812E+02
97
98
99 SOLN AT FLOOR POINT 2
100 DISPLACEMENT                VELOCITY                ACCELERATION
101 0.0                          0.0                    0.462338E+04
102
103
104 SOLUTION FOR DROPPED MASS 1
105 DISPLACEMENT                VELOCITY                ACCELERATION
106 0.0                          0.0                    0.0
107
108
109 SOLUTION FOR DROPPED MASS 2
110 DISPLACEMENT                VELOCITY                ACCELERATION
111 0.0                          0.383100E+02          -0.682278E+02
112

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```

1 0.0 0.0 0.0 0.0 0.0
2 0.25000 -0.5011E-06 0.3418E-02 0.3548E-07 0.2498E-00
3 0.50000 -0.2618E-05 0.1279E-01 0.1094E-06 0.4990E-00
4 0.75000 -0.2618E-03 0.2726E-01 -0.6208E-06 0.7494E-00
5 1.00000 -0.1022E-02 0.4808E-01 -0.3673E-05 0.9977E-00
6 1.50000 -0.3481E-02 0.9480E-01 -0.2200E-04 0.1498E-01
7 2.00000 -0.4409E-02 0.1573E+00 -0.5002E-04 0.1994E-01
8 2.50000 -0.1636E-02 0.2311E+00 -0.8608E-04 0.2491E-01
9 3.00000 0.5803E-02 0.3125E+00 -0.3684E-04 0.2988E-01
10 3.50000 0.1828E-01 0.3987E+00 0.7790E-04 0.3485E-01
11 4.00000 0.3680E-01 0.4882E+00 0.3281E-03 0.3981E-01
12 4.50000 0.8158E-01 0.5808E+00 0.7633E-03 0.4478E-01
13 5.00000 0.8313E-01 0.8752E+00 0.1468E-02 0.4971E-01
14 5.50000 0.1308E+00 0.7713E+00 0.2438E-02 0.5468E-01
15 6.00000 0.1729E+00 0.8858E+00 0.3780E-02 0.5959E-01
16 6.50000 0.2194E+00 0.9670E+00 0.5524E-02 0.6452E-01
17 7.00000 0.2893E+00 0.1067E+01 0.7709E-02 0.6943E-01
18 7.50000 0.3218E+00 0.1167E+01 0.1037E-01 0.7434E-01
19 8.00000 0.3789E+00 0.1288E+01 0.1353E-01 0.7924E-01
20 8.50000 0.4308E+00 0.1388E+01 0.1721E-01 0.8413E-01
21 9.00000 0.4868E+00 0.1470E+01 0.2144E-01 0.8900E-01
22 9.50000 0.5429E+00 0.1670E+01 0.2621E-01 0.9386E-01
23 10.00000 0.5989E+00 0.1870E+01 0.3158E-01 0.9871E-01
24 11.00000 0.7103E+00 0.1888E+01 0.4385E-01 0.1084E-02
25 12.00000 0.8220E+00 0.2088E+01 0.5871E-01 0.1180E-02
26 13.00000 0.9338E+00 0.2248E+01 0.7588E-01 0.1275E-02
27 14.00000 0.1048E+01 0.2425E+01 0.9550E-01 0.1370E-02
28 15.00000 0.1154E+01 0.2589E+01 0.1178E+00 0.1463E-02
29 16.00000 0.1262E+01 0.2744E+01 0.1423E+00 0.1568E-02
30 17.00000 0.1367E+01 0.2921E+01 0.1698E+00 0.1648E-02
31 18.00000 0.1464E+01 0.3071E+01 0.1982E+00 0.1740E-02
32 19.00000 0.1565E+01 0.3213E+01 0.2314E+00 0.1830E-02
33 20.00000 0.1657E+01 0.3348E+01 0.2680E+00 0.1919E-02
34 22.00000 0.1827E+01 0.3597E+01 0.3424E+00 0.2094E-02
35 24.00000 0.1974E+01 0.3818E+01 0.4278E+00 0.2253E-02
36 26.00000 0.2104E+01 0.4018E+01 0.5218E+00 0.2428E-02
37 28.00000 0.2217E+01 0.4191E+01 0.6234E+00 0.2587E-02
38 30.00000 0.2307E+01 0.4346E+01 0.7318E+00 0.2740E-02
39 32.00000 0.2388E+01 0.4478E+01 0.8484E+00 0.2886E-02
40 34.00000 0.2467E+01 0.4580E+01 0.9856E+00 0.3028E-02
41 36.00000 0.2550E+01 0.4661E+01 0.1092E+01 0.3159E-02
42 38.00000 0.2630E+01 0.4733E+01 0.1223E+01 0.3285E-02
43 40.00000 0.2701E+01 0.4807E+01 0.1357E+01 0.3404E-02
44 45.00000 0.2829E+01 0.5025E+01 0.1708E+01 0.3666E-02
45 50.00000 0.2930E+01 0.5218E+01 0.2069E+01 0.3880E-02
46 55.00000 0.3024E+01 0.5320E+01 0.2434E+01 0.4044E-02
47 60.00000 0.3091E+01 0.5343E+01 0.2791E+01 0.4157E-02
48 65.00000 0.3120E+01 0.5308E+01 0.3131E+01 0.4220E-02
49 70.00000 0.3114E+01 0.5223E+01 0.3445E+01 0.4234E-02
50 75.00000 0.3074E+01 0.5099E+01 0.3723E+01 0.4201E-02
51 80.00000 0.3002E+01 0.4930E+01 0.3955E+01 0.4124E-02

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A part of output file "-3"

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1 NO OF ITERATIONS FOR SOLN AT TIME=0.00025 ARE 2
2 NO OF ITERATIONS FOR SOLN AT TIME=0.00050 ARE 2
3 NO OF ITERATIONS FOR SOLN AT TIME=0.00075 ARE 2
4 NO OF ITERATIONS FOR SOLN AT TIME=0.00100 ARE 2
5 NO OF ITERATIONS FOR SOLN AT TIME=0.00150 ARE 2
6 NO OF ITERATIONS FOR SOLN AT TIME=0.00200 ARE 2
7 NO OF ITERATIONS FOR SOLN AT TIME=0.00250 ARE 2
8 NO OF ITERATIONS FOR SOLN AT TIME=0.00300 ARE 2
9 NO OF ITERATIONS FOR SOLN AT TIME=0.00350 ARE 2
10 NO OF ITERATIONS FOR SOLN AT TIME=0.00400 ARE 2
11 NO OF ITERATIONS FOR SOLN AT TIME=0.00450 ARE 2
12 NO OF ITERATIONS FOR SOLN AT TIME=0.00500 ARE 2
13 NO OF ITERATIONS FOR SOLN AT TIME=0.00550 ARE 2
14 NO OF ITERATIONS FOR SOLN AT TIME=0.00600 ARE 2
15 NO OF ITERATIONS FOR SOLN AT TIME=0.00650 ARE 2
16 NO OF ITERATIONS FOR SOLN AT TIME=0.00700 ARE 2
17 NO OF ITERATIONS FOR SOLN AT TIME=0.00750 ARE 2
18 NO OF ITERATIONS FOR SOLN AT TIME=0.00800 ARE 2
19 NO OF ITERATIONS FOR SOLN AT TIME=0.00850 ARE 2
20 NO OF ITERATIONS FOR SOLN AT TIME=0.00900 ARE 2
21 NO OF ITERATIONS FOR SOLN AT TIME=0.00950 ARE 2
22 NO OF ITERATIONS FOR SOLN AT TIME=0.01000 ARE 2
23 NO OF ITERATIONS FOR SOLN AT TIME=0.01100 ARE 3
24 NO OF ITERATIONS FOR SOLN AT TIME=0.01200 ARE 3
25 NO OF ITERATIONS FOR SOLN AT TIME=0.01300 ARE 3
26 NO OF ITERATIONS FOR SOLN AT TIME=0.01400 ARE 3
27 NO OF ITERATIONS FOR SOLN AT TIME=0.01500 ARE 3
28 NO OF ITERATIONS FOR SOLN AT TIME=0.01600 ARE 3
29 NO OF ITERATIONS FOR SOLN AT TIME=0.01700 ARE 3
30 NO OF ITERATIONS FOR SOLN AT TIME=0.01800 ARE 3
31 NO OF ITERATIONS FOR SOLN AT TIME=0.01900 ARE 3
32 NO OF ITERATIONS FOR SOLN AT TIME=0.02000 ARE 3
33 NO OF ITERATIONS FOR SOLN AT TIME=0.02200 ARE 4
34 NO OF ITERATIONS FOR SOLN AT TIME=0.02400 ARE 4
35 NO OF ITERATIONS FOR SOLN AT TIME=0.02600 ARE 4
36 NO OF ITERATIONS FOR SOLN AT TIME=0.02800 ARE 4
37 NO OF ITERATIONS FOR SOLN AT TIME=0.03000 ARE 4
38 NO OF ITERATIONS FOR SOLN AT TIME=0.03200 ARE 4
39 NO OF ITERATIONS FOR SOLN AT TIME=0.03400 ARE 4
40 NO OF ITERATIONS FOR SOLN AT TIME=0.03600 ARE 4
41 NO OF ITERATIONS FOR SOLN AT TIME=0.03800 ARE 4
42 NO OF ITERATIONS FOR SOLN AT TIME=0.04000 ARE 4
43 NO OF ITERATIONS FOR SOLN AT TIME=0.04500 ARE 4
44 NO OF ITERATIONS FOR SOLN AT TIME=0.05000 ARE 4
45 NO OF ITERATIONS FOR SOLN AT TIME=0.05500 ARE 4
46 NO OF ITERATIONS FOR SOLN AT TIME=0.06000 ARE 4
47 NO OF ITERATIONS FOR SOLN AT TIME=0.06500 ARE 4
48 NO OF ITERATIONS FOR SOLN AT TIME=0.07000 ARE 4
49 NO OF ITERATIONS FOR SOLN AT TIME=0.07500 ARE 4
50 NO OF ITERATIONS FOR SOLN AT TIME=0.08000 ARE 4
51 NO OF ITERATIONS FOR SOLN AT TIME=0.08500 ARE 4

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A part of output file "-6"

1	0.0	0.1082E+01
2	0.250000	0.1061E+01
3	0.500000	0.1035E+01
4	0.750000	0.1031E+01
5	1.000000	0.1030E+01
6	1.500000	0.1030E+01
7	2.000000	0.1033E+01
8	2.500000	0.1042E+01
9	3.000000	0.1056E+01
10	3.500000	0.1077E+01
11	4.000000	0.1098E+01
12	4.500000	0.1120E+01
13	5.000000	0.1143E+01
14	5.500000	0.1167E+01
15	6.000000	0.1180E+01
16	6.500000	0.1214E+01
17	7.000000	0.1237E+01
18	7.500000	0.1261E+01
19	8.000000	0.1288E+01
20	8.500000	0.1311E+01
21	9.000000	0.1336E+01
22	9.500000	0.1361E+01
23	10.000000	0.1388E+01
24	11.000000	0.1440E+01
25	12.000000	0.1492E+01
26	13.000000	0.1545E+01
27	14.000000	0.1598E+01
28	15.000000	0.1651E+01
29	16.000000	0.1704E+01
30	17.000000	0.1758E+01
31	18.000000	0.1807E+01
32	19.000000	0.1856E+01
33	20.000000	0.1907E+01
34	22.000000	0.2002E+01
35	24.000000	0.2093E+01
36	26.000000	0.2178E+01
37	28.000000	0.2257E+01
38	30.000000	0.2333E+01
39	32.000000	0.2406E+01
40	34.000000	0.2475E+01
41	36.000000	0.2534E+01
42	38.000000	0.2581E+01
43	40.000000	0.2615E+01
44	45.000000	0.2679E+01
45	50.000000	0.2725E+01
46	55.000000	0.2745E+01
47	60.000000	0.2732E+01
48	65.000000	0.2685E+01
49	70.000000	0.2608E+01
50	75.000000	0.2506E+01
51	80.000000	0.2385E+01

A part of output file "-7"

1	0.3120E+01	55.00	0.1860E+01	310.00
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Output file "-8"

1	0.140E+07	0.180E+07	0.122E+07	0.133E+07	0.118E+07	0.130E+07	0.155E+07	0.138E+07	0.179E+07
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Output file "-9"

APPENDIX III

DYNAMIC FLOOR ANALYSIS PROGRAM

PROGRAM LISTING

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1      C *****
2      C PROGRAM FOR DYNAMIC ANALYSIS OF FLOORS
3      C *****
4      C
5      C THE NUMBER OF STIFFENERS ARE LIMITED TO 10
6      C THE NUMBER OF FOURIER SERIES TERMS WHICH CAN BE CONSIDERED
7      C FOR SOLUTION ARE LIMITED TO 3
8      C
9      C
10     C
11     C IMPLICIT REAL*8(A - H, O - Z)
12     C COMMON /B4/ ETA(5), H(5)
13     C COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL, D, ALPHA, BETA, NJTM,
14     C   1 BJ(10), NJ(10), NPLOR, INPTE
15     C COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPER,
16     C   1 RKROT, RHOC, CP, CNPAL, CNPER, CNROT
17     C COMMON /B7/ GAPX(5), GAPO(5), GAPX(5), GAP(5), ENL, XIN, NGAPS,
18     C   1 NAI, NDISCR
19     C COMMON /B10/ RC(5), RK(5), RM(5), RFORC1(5), NDRMAS, NJDR(5),
20     C   1 RXO(5), RYO(5), VEL(5), TIMIMP(5)
21     C COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
22     C COMMON /B12/ YMOD(10), DNSTY(10), CB(10), THETA, GRVITY, SMOO(10)
23     C COMMON /B13/ GMASS(3,2584), GDAMP(3,2584), ADAMP(3,5032),
24     C   1 GSTIF(3,2584), ASTIF(3,5032), DCPMAS(3,2584), FORCE1(3,136)
25     C COMMON /B14/ P1, PIN2, PIN4, NEO, LMB, NA, NAI, AJT(10), RIV(10),
26     C   1 RIZ(10), RIT(10)
27     C COMMON /B15/ NLOAD, NLU, PLOAD, STORE(10,5), NLJD(10)
28     C COMMON /B16/ SVEC1(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
29     C   1 SVEC3(3,136), RVEC3(5)
30     C COMMON /B17/ EPSTIF(3,2584), APSTIF(3,5032), REPSTF(5),
31     C   1 REPECT(15,136)
32     C COMMON /B18/ FORCE2(3,136), RFORCE2(5)
33     C COMMON /B19/ ISYM, NTMZON, TIME(10,3), REG, TOL
34     C COMMON /B20/ EO, EM, EK, EMIN, EMAX, SEED, NREPL
35     C COMMON /B21/ NBC, IBC(50,2)
36     C COMMON /B22/ NDEFJT(10), DEFM(10,2), NPNTS
37     C COMMON /B23/ AO, A1, A2, A3, A4, A5, A6, A7, A8, A9
38     C COMMON /B25/ SCALE(3), AMPL1, OCCUR1, AMPL2, OCCUR2
39
40     C *****DEFINING VARIABLES*****
41     C
42     C AO...A8 :CONSTANT FACTORS USED FOR EFFECTIVE STIFFNESS MATRIX
43     C AND EFFECTIVE LOAD VECTOR
44     C AFSTIF :OFF-DIAGONAL SUBMATRICES OF EFFECTIVE STIFFNESS MATRIX
45     C STORED COLUMNWISE
46     C ASTIF :OFF-DIAGONAL SUBMATRICES OF STIFFNESS MATRIX STORED
47     C COLUMNWISE
48     C ADAMP :OFF-DIAGONAL SUBMATRICES OF DAMPING MATRIX STORED
49     C COLUMNWISE
50     C ALPHA :SHEAR DEFLECTION CONSTANT FOR RECTANGULAR C.S.
51     C AMPL1 :FIRST DISPLACEMENT PEAK
52     C AMPL2 :SECOND DISPLACEMENT PEAK
53     C BETA :TORSION CONSTANT
54     C BJ(1) :WIDTH OF JOIST 1
55     C CB :DAMPING COEFFICIENT OF JOIST
56     C CP :DAMPING COEFFICIENT OF SLAB
57     C CNPAL :DAMPING COEFFICIENT FOR SLIP PARALLEL TO CONNECTORS
58     C CNPER :DAMPING COEFFICIENT FOR SLIP PERPENDICULAR TO
59     C CONNECTORS
60     C CNROT :DAMPING COEFFICIENT FOR ROTATIONAL SLIP AT CONNECTORS
61     C D :THICKNESS OF SLAB
62     C DNSTY(1) :MASS DENSITY OF JOIST 1
63     C DXBDY :AXIAL STIFFNESS OF SLAB IN X&Y DIRECTIONS RESPECTIVELY
64     C DYSDG :PARAMETERS FOR AXIAL STIFFNESS RELATED TO POISSON'S
65     C EFFECT AND SHEAR RESPECTIVELY
66     C DCPMAS :DECOMPOSED DIAGONAL SUBMATRICES OF MASS MATRIX STORED
67     C COLUMNWISE
68     C EPSTIF :DECOMPOSED DIAGONAL SUBMATRICES OF EFFECTIVE STIFFNESS
69     C MATRIX STORED COLUMNWISE
70     C ENL :SPACING OF CONNECTORS
71     C FORCE1 :LOAD VECTOR
72     C FORCE2 :EFFECTIVE LOAD VECTOR AND ALSO USED AS WORKING LOAD
73     C VECTOR
74     C GDAMP :DIAGONAL SUBMATRICES OF DAMPING MATRIX
75     C GSTIF :DIAGONAL SUBMATRICES OF STIFFNESS MATRIX
76     C GRVITY :ACCELERATION DUE TO GRAVITY
77     C NJ(1) :HEIGHT OF JOIST 1
78     C ISYM :#1, IF SYMMETRIC PROBLEM; # 0 IF NON-SYMMETRIC
79     C IBC(1,1) :NO. OF JOIST ON WHICH B.C. 1 IS IMPOSED
80     C IBC(1,2) :CODE NO. FOR B.C. 1
81     C INPTE :FOR SIMULATION = 1 ; OTHERWISE = 2
82     C LMB :HALF BAND WIDTH
83     C NM :MAXM ORDER OF SINE/COSINE TERMS IN FOURIER SERIES
84     C NMAX :MAXM NO. OF TERMS IN FOURIER SERIES
85     C NJT :NO. OF JOISTS
86     C NGAPS :NO. OF GAPS IN FLOOR
87     C NAI :NO. OF CONNECTORS BETWEEN ONE JOIST AND SLAB
88     C NDISCR :#0, IF ACTUAL CONNECTORS TRANSFORMED TO AN EQUIVALENT
89     C CONTINUOUS CONNECTOR FOR ANALYSIS
90     C NDRMAS :#1, IF CONNECTORS TREATED AS DISCRETE
91     C NJDR(1) :NO. OF MASSES ON FLOOR
92     C NLOAD :NO. OF JOIST UNDER MASS 1
93     C NLU :#0, IF LOADED AREAS; IF #0, LOAD UNIFORMLY DISTRIBUTED
94     C NLJD(1) :#1, IF ALL JOISTS HAVE SAME LOAD DISTRIBUTION
95     C :#0, IF DIFFERENT JOISTS HAVE DIFFERENT LOADINGS
96     C NLJD(1) :NO. OF JOIST LOADED WITH LOADING 1
97     C NTMZON :NO. OF TIME ZONES
98     C NBC :NO. OF BOUNDARY CONDITIONS
99     C NPNTS :NO. OF POINTS ON FLOOR WHERE RESPONSE DESIRED
100    C NDEFJT(1) :NO. OF JOIST ON WHICH POINT 1 IS LOCATED
101    C NEO :NO. OF UNKNOWN IN PROBLEM OR NO. OF EQUATIONS
102    C NREPL :NO. OF REPLICATIONS FOR SIMULATION
103    C NPROP :#1, IF ALL BEAMS HAVE SAME PROPERTIES; #0, OTHERWISE
104    C OCCUR1 :TIME OF OCCURENCE OF FIRST DISPLACEMENT PEAK
105    C OCCUR2 :TIME OF OCCURENCE OF SECOND DISPLACEMENT PEAK
106    C PLOAD :VALUE OF UNIFORMLY DISTRIBUTED LOAD
107    C RL :SPAN OF FLOOR
108    C RKX&RKV :BENDING STIFFNESS OF SLAB IN X&Y DIRECTIONS
109    C RESPECTIVELY
110    C RKV&RKG :PARAMETERS FOR PLATE BENDING CONNECTED RESPECTIVELY

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111 C          TO POISSON'S EFFECT AND SHEAR BY TORSION
112 C      RXO(I) : X COORDINATE OF MASS I
113 C      RYO(I) : Y COORDINATE OF MASS I
114 C      RSTIF  : VECTOR IN STIFFNESS MATRIX DUE TO INTERACTION OF
115 C              MASS AND FLOOR
116 C      RDAMP   : SAME AS ABOVE EXCEPT FOR DAMPING MATRIX
117 C      REFECT  : SAME AS ABOVE EXCEPT FOR EFFECTIVE STIFFNESS MATRIX
118 C      RFORC1  : LOAD VECTOR FOR MASSES
119 C      RFORC2  : EFFECTIVE LOAD VECTOR FOR MASSES & ALSO USED AS
120 C              WORKING LOAD VECTOR
121 C      RVEC1,  : DISPLACEMENT, VELOCITY AND ACCELERATION
122 C      RVEC2,  : RESPECTIVELY OF MASSES
123 C      RVEC3
124 C      RM,RC,RK : VALUES OF MASS, DAMPING COEFFICIENT AND STIFFNESS FOR
125 C              MASSES
126 C      REPSTF  : EFFECTIVE STIFFNESS FOR MASSES
127 C      REG     : E/G RATIO
128 C      RKPAL   : CONNECTOR LOAD-SLIP MODULUS PARALLEL TO JOIST
129 C      RKPERR  : CONNECTOR LOAD-SLIP MODULUS PERPENDICULAR TO JOIST
130 C      RKROT   : ROTATIONAL SLIP MODULUS AT CONNECTORS
131 C      RHOC    : MASS DENSITY OF SLAB
132 C      S       : SPACING OF JOISTS
133 C      SMOD    : SHEAR MODULUS
134 C      STREN   : STRENGTH OF JOISTS
135 C      SCALE   : MULTIPLYING FACTORS : SEE ROUTINE RESULT
136 C      SEED    : RANDOM NUMBER INITIALIZER
137 C      TIMIMP  : CONTACT TIME OF MASS WITH FLOOR
138 C      VEL     : VELOCITY OF FALL OF MASSES
139 C      YMOD    : YOUNG'S MODULUS OF ELASTICITY
140 C
141 C
142 C      *****
143 C      PI = 4.D0 * DATAN(1.D0)
144 C      ETA(1) = 0.932469514203152D0
145 C      ETA(2) = 0.661209386468265D0
146 C      ETA(3) = 0.238619186083319D0
147 C      H(1) = 0.171324492379170D0
148 C      H(2) = 0.380761573048138D0
149 C      H(3) = 0.467913934572691D0
150 C      DO 10 I = 1, 3
151 C          ETA(7 - I) = -ETA(I)
152 C          H(7 - I) = H(I)
153 C
154 C      10 CONTINUE
155 C      CALL GENMTX
156 C      CALL DATA
157 C      IF (INPTE.EQ. 1) GO TO 20
158 C      GO TO 40
159 C
160 C      20 NCOUNT = 0
161 C      X = RAND(SEED)
162 C      30 CALL EPICK(NJT)
163 C      40 DO 170 NF = 1, NFLOP
164 C          IF (NF.EQ. 1) GO TO 50
165 C          CALL UPDATE(NF)
166 C          DO 60 I = 1, NJT
167 C              AJT(I) = BJ(I) = HJ(I)
168 C              RIY(I) = BJ(I) = HJ(I) ** 3 / 12.D0
169 C              RIZ(I) = HJ(I) = BJ(I) ** 3 / 12.D0
170 C              RIT(I) = BETA = HJ(I) = BJ(I) ** 3
171 C              SMOD(I) = YMOD(I) / REG
172 C          60 CONTINUE
173 C          PIN2 = PI ** 2 / (2.D0*RL)
174 C          PIN4 = PI ** 4 / (2.D0*RL**3)
175 C          NEO = NJT = 13 + 8
176 C          LMB = 19
177 C          NA = 18 = NEO
178 C          NA1 = 37 = NEO
179 C          NSTEP = 1
180 C          IF (ISYM.EQ. 1) NSTEP = 2
181 C          NMAX = NM
182 C          IF (NSTEP.EQ. 2) NMAX = (NM + 1) / 2
183 C          CALL PRINT
184 C          CALL ASMBLY
185 C          DO 70 I = 1, NMAX
186 C              DO 70 J = 1, NEO
187 C                  SVEC1(I,J) = 0.D0
188 C          70 SVEC2(I,J) = 0.D0
189 C          IF (NORMAS.EQ. 0) GO TO 80
190 C          DO 80 I = 1, NORMAS
191 C              RVEC1(I) = 0.D0
192 C          80 RVEC2(I) = VEL(I)
193 C          PERIOD = TIMIMP(NORMAS)
194 C          90 CONTINUE
195 C          AMPL1 = 0.D0
196 C          AMPL2 = 0.D0
197 C          OCCUR1 = 0.D0
198 C          OCCUR2 = 0.D0
199 C          CALL AXLRN(NEO, LMB, NA)
200 C          WRITE (2,100)
201 C          100 FORMAT (/, 10X, 'SOLUTION AT START', /)
202 C          ELTIM = 0.D0
203 C          CALL RESULT(PERIOD, ELTIM, NORMAS, PI)
204 C          DO 180 I = 1, NTMZON
205 C              ELTIM = TIME(I,1)
206 C              A0 = 8.D0 / ((THETA*TIME(I,3))**2)
207 C              A1 = 3.D0 / (THETA*TIME(I,3))
208 C              A2 = 2.D0 = A1
209 C              A3 = THETA * TIME(I,3) / 2.D0
210 C              A4 = A0 / THETA
211 C              A5 = -A2 / THETA
212 C              A6 = 1.D0-3.D0 / THETA
213 C              A7 = TIME(I,3) / 2.D0
214 C              A8 = TIME(I,3) ** 2 / 8.D0
215 C              A9 = TIME(I,3)
216 C              CALL EPMAT(NMAX, NA, NA1, LMB, NEO)
217 C              ELTIM = ELTIM + TIME(I,3)
218 C          110 CALL EPLDAD(NMAX, NEO, LMB)
219 C              CALL SOLVE(NM, NMAX, NEO, LMB, TOL, ELTIM, NA, NORMAS)
220 C              WRITE (2,120) ELTIM
221 C          120 FORMAT (/, 10X, 'SOLUTION AT TIME=', F7.5, /)
222 C              CALL RESULT(PERIOD, ELTIM, NORMAS, PI)

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221      ELTIM = ELTIM + TIME(1,3)
222      C1 = 0.000100 * TIME(1,3)
223      C2 = ELTIM - TIME(1,2)
224      C3 = ELTIM - TIMIMP(NORMAS)
225      C4 = TIME(1,3) + C1
226      IF (C3 .GT. C1 .AND. C3 .LT. C4) GO TO 130
227      IF (C2 .GT. C1) GO TO 150
228      GO TO 110
229      IF (1 .EQ. NTMZON .AND. C2 .GT. C1) GO TO 150
230      NORMAS = NORMAS - 1
231      CALL ASMBLY
232      CALL AXLRTH(NEO, LMS, NA)
233      CALL EPMAT(NMAX, NA, NA1, LMS, NEO)
234      WRITE (2,140)
235      140      FORMAT (/, 10X, 'SOLUTION AT SEPARATION OF MASS', /)
236      SEPTIM = ELTIM - TIME(1,3)
237      CALL RESULT(PERIOD, SEPTIM, NORMAS, P1)
238      IF (C2 .GT. C1) GO TO 150
239      GO TO 110
240      150      CONTINUE
241      WRITE (8,180) AMPL1, OCCUR1, AMPL2, OCCUR2
242      180      FORMAT (E11.4, 1X, F8.2, 1X, E11.4, 1X, F8.2)
243      170      CONTINUE
244      IF (INPTE .EQ. 2) GO TO 180
245      NCOUNT = NCOUNT + 1
246      IF (NCOUNT .EQ. NREPL) GO TO 180
247      GO TO 30
248      180      CONTINUE
249      STOP
250      END
251
252      C
253      SUBROUTINE DATA
254      IMPLICIT REAL*8(A - H, O - Z)
255      COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL, D, ALPHA, BETA, NJTM,
256      1      BJ(10), HJ(10), NPLOR, INPTE
257      COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPFR,
258      1      RKROT, RHOC, CP, CNPAL, CNPER, CNROT
259      COMMON /B7/ GAPX(5), GAPO(5), GAPX(5), GAP(5), ENL, XIN, NGAPS,
260      1      NA1, NOISCR
261      COMMON /B10/ RC(5), RK(5), RM(5), RFORC(5), NORMAS, NJDR(5),
262      1      RXO(5), RYO(5), VEL(5), TIMIMP(5)
263      COMMON /B12/ YMOD(10), DNSTY(10), CB(10), THETA, GRVITY
264      COMMON /B15/ NLOAD, NLU, PLOAD, STORE(10,5), NLJO(10)
265      COMMON /B18/ ISYM, NTMZON, TIME(10,3), REG, TOL
266      COMMON /B20/ EO, EM, EK, EMIN, EMAX, SEED, NREPL
267      COMMON /B21/ NBC, IBC(50,2)
268      COMMON /B22/ NDEFJT(10), DEFM(10,2), NPNTS
269      COMMON /B25/ SCALE(3)
270      INTEGER LIST(1) /'/'
271      READ (1,LIST) NPLOR, NM, NJT, ISYM, NPROP, INPTE, TOL
272      READ (1,LIST) THETA, NTMZON
273      DO 10 I = 1, NTMZON
274      10      READ (1,LIST) (TIME(I,J), J=1,3)
275      IF (INPTE .EQ. 2) GO TO 20
276      READ (1,LIST) NREPL, SEED
277      READ (1,LIST) EMIN, EMAX
278      READ (1,LIST) EO, EM, EK
279      20      CONTINUE
280      READ (1,LIST) S, RL, D
281      READ (1,LIST) RKX, RKY, RKV, RKG, RHOC
282      READ (1,LIST) DX, DY, DV, DG
283      IF (NPROP .EQ. 0) GO TO 60
284      READ (1,LIST) BJT, HJT, RHOJT, CBT
285      IF (INPTE .EQ. 1) GO TO 40
286      READ (1,LIST) EJT
287      DO 30 I = 1, NJT
288      30      YMOD(I) = EJT
289      40      DO 50 I = 1, NJT
290      50      BJ(I) = BJT
291      50      HJ(I) = HJT
292      50      DNSTY(I) = RHOJT
293      50      CB(I) = CBT
294      GO TO 80
295      80      READ (1,LIST) (BJ(I), I=1, NJT)
296      READ (1,LIST) (HJ(I), I=1, NJT)
297      IF (INPTE .EQ. 1) GO TO 70
298      READ (1,LIST) (YMOD(I), I=1, NJT)
299      70      READ (1,LIST) (DNSTY(I), I=1, NJT)
300      READ (1,LIST) (CB(I), I=1, NJT)
301      80      READ (1,LIST) BETA, ALPHA, REG
302      NJTM = 0.000
303      DO 90 I = 1, NJT
304      90      NJTM = NJTM + HJ(I)
305      NJTM = NJTM / NJT
306      READ (1,LIST) ENL, XIN, RKPAL, RKPFR, RKROT, NOISCR
307      READ (1,LIST) CP, CNPAL, CNPER, CNROT
308      NA1 = (RL - 2.000 * XIN) / ENL
309      NA1 = NA1 + 1
310      READ (1,LIST) NGAPS
311      IF (NGAPS .EQ. 0) GO TO 120
312      READ (1,LIST) NGT
313      DO 110 I = 1, NGAPS
314      110      READ (1,LIST) GAPX(I), GAP(I)
315      GAPXO(I) = GAPX(I)
316      GAPO(I) = GAP(I)
317      IF (NGT .EQ. 0) GO TO 110
318      NG = (GAPX(I) - XIN) / ENL
319      XG1 = XIN + NG * ENL
320      XG2 = XG1 + ENL
321      IF (XG1 .EQ. GAPX(I)) GO TO 100
322      XG3 = GAPX(I) + GAP(I)
323      GAPX(I) = XG1
324      GAP(I) = 2.000 * ENL
325      IF (XG2 .GT. XG3) GAP(I) = ENL
326      GO TO 110
327      100      GAPX(I) = XG1 - ENL
328      GAP(I) = 2.000 * ENL
329      110      CONTINUE
330      120      CONTINUE
331      READ (1,LIST) NLOAD, NLU, PLOAD

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331      READ (1,LIST) NDRMAS
332      IF (NDRMAS.EQ. 0) GO TO 130
333      READ (1,LIST) (RM(I),I=1,NDRMAS)
334      READ (1,LIST) (RC(I),I=1,NDRMAS)
335      READ (1,LIST) (RK(I),I=1,NDRMAS)
336      READ (1,LIST) (VEL(I),I=1,NDRMAS)
337      READ (1,LIST) (NJDR(I),I=1,NDRMAS)
338      READ (1,LIST) (RXO(I),I=1,NDRMAS)
339      READ (1,LIST) (RYO(I),I=1,NDRMAS)
340      READ (1,LIST) (TIMIMP(I),I=1,NDRMAS)
341      READ (1,LIST) (RFORC(I),I=1,NDRMAS)
342 130 CONTINUE
343      IF (NLOAD.NE. 0) GO TO 150
344      DO 140 I = 1, NJT
345          STORE(I,1) = 0.00
346          STORE(I,2) = RL
347          STORE(I,3) = -S / 2.000
348          STORE(I,4) = S / 2.000
349          STORE(I,5) = PLOAD
350 140 CONTINUE
351      GO TO 170
352 150 DO 160 I = 1, NLOAD
353          READ (1,LIST) NLJO(I), STORE(I,5)
354          READ (1,LIST) (STORE(I,J),J=1,4)
355 160 CONTINUE
356 170 CONTINUE
357      READ (1,LIST) GRVITY
358      READ (1,LIST) NBC
359      IF (NBC.EQ. 0) GO TO 190
360      DO 180 I = 1, NBC
361          READ (1,LIST) (ISC(I,J),J=1,2)
362 180 CONTINUE
363      READ (1,LIST) NPNTS
364      IF (NPNTS.EQ. 0) GO TO 210
365      DO 200 I = 1, NPNTS
366          READ (1,LIST) NDEFJT(I), DEPM(I,1), DEPM(I,2)
367 200 CONTINUE
368      READ (1,LIST) (SCALE(I),I=1,3)
369      RETURN
370      END
371
372      C
373      SUBROUTINE PRINT
374      IMPLICIT REAL*8(A - H,D - Z)
375      COMMON /B5/ NM, NSTEP, WMAX, NJT, S, RL, D, ALPHA, BETA, NJTM,
376      1      BJ(10), MJ(10), WFLOR, INPTE
377      COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPER,
378      1      RKROD, RHOC, CP, CNPAL, CNPER, CNROT
379      COMMON /B7/ GAPX(5), GAPY(5), GAPZ(5), GAP(5), ENL, XIN, NGAPS,
380      1      NAI, NDISC
381      COMMON /B10/ RC(5), RK(5), RM(5), RFORC(5), NDRMAS, NJDR(5),
382      1      RXO(5), RYO(5), VEL(5), TIMIMP(5)
383      COMMON /B12/ YMOD(10), DNSTY(10), CB(10), THETA, GRVITY, SMOD(10)
384      COMMON /B15/ NLOAD, NLU, PLOAD, STORE(10,5), NLJO(10)
385      COMMON /B19/ ISYM, NTMZON, TIME(10,3), REG, TOL
386      COMMON /B20/ EO, EM, EK, EMIN, EMAX, SEED, NREPL
387      COMMON /B21/ NBC, IBC(50,2)
388      WRITE (2,10)
389      10 FORMAT (/, 'DYNAMIC ANALYSIS OF FLOOR FOR IMPACT LOADING', //)
390      WRITE (2,20) NFLOR, NJT, NM, NGAPS
391      20 FORMAT (' NUMBER OF FLOORS =', I5, 10X, 'NO OF ELEMENTS=', I5, //,
392      1      10X, 'NM=', I5, 10X, 'NO OF GAPS =', I5, //)
393      WRITE (2,30) NTMZON, THETA
394      30 FORMAT ('NO OF TIME ZONES=', I3, 10X, 'THETA=', F5.2)
395      DO 40 I = 1, NTMZON
396      40 WRITE (2,50) I, (TIME(I,J),J=1,3)
397      50 FORMAT ('ZONE', I2, 5X, 'START=', F7.5, 5X, 'END=', F7.5, 5X,
398      1      'INCREMENT=', F7.5)
399      WRITE (2,60)
400      60 FORMAT (' PROPERTIES AND DIMENSIONS FOR FLANGE')
401      WRITE (2,70) S, RL, D
402      70 FORMAT (' S =', E13.6, 10X, 'L =', E13.6, 10X, 'D =', E13.6)
403      WRITE (2,80) RKX, RKY, RKV, RKG
404      80 FORMAT (' K(X) =', E13.6, 5X, 'K(Y) =', E13.6, 5X,
405      1      'K(V) =', E13.6, 5X, 'K(G) =', E13.6)
406      WRITE (2,90) DX, DY, DV, DG
407      90 FORMAT (' D(X) =', E13.6, 5X, 'D(Y) =', E13.6, 5X,
408      1      'D(V) =', E13.6, 5X, 'D(G) =', E13.6)
409      WRITE (2,95) CP, RHOC
410      95 FORMAT ('CP =', E13.6, 5X, 'RHOC =', E13.6)
411      WRITE (2,100)
412      100 FORMAT (/, ' PROPERTIES FOR CONNECTORS')
413      WRITE (2,110) RKPAL, RKPER, RKROT
414      110 FORMAT (' STIFFNESS PARALLEL TO JOIST =', E13.6, 10X, 'STIFFNESS',
415      1      ' PERPENDICULAR TO JOIST =', E13.6, //,
416      2      ' ROTATIONAL STIFFNESS FLANGE/JOIST =', E13.6)
417      WRITE (2,120) CNPAL, CNPER, CNROT
418      120 FORMAT ('DAMPING COEFFICIENTS', //, 'CNPAL =', E13.6, 5X, 'CNPER =',
419      1      E13.6, 5X, 'CNROT =', E13.6)
420      WRITE (2,130) ENL
421      130 FORMAT (' SPACING BETWEEN CONNECTORS =', E13.6, //)
422      WRITE (2,140) BETA, ALPHA, REG
423      140 FORMAT (' CONSTANTS FOR JOISTS', //, ' BETA =', E13.6, //,
424      1      ' ALPHA =', E13.6, //, ' E/G =', E13.6, //)
425      WRITE (2,150) NLOAD, NLU
426      150 FORMAT (/, ' LOADING', 15X, 'NLOAD =', I3, 5X, 'NLU =', I3)
427      WRITE (2,160)
428      160 FORMAT (' JOIST', 11X, 'X1', 14X, 'X2', 14X, 'Y1', 14X, 'Y2',
429      1      12X, 'LOAD')
430      IF (NLOAD.NE. 0) GO TO 180
431      DO 170 I = 1, NJT
432          WRITE (2,200) I, (STORE(I,J),J=1,5)
433 170 CONTINUE
434      GO TO 210
435 180 DO 190 I = 1, NLOAD
436          WRITE (2,200) NLJO(I), (STORE(I,J),J=1,5)
437 200 FORMAT (3X, I2, 3X, 5(3X,E13.6))
438 210 WRITE (2,220) NDRMAS
439      220 FORMAT (/, 10X, 'NO OF MASSES ON FLOOR =', I3, //)
440      DO 270 I = 1, NDRMAS
441          WRITE (2,230) I

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441 230 FORMAT (10X, 'MASS NO=', I3)
442 WRITE (2,240) RM(I), RC(I), RK(I)
443 FORMAT (10X, 'M=', E13.6, 10X, 'C=', E13.6, 10X, 'K=', E13.6)
444 WRITE (2,250) NJDR(I), RXO(I), RYO(I)
445 250 FORMAT (10X, 'MASS ON JOIST NO=', I2, /, 'COORDINATES', 10X,
446 1 'X=', E13.6, 5X, 'Y=', E13.6)
447 WRITE (2,260) VEL(I), TIMIMP(I)
448 260 FORMAT ('INITIAL VELOCITY=', E13.6, 5X, 'CONTACT TIME=', E13.6)
449 270 CONTINUE
450 IF (NGAPS .EQ. 0) GO TO 310
451 WRITE (2,280)
452 280 FORMAT (///, 'GAPS', 5X, 'X', 7X, 'WIDTH')
453 DO 290 I = 1, NGAPS
454 290 WRITE (2,300) GAPX(I), GAP(I)
455 300 FORMAT (1X, 4X, F8.3, 2X, F8.3)
456 310 CONTINUE
457 WRITE (2,320)
458 320 FORMAT (10X, 'JOIST PROPERTIES', /)
459 DO 330 I = 1, NJT
460 330 WRITE (2,340) YMOD(I), SMOD(I), DNSTY(I), CB(I), BJ(I), NJ(I)
461 340 FORMAT ('E=', E13.6, 2X, 'G=', E13.6, 2X, 'RHO=', E13.6, 2X, 'C=',
462 1 E13.6, 2X, 'B=', F7.3, 2X, 'H=', F7.3)
463 WRITE (2,350) NBC
464 350 FORMAT ('NO OF BOUNDARY CONDITIONS=', I3)
465 IF (NBC .EQ. 0) GO TO 380
466 DO 360 I = 1, NBC
467 360 WRITE (2,370) (IBC(I,J), J=1,2)
468 370 FORMAT ('B.C. ON JOIST NO=', I3, 5X, 'B.C. CODE NO=', I2)
469 380 CONTINUE
470 IF (INPTE .EQ. 2) GO TO 420
471 WRITE (2,380) NREPL
472 380 FORMAT (/, 'NO OF REPLICATIONS FOR SIMULATION=', I7)
473 WRITE (2,400) EMIN, EMAX
474 400 FORMAT (5X, 'EMIN=', E13.6, 10X, 'EMAX=', E13.6, /)
475 WRITE (2,410) EO, EM, EK
476 410 FORMAT (/, 'WEIBULL DISTRIBUTION PARAMETERS', /, 5X, 'EO=', E13.6,
477 1 5X, 'EM=', E13.6, 5X, 'EK=', E13.6, /)
478 420 CONTINUE
479 RETURN
480 END
481 C
482 SUBROUTINE ASMBLY
483 IMPLICIT REAL*8(A - H, O - Z)
484 COMMON /B4/ ETA(6), H(6)
485 COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL, D, ALPHA, BETA, NJTM,
486 1 BJ(10), NJ(10)
487 COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPER,
488 1 RKR0T, RHOC, CP, CNPAL, CNPER, CNROT
489 COMMON /B7/ GAPXO(5), GAPO(5), GAPX(5), GAP(5), ENL, XIN, NGAPS,
490 1 NAI, NDISCR
491 COMMON /B8/ DMAS(19,19), STIFF(19,19), DAMP(19,19)
492 COMMON /B9/ EJT, GJT, RHOJT, PLO, X1, X2, Y1, Y2
493 COMMON /B10/ RC(5), RK(5), RM(5), RPDRC(5), NORMAS, NJDR(5),
494 1 RXO(5), RYO(5)
495 COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
496 COMMON /B12/ YMOD(10), DNSTY(10), CB(10), THETA, CRVITY, SMOD(10)
497 COMMON /B13/ GMAS(3,2584), GDAMP(3,2584), ADAMP(3,5032),
498 1 GSTIF(3,2584), ASTIF(3,5032), DCPMAS(3,2584), FORCE1(3,136)
499 COMMON /B14/ P1, PIN2, PIN4, NEO, LHB, NA, NAI, AJT(10), RIY(10),
500 1 RIZ(10), RIT(10)
501 COMMON /B15/ MLOAD, NLU, PLOAD, STORE(10,5), MLJD(10)
502 COMMON /B21/ NBC, IBC(50,2)
503 DIMENSION DM(2584), DK(2584), DD(2584), VECTR(19), RDRP1(19,19),
504 1 RDRP2(19,19)
505 IF (NORMAS .EQ. 0) GO TO 10
506 CALL DRPMAS(NEO, NM, NMAX, NSTEP, RL, PI, S)
507 10 CONTINUE
508 DO 410 IK = 1, NM, NSTEP
509 DO 410 IN = 1, IK, NSTEP
510 IKM = IK
511 INM = IN
512 IF (NSTEP .EQ. 1) GO TO 20
513 IKM = (IK + 1) / 2
514 INM = (IN + 1) / 2
515 20 IF (IN .EQ. IK) GO TO 40
516 IKD = (INM - 1) = NMAX + IKM - INM = (INM + 1) / 2
517 DO 30 I = 1, NAI
518 ADAMP(IKD,I) = 0.00
519 30 ASTIF(IKD,I) = 0.00
520 IF (NORMAS .EQ. 0) GO TO 410
521 GO TO 300
522 40 IKD = IKM
523 DO 50 I = 1, NA
524 DM(I) = 0.000
525 DD(I) = 0.000
526 DK(I) = 0.000
527 DO 60 I = 1, NEO
528 FORCE1(IKD,I) = 0.000
529 60 DO 220 IE = 1, NJT
530 IJ = (IE - 1) = 13
531 DO 70 J = 1, 19
532 DO 70 J = 1, 19
533 RDRP1(I,J) = 0.00
534 70 RDRP2(I,J) = 0.00
535 IF (NORMAS .EQ. 0) GO TO 110
536 IDR = 1
537 IF (NJDR(IDR) .EQ. IE) GO TO 80
538 IDR = IDR + 1
539 IF (IDR .GT. NORMAS) GO TO 110
540 GO TO 80
541 80 ID = (IDR - 1) = NMAX + IKM
542 DO 100 I = 1, 19
543 DO 100 J = 1, 19
544 RDRP1(I,J) = RDRP1(I,J) + RSTIF(ID,IJ + 1) = RSTIF(ID,
545 1 IJ + J) / RK(IDR)
546 100 RDRP2(I,J) = RDRP2(I,J) + RDAMP(ID,IJ + 1) = RDAMP(ID,IJ +
547 1 J) / RC(IDR)
548 IDR = IDR + 1
549 IF (IDR .GT. NORMAS) GO TO 110
550 GO TO 80

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551      110      CONTINUE
552      EJT = YMOD(IE)
553      GJT = SMOD(IE)
554      RHOJT = DNSTY(IE)
555      KLO = 0
556      ILO = 1
557      IF (NLOAD .NE. 0) GO TO 130
558      X1 = STORE(IE,1)
559      X2 = STORE(IE,2)
560      Y1 = STORE(IE,3)
561      Y2 = STORE(IE,4)
562      IF (NLU .EQ. 1) GO TO 120
563      IF (IE .EQ. 1) Y1 = 0.000
564      IF (IE .EQ. NJT) Y2 = 0.000
565      120      PLD = STORE(IE,5)
566      GO TO 180
567      130      IF (NLJDILO) .EQ. IE .OR. NLU .EQ. 1) GO TO 140
568      ILO = ILO + 1
569      IF (ILO .GT. NLOAD) GO TO 180
570      GO TO 130
571      140      X1 = STORE(ILO,1)
572      X2 = STORE(ILO,2)
573      Y1 = STORE(ILO,3)
574      Y2 = STORE(ILO,4)
575      PLD = STORE(ILO,5)
576      150      CALL STFMAS(VECTR, IE, KLO, IN, IK, PI)
577      GO TO 170
578      160      IF (KLO .EQ. 1) GO TO 210
579      PLD = 0.000
580      CALL STFMAS(VECTR, IE, KLO, IN, IK, PI)
581      170      IJ = (IE - 1) * 13
582      DO 200 J = 1, 19
583          IF (KLO .EQ. 1) GO TO 190
584          DO 180 K = 1, J
585              JK = LMS = (IJ + K - 1) + J - K + 1
586              DK(JK) = DK(JK) + STIFF(J,K) + RDRP1(J,K)
587              DM(JK) = DM(JK) + DMAS(J,K)
588              DD(JK) = DD(JK) + DAMP(J,K) + RDRP2(J,K)
589      180      CONTINUE
590      190      FORCE1(IK0,IJ + J) = FORCE1(IK0,IJ + J) + VECTR(J)
591      200      CONTINUE
592      KLO = 1
593      IF (NLOAD .EQ. 0) GO TO 210
594      ILO = ILO + 1
595      IF (ILO .GT. NLOAD) GO TO 210
596      GO TO 130
597      210      JK = LMS = (IJ + 9) + 1
598      DK(JK) = DK(JK) + EJT = RIY(IE) = PINA = IK == 4
599      DM(JK) = DM(JK) + RHOJT = ((AJT(IE)*RL/2.000) + (RIY(IE)=
600      PIN2=IK==2))
601      DD(JK) = DD(JK) + CB(IE) = ((AJT(IE)*RL/2.000) + (RIY(IE)=
602      PIN2=IK==2))
603      JK = LMS = (IJ + 10) + 1
604      DK(JK) = DK(JK) + EJT = AJT(IE) = PIN2 = IK == 2
605      DM(JK) = DM(JK) + RHOJT = AJT(IE) = RL / 2.000
606      DD(JK) = DD(JK) + CB(IE) = AJT(IE) = RL / 2.000
607      JK = LMS = (IJ + 11) + 1
608      DK(JK) = DK(JK) + EJT = RIZ(IE) = PINA = IK == 4
609      DM(JK) = DM(JK) + RHOJT = ((AJT(IE)*RL/2.000) + (RIZ(IE)=
610      PIN2=IK==2))
611      DD(JK) = DD(JK) + CB(IE) = ((AJT(IE)*RL/2.000) + (RIZ(IE)=
612      PIN2=IK==2))
613      JK = LMS = (IJ + 12) + 1
614      DK(JK) = DK(JK) + GJT = RIT(IE) = PIN2 = IK == 2 / (S==2)
615      DM(JK) = DM(JK) + RHOJT = (RIY(IE) + RIZ(IE)) = RL / (2.000*
616      S==2)
617      DD(JK) = DD(JK) + CB(IE) = (RIY(IE) + RIZ(IE)) = RL / (2.
618      000*S==2)
619      220      CONTINUE
620      IF (NBC .EQ. 0) GO TO 270
621      DO 260 I = 1, NBC
622          NE = IBC(I,1)
623          NDOF = IBC(I,2)
624          M = (NE - 1) * 13 + NDOF
625          J1 = 1
626          MM = M - 1
627          IF (M .GE. 19) J1 = M - 18
628          DO 230 J = J1, MM
629              JK = (LMS - 1) = (J - 1) + M
630              DM(JK) = 0.00
631              DD(JK) = 0.00
632      230      DK(JK) = 0.000
633      M1 = M + 1
634      M8 = M + 18
635      IF (M8 .GT. NEO) M8 = NEO
636      DO 240 J = M1, M8
637          JK = (LMS - 1) = (M - 1) + J
638          DM(JK) = 0.00
639          DD(JK) = 0.00
640      240      DK(JK) = 0.000
641      JK = (LMS - 1) = (M - 1) + M
642      DM(JK) = 1.00
643      DD(JK) = 1.00
644      DK(JK) = 1.00
645      FORCE1(IK0,M) = 0.000
646      IF (NDRMAS .EQ. 0) GO TO 260
647      DO 250 IM = 1, NDRMAS
648          IKDR = (IM - 1) * NMAX + IK0
649          RSTIF(IKDR,M) = 0.00
650          RDAMP(IKDR,M) = 0.00
651      250      CONTINUE
652      CONTINUE
653      270      CONTINUE
654      DO 280 I = 1, NA
655          GSTIF(IK0,I) = DK(I)
656          GMAS(IK0,I) = DM(I)
657      280      GDAMP(IK0,I) = DD(I)
658      CALL DECPM(NEO, LMS, DM)
659      DO 290 I = 1, NA
660      290      DCPMAS(IK0,I) = DM(I)

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881      GO TO 410
882 300      CONTINUE
883      DO 370 IE = 1, NJT
884          IJ = (IE - 1) * 13
885          DO 310 I = 1, 19
886              DO 310 J = 1, 19
887                  RDRP1(I,J) = 0.00
888 310          RDRP2(I,J) = 0.00
889          IF (NDRMAS .EQ. 0) GO TO 350
890          IDR = 1
891 320          IF (NJDR(IDR) .EQ. IE) GO TO 330
892          IDR = IDR + 1
893          IF (IDR .GT. NDRMAS) GO TO 350
894          GO TO 320
895 330          ID1 = (IDR - 1) * NMAX + IKM
896          ID2 = (IDR - 1) * NMAX + INM
897          DO 340 I = 1, 19
898              DO 340 J = 1, 19
899                  RDRP1(I,J) = RDRP1(I,J) + RSTIF(ID1,IJ + I) * RSTIF(ID2,
900                      IJ + J) / RK(IDR)
901 340          RDRP2(I,J) = RDRP2(I,J) + RDAMP(ID1,IJ + I) * RDAMP(ID2,IJ +
902                      J) / RC(IDR)
903          IDR = IDR + 1
904          IF (IDR .GT. NDRMAS) GO TO 350
905          GO TO 320
906 350          CONTINUE
907          DO 360 J = 1, 19
908              DO 360 K = 1, 19
909                  JK = (IJ + K - 1) * (2*LHB - 1) + LHB + J - K
910                  ASTIF(IK0,JK) = ASTIF(IK0,JK) + RDRP1(J,K)
911                  ADAMP(IK0,JK) = ADAMP(IK0,JK) + RDRP2(J,K)
912 360          CONTINUE
913 370          CONTINUE
914          IF (NBC .EQ. 0) GO TO 400
915          DO 390 I = 1, NBC
916              NE = IBC(I,1)
917              NDOF = IBC(I,2)
918              M = (NE - 1) * 13 + NDOF
919              M1 = M - 18
920              M2 = M - 18
921              IF (M1 .LE. 0) M1 = 1
922              IF (M2 .GT. NEO) M2 = NEO
923              DO 380 J = M1, M2
924                  JK = (M - 1) * (2*LHB - 1) + J - M + LHB
925                  ADAMP(IK0,JK) = 0.00
926                  ASTIF(IK0,JK) = 0.00
927                  JK = (J - 1) * (2*LHB - 1) + M - J + LHB
928                  ADAMP(IK0,JK) = 0.00
929                  ASTIF(IK0,JK) = 0.00
930 380          CONTINUE
931 390          CONTINUE
932 400          CONTINUE
933 410          CONTINUE
934          RETURN
935          END
936
937 C
938 SUBROUTINE AXLRN(NEO, LHB, MA)
939 IMPLICIT REAL*8(A - H, O - Z)
940 COMMON /B5/ NM, NSTEP, NMAX
941 COMMON /B10/ RC(5), RK(5), RM(5), RFORC1(5), NDRMAS
942 COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
943 COMMON /B12/ GMAS(3,2584), GDAMP(3,2584), ADAMP(3,5032),
944 1 GSTIF(3,2584), ASTIF(3,5032), DCPMAS(3,2584), FORCE1(3,136)
945 COMMON /B16/ SVEC1(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
946 1 SVEC3(3,136), RVEC3(5)
947 DIMENSION FORCE2(3,136), DM(2584), X(136)
948 DO 180 IK = 1, NM, NSTEP
949     IKM = IK
950     IF (NSTEP .EQ. 2) IKM = (IKM + 1) / 2
951     DO 10 I = 1, NEO
952 10      FORCE2(IK,M,I) = FORCE1(IK,M,I)
953     DO 110 IN = 1, NM, NSTEP
954         INM = IN
955         IF (NSTEP .EQ. 2) INM = (INM + 1) / 2
956         IF (INM .GT. IKM) GO TO 20
957         IKD = (INM - 1) * NMAX + IKM - INM = (INM + 1) / 2
958         GO TO 30
959 20      IKD = (IKM - 1) * NMAX + INM - IKM = (IKM + 1) / 2
960 30      DO 100 I = 1, NEO
961          J1 = I - 18
962          J2 = I + 18
963          IF (J1 .LE. 0) J1 = 1
964          IF (J2 .GT. NEO) J2 = NEO
965          SUM = 0.000
966          DO 90 J = J1, J2
967              TEMP1 = SVEC1(INM,J)
968              TEMP2 = SVEC2(INM,J)
969              IF (INM .EQ. IKM) GO TO 60
970              IF (INM .GT. IKM) GO TO 40
971              IJ = (J - 1) * (2*LHB - 1) + LHB + I - J
972              GO TO 80
973 40              IJ = (I - 1) * (2*LHB - 1) + LHB + J - I
974              GO TO 80
975 50          CONTINUE
976              IF (I .GT. J) GO TO 60
977              JK = (I - 1) * LHB + J - I + 1
978              GO TO 70
979 60              JK = (J - 1) * LHB + I - J + 1
980 70              SUM = SUM + GSTIF(IK,M,JK) * TEMP1 + GDAMP(IK,M,JK) * TEMP2
981              GO TO 90
982 80              SUM = SUM + ASTIF(IK0,IJ) * TEMP1 + ADAMP(IK0,IJ) * TEMP2
983 90          CONTINUE
984          FORCE2(IK,M,I) = FORCE2(IK,M,I) - SUM
985 100         CONTINUE
986 110        CONTINUE
987          IF (NDRMAS .EQ. 0) GO TO 140
988          DO 130 I = 1, NEO
989              SUM1 = 0.00
990              DO 120 J = 1, NDRMAS
991                  JM = (J - 1) * NMAX + IKM
992 120          SUM1 = SUM1 + RDAMP(JM,I) * RVEC2(J) + RSTIF(JM,I) * RVEC1(J)

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771          FORCE2(IKM,I) = FORCE2(IKM,I) - SUM1
772      130  CONTINUE
773      140  CONTINUE
774      DO 150 I = 1, NA
775      150  DM(I) = DCPMAS(IKM,I)
776      DO 160 I = 1, NEO
777      160  X(I) = FORCE2(IKM,I)
778          CALL SOLV(NEO, LHB, DM, X)
779      DO 170 I = 1, NEO
780      170  SVEC3(IKM,I) = X(I)
781      180  CONTINUE
782          IF (NDRMAS .EQ. 0) GO TO 220
783      DO 210 I = 1, NDRMAS
784          SUM = RC(I) + RVEC2(I) + RK(I) + RVEC1(I)
785          DO 200 IK = 1, NMAX
786          IKM = (I - 1) * NMAX + IK
787          DO 180 J = 1, NEO
788      180  SUM = SUM + RDAMP(IKM,J) + SVEC2(IK,J) + RSTIF(IKM,J) + SVEC1(
789      1  IK,J)
790      200  CONTINUE
791          RVEC3(I) = (RFORC1(I) - SUM) / RM(I)
792      210  CONTINUE
793      220  CONTINUE
794      RETURN
795  END
796
797  C
798  SUBROUTINE EPMAT(NMAX, NA, NA1, LHB, NEO)
799  IMPLICIT REAL*8(A - H, O - Z)
800  COMMON /B10/ RC(5), RK(5), RM(5), RFORC1(5), NDRMAS
801  COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
802  COMMON /B13/ GMASS(3,2584), GDAMP(3,2584), ADAMP(3,5032),
803  1  GSTIF(3,2584), ASTIF(3,5032)
804  COMMON /B17/ EFSTIF(3,2584), AFSTIF(3,5032), REFSTF(5),
805  1  REPEAT(15,136)
806  COMMON /B23/ AO, A1
807  DIMENSION DK(2584)
808  DO 60 IK = 1, NMAX
809  DO 60 IN = 1, IK
810  IF (IN .EQ. IK) GO TO 10
811  IKO = (IN - 1) * NMAX + IK - IN = (IN + 1) / 2
812  GO TO 40
813  10  DO 20 I = 1, NA
814  20  DK(I) = GSTIF(IK,I) + AO * GMASS(IK,I) + A1 * GDAMP(IK,I)
815  CALL DECPM(NEO, LHB, DK)
816  DO 30 I = 1, NA
817  30  EFSTIF(IK,I) = DK(I)
818  GO TO 60
819  40  DO 50 I = 1, NA1
820  50  AFSTIF(IKO,I) = ASTIF(IKO,I) + A1 * ADAMP(IKO,I)
821  CONTINUE
822  IF (NDRMAS .EQ. 0) GO TO 100
823  DO 90 I = 1, NDRMAS
824  REFSTF(I) = RK(I) + AO * RM(I) + A1 * RC(I)
825  DO 80 J = 1, NMAX
826  IM = (I - 1) * NMAX + J
827  DO 70 K = 1, NEO
828  70  REPEAT(IM,K) = RSTIF(IM,K) + A1 * RDAMP(IM,K)
829  CONTINUE
830  CONTINUE
831  CONTINUE
832  RETURN
833  END
834
835  C
836  SUBROUTINE EFLDAD(NMAX, NEO, LHB)
837  IMPLICIT REAL*8(A - H, O - Z)
838  COMMON /B10/ RC(5), RK(5), RM(5), RFORC1(5), NDRMAS
839  COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
840  COMMON /B13/ GMASS(3,2584), GDAMP(3,2584), ADAMP(3,5032),
841  1  GSTIF(3,2584), ASTIF(3,5032), DCPMAS(3,2584), FORCE1(3,136)
842  COMMON /B16/ SVEC1(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
843  1  SVEC3(3,136), RVEC3(5)
844  COMMON /B18/ FORCE2(3,136), RFORC2(5)
845  COMMON /B23/ AO, A1, A2, A3
846  DO 10 I = 1, NMAX
847  DO 10 J = 1, NEO
848  10  FORCE2(I,J) = FORCE1(I,J)
849  DO 120 IKM = 1, NMAX
850  DO 110 INM = 1, NMAX
851  IF (INM .GT. IKM) GO TO 20
852  IKO = (INM - 1) * NMAX + IKM - INM = (INM + 1) / 2
853  GO TO 30
854  20  IKO = (IKM - 1) * NMAX + INM - IKM = (IKM + 1) / 2
855  DO 100 I = 1, NEO
856  J1 = I - 18
857  J2 = I + 18
858  IF (J1 .LE. 0) J1 = 1
859  IF (J2 .GT. NEO) J2 = NEO
860  SUM = 0.00
861  DO 90 J = J1, J2
862  TEMP1 = SVEC1(INM,J) = AO + SVEC2(INM,J) = A2 + SVEC3(INM,
863  1  J) = 2.00
864  TEMP2 = SVEC1(INM,J) = A1 + SVEC2(INM,J) = 2.00 + SVEC3(INM,
865  1  J) = A3
866  IF (INM .EQ. IKM) GO TO 50
867  IF (INM .GT. IKM) GO TO 40
868  IJ = (J - 1) * (2*LHB - 1) + LHB + I - J
869  GO TO 60
870  40  IJ = (I - 1) * (2*LHB - 1) + LHB + J - I
871  GO TO 60
872  CONTINUE
873  IF (I .GT. J) GO TO 60
874  IJ = (I - 1) * LHB + J - I + 1
875  GO TO 70
876  50  IJ = (J - 1) * LHB + I - J + 1
877  GO TO 70
878  SUM = SUM + GMASS(IKM,IJ) * TEMP1 + GDAMP(IKM,IJ) * TEMP2
879  GO TO 90
880  SUM = SUM + ADAMP(IKO,IJ) * TEMP2
881  CONTINUE
882  FORCE2(IKM,I) = FORCE2(IKM,I) + SUM
883  CONTINUE

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881      110 CONTINUE
882      120 CONTINUE
883      IF (NDRMAS .EQ. 0) GO TO 180
884      DO 150 IK = 1, NMAX
885      DO 140 I = 1, NEO
886      SUM = 0.00
887      DO 130 J = 1, NDRMAS
888      JM = (J - 1) * NMAX + IK
889      TEMP = A1 = RVEC1(J) + 2.00 * RVEC2(J) + A3 = RVEC3(J)
890      130 SUM = SUM + RDAMP(JM,I) * TEMP
891      140 FORCE2(IK,I) = FORCE2(IK,I) + SUM
892      150 CONTINUE
893      DO 160 I = 1, NDRMAS
894      SUM = 0.00
895      DO 170 IK = 1, NMAX
896      IJ = (I - 1) * NMAX + IK
897      DO 180 J = 1, NEO
898      SUM = SUM + RDAMP(IJ,J) * (A1*SVEC1(IK,J) + 2.00*SVEC2(IK,J) +
899      1 A3*SVEC3(IK,J))
900      170 CONTINUE
901      SUM = SUM + RM(I) * (A0*RVEC1(I) + A2*RVEC2(I) + 2.00*RVEC3(I))
902      1 RC(I) = (A1*RVEC1(I) + 2.00*RVEC2(I) + A3*RVEC3(I))
903      RFORC2(I) = RFORC2(I) + SUM
904      180 CONTINUE
905      190 CONTINUE
906      RETURN
907      END
908
909      C
910      SUBROUTINE SOLVE(NM, NMAX, NEO, LHB, TOL, ELTIM, NA, NDRMAS)
911      IMPLICIT REAL*8(A - H, O - Z)
912      COMMON /B16/ SVEC1(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
913      1 SVEC3(3,136), RVEC3(5)
914      COMMON /B17/ EFSTIF(3,2564), AFSTIF(3,5032), REFSTF(5),
915      1 REFECT(15,136)
916      COMMON /B18/ FORCE2(3,136), RFORC2(5)
917      COMMON /B23/ A0, A1, A2, A3, A4, A5, A6, A7, A8, A9
918      DIMENSION SVEC4(3,136), SVEC5(3,136), RVEC4(5), RVEC5(5), XX(136),
919      1 X(136), DK(2564)
920      DO 10 I = 1, NMAX
921      DO 10 J = 1, NEO
922      10 SVEC4(I,J) = 0.00
923      DO 50 IK = 1, NMAX
924      DO 20 I = 1, NA
925      DK(I) = EFSTIF(IK,I)
926      DO 30 I = 1, NEO
927      X(I) = FORCE2(IK,I)
928      CALL SOLV(NEO, LHB, DK, X)
929      DO 40 I = 1, NEO
930      SVEC4(IK,I) = X(I)
931      50 CONTINUE
932      NITER = 0
933      IF (NDRMAS .EQ. 0 .AND. NM .EQ. 1) GO TO 320
934      IF (NDRMAS .EQ. 0) GO TO 70
935      DO 80 I = 1, NDRMAS
936      80 RVEC4(I) = RFORC2(I) / REFSTF(I)
937      70 CONTINUE
938      NFLAG = 1
939      DO 230 IKM = 1, NMAX
940      DO 80 I = 1, NEO
941      XX(I) = FORCE2(IKM,I)
942      DO 160 INM = 1, NMAX
943      IF (INM .EQ. IKM) GO TO 160
944      IF (INM .GT. IKM) GO TO 100
945      IKD = (INM - 1) * NMAX + IKM - INM = (INM + 1) / 2
946      GO TO 110
947      100 IKD = (IKM - 1) * NMAX + INM - IKM = (IKM + 1) / 2
948      DO 160 I = 1, NEO
949      J1 = I - 18
950      J2 = I + 18
951      IF (J1 .LE. 0) J1 = 1
952      IF (J2 .GT. NEO) J2 = NEO
953      SUM = 0.00
954      DO 140 J = J1, J2
955      TEMP = SVEC4(INM,J)
956      IF (IN .GT. IK) GO TO 120
957      IJ = (J - 1) * (2*LHB - 1) + LHB + I - J
958      GO TO 130
959      120 IJ = (I - 1) * (2*LHB - 1) + LHB + J - I
960      130 SUM = SUM + AFSTIF(IKD,IJ) * TEMP
961      140 CONTINUE
962      XX(I) = XX(I) - SUM
963      150 CONTINUE
964      160 CONTINUE
965      IF (NDRMAS .EQ. 0) GO TO 180
966      DO 180 I = 1, NEO
967      SUM1 = 0.00
968      DO 170 J = 1, NDRMAS
969      JM = (J - 1) * NMAX + IKM
970      SUM1 = SUM1 + REFECT(JM,I) * RVEC4(J)
971      XX(I) = XX(I) - SUM1
972      170 CONTINUE
973      180 CONTINUE
974      DO 200 I = 1, NA
975      DK(I) = EFSTIF(IKM,I)
976      DO 210 I = 1, NEO
977      X(I) = XX(I)
978      CALL SOLV(NEO, LHB, DK, X)
979      DO 220 I = 1, NEO
980      SVEC5(IKM,I) = X(I)
981      230 CONTINUE
982      IF (NDRMAS .EQ. 0) GO TO 270
983      DO 260 I = 1, NDRMAS
984      SUM = 0.00
985      DO 250 IK = 1, NMAX
986      IM = (I - 1) * NMAX + IK
987      DO 240 J = 1, NEO
988      SUM = SUM + REFECT(IM,J) * SVEC4(IK,J)
989      240 CONTINUE
990      RVEC5(I) = (RFORC2(I) - SUM) / REFSTF(I)
991      250 CONTINUE
992      260 CONTINUE

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891      270 CONTINUE
892      DO 280 I = 1, NMAX
893          TEMP1 = 0.00
894          TEMP2 = 0.00
895          DO 280 J = 1, NEO
896              TEMP1 = TEMP1 + SVEC5(IK,J) ** 2
897              TEMP2 = TEMP2 + SVEC4(IK,J) ** 2
898      280      SVEC4(IK,J) = SVEC5(IK,J)
899          TEMP1 = DSORT(TEMP1)
900          TEMP2 = DSORT(TEMP2)
901          EPS1 = DABS((TEMP1 - TEMP2)/TEMP1)
902          NAC = 1
903          IF (EPS1 .GT. TOL) NAC = 0
904          NFLAG = NFLAG + NAC
905      280 CONTINUE
906      NITER = NITER + 1
907      IF (NFLAG .EQ. 1) GO TO 300
908      GO TO 80
909      300 IF (NDRMAS .EQ. 0) GO TO 320
910          TEMP3 = 0.00
911          TEMP4 = 0.00
912          DO 310 I = 1, NDRMAS
913              TEMP3 = TEMP3 + RVEC5(I) ** 2
914              TEMP4 = TEMP4 + RVEC4(I) ** 2
915      310      RVEC4(I) = RVEC5(I)
916          TEMP3 = DSORT(TEMP3)
917          TEMP4 = DSORT(TEMP4)
918          EPS2 = DABS((TEMP3 - TEMP4)/TEMP3)
919          NAC = 1
920          IF (EPS2 .GT. TOL) NAC = 0
921          NFLAG = NFLAG + NAC
922          IF (NFLAG .EQ. 1) GO TO 320
923          GO TO 80
924      320 CONTINUE
925      WRITE (6,330) ELTIM, NITER
926      330 FORMAT ('NO OF ITERATIONS FOR SOLN AT TIME=', F7.5, 3X, 'ARE', I3)
927      DO 340 I = 1, NMAX
928          DO 340 J = 1, NEO
929              TEMP1 = SVEC1(I,J)
930              TEMP2 = SVEC2(I,J)
931              TEMP3 = SVEC3(I,J)
932              TEMP4 = SVEC4(I,J)
933              SVEC3(I,J) = A4 + (TEMP4 - TEMP1) + A5 = TEMP2 + A6 = TEMP3
934              SVEC2(I,J) = TEMP2 + A7 = (SVEC3(I,J) + TEMP3)
935              SVEC1(I,J) = TEMP1 + A8 = TEMP2 + A6 = (SVEC3(I,J) + 2.00=
936              TEMP3)
937      340 CONTINUE
938      IF (NDRMAS .EQ. 0) GO TO 360
939      DO 350 I = 1, NDRMAS
940          TEMP1 = RVEC1(I)
941          TEMP2 = RVEC2(I)
942          TEMP3 = RVEC3(I)
943          TEMP4 = RVEC4(I)
944          RVEC3(I) = A4 + (TEMP4 - TEMP1) + A5 = TEMP2 + A6 = TEMP3
945          RVEC2(I) = TEMP2 + A7 = (RVEC3(I) + TEMP3)
946          RVEC1(I) = TEMP1 + A8 = TEMP2 + A6 = (RVEC3(I) + 2.00=TEMP3)
947      350 CONTINUE
948      360 CONTINUE
949      RETURN
950      END
951
952      C
953      SUBROUTINE RESULT(PERIOD, ELTIM, NDRMAS, P1)
954      IMPLICIT REAL*8(A - H, D - Z)
955      COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL
956      COMMON /B10/ RC(5), RK(5)
957      COMMON /B16/ SVEC(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
958      1      SVEC3(3,136), RVEC3(5)
959      COMMON /B22/ NDEFJT(10), DEFM(10,2), NPNTS
960      COMMON /B24/ W1, W2, W3
961      COMMON /B25/ SCALE(3), AMPL1, OCCUR1, AMPL2, OCCUR2
962      DIMENSION GRAPH1(16), GRAPH2(16), GRAPH3(16)
963      GRAPH1(1) = ELTIM = SCALE(1)
964      GRAPH2(1) = ELTIM = SCALE(1)
965      GRAPH3(1) = ELTIM = SCALE(1)
966      DO 10 I = 1, NPNTS
967          IE = NDEFJT(I)
968          XO = DEFM(I,1)
969          YO = DEFM(I,2)
970          XIO = YO = 2.00 / S
971          CALL VERDIS(1, NM, NSTEP, IE, XO, XIO, RL, P1)
972          GRAPH1(I + 1) = W1 = SCALE(2)
973          GRAPH2(I + 1) = W2 = SCALE(2)
974          GRAPH3(I + 1) = W3 = SCALE(2)
975      10 CONTINUE
976      L = NPNTS + 1
977      IF (NDRMAS .EQ. 0) GO TO 50
978      DO 30 I = 1, NDRMAS
979          WRITE (2,20) I, RVEC1(I), RVEC2(I), RVEC3(I)
980      20      FORMAT ('/', 'SOLUTION FOR DROPPED MASS', 5X, I3, '/', 5X,
981      1      'DISPLACEMENT', 15X, 'VELOCITY', 15X, 'ACCELERATION', '/',
982      2      5X, 3E13.5, 12X, '/')
983          GRAPH1(L + 1) = RVEC1(I) = SCALE(2)
984          GRAPH2(L + 1) = RVEC2(I) = SCALE(2)
985          GRAPH3(L + 1) = RVEC3(I) = SCALE(2)
986      30 CONTINUE
987      IF (ELTIM .GT. PERIOD) GO TO 50
988      F = RK(NDRMAS) = SCALE(3) = (GRAPH1(L + NDRMAS) - GRAPH1(L)) + RC(
989      1NDRMAS) = SCALE(3) = (GRAPH2(L + NDRMAS) - GRAPH2(L))
990      WRITE (7,40) GRAPH1(1), F
991      40 FORMAT (F9.5, 1X, E11.4)
992      50 CONTINUE
993      K = NPNTS + NDRMAS + 1
994      WRITE (3,60) GRAPH1(1), (GRAPH1(N), N=2,K)
995      WRITE (4,60) GRAPH2(1), (GRAPH2(N), N=2,K)
996      WRITE (5,60) GRAPH3(1), (GRAPH3(N), N=2,K)
997      60 FORMAT (F9.5, 1X, 8(E11.4, 1X))
998      IF (GRAPH1(2) .GT. AMPL1) GO TO 80
999      IF (AMPL1 .GT. 0.00) GO TO 70
1000      GO TO 100
1001      70 IF (GRAPH1(1) .LT. (2.500=OCCUR1)) GO TO 100

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1101 IF (GRAPH1(2) .GT. AMPL2) GO TO 80
1102 GO TO 100
1103 80 AMPL2 = GRAPH1(2)
1104 OCCUR2 = GRAPH1(1)
1105 GO TO 100
1106 90 AMPL1 = GRAPH1(2)
1107 OCCUR1 = GRAPH1(1)
1108 100 CONTINUE
1109 RETURN
1110 END
1111 C
1112 SUBROUTINE DMAT(II)
1113 IMPLICIT REAL*8(A - H, D - Z)
1114 COMMON /B2/ A(19,19)
1115 COMMON /B3/ RM(6,19), RM1(6,19)
1116 COMMON /B4/ ETA(6), H(6)
1117 DO 10 I = 1, 19
1118   DO 10 J = 1, 19
1119     A(I,J) = 0.00
1120 10 CONTINUE
1121 DO 40 I = 1, 6
1122   DO 30 J = 1, 19
1123     F1 = RM(I,J)
1124     IF (II .EQ. 2 .OR. II .EQ. 4) F1 = RM1(I,J)
1125     IF (F1 .EQ. 0.000) GO TO 30
1126     DO 20 K = 1, 19
1127       F2 = RM1(I,K)
1128       IF (II .EQ. 1 .OR. II .EQ. 4) F2 = RM(I,K)
1129       IF (F2 .EQ. 0.000) GO TO 20
1130       A(J,K) = A(J,K) + F1 * F2 * H(I)
1131 20 CONTINUE
1132 30 CONTINUE
1133 40 CONTINUE
1134 RETURN
1135 END
1136 C
1137 SUBROUTINE DECOMP(N, LHS, A)
1138 IMPLICIT REAL*8(A - H, D - Z)
1139 DIMENSION A(2564)
1140 C *A IS STORED COLUMNWISE*
1141 KB = LHS - 1
1142 C *DECOMPOSITION*
1143 TEMP = A(1)
1144 TEMP = DSORT(TEMP)
1145 A(1) = TEMP
1146 DO 10 I = 2, LHS
1147 10 A(I) = A(I) / TEMP
1148 DO 60 J = 2, N
1149   J1 = J - 1
1150   IJD = LHS * J - KB
1151   SUM = A(IJD)
1152   KO = 1
1153   IF (J .GT. LHS) KO = J - KB
1154   DO 20 K = KO, J1
1155     JK = KB * K + J - KB
1156     TEMP = A(JK)
1157 20 SUM = SUM - TEMP ** 2
1158     A(IJD) = DSORT(SUM)
1159     DO 50 I1 = 1, KB
1160       I1 = J + I1
1161       KO = 1
1162       IF (I1 .GT. LHS) KO = I1 - KB
1163       SUM = A(IJD + I1)
1164       IF (I1 .EQ. KB) GO TO 40
1165       DO 30 K = KO, J1
1166         JK = KB * K + J - KB
1167         IK = KB * K + I1 - KB
1168         TEMP = A(JK)
1169 30 SUM = SUM - A(IK) * TEMP
1170 40 A(IJD + I1) = SUM / A(IJD)
1171 50 CONTINUE
1172 60 CONTINUE
1173 RETURN
1174 END
1175 C
1176 SUBROUTINE SOLV(N, LHS, A, B)
1177 IMPLICIT REAL*8(A - H, D - Z)
1178 DIMENSION A(2564), B(136)
1179 C *FORWARD SUBSTITUTION*
1180 KB = LHS - 1
1181 TEMP = A(1)
1182 B(1) = B(1) / TEMP
1183 DO 20 I = 2, N
1184   I1 = I - 1
1185   KO = 1
1186   IF (I .GT. LHS) KO = I - KB
1187   SUM = B(I1)
1188   I1 = LHS * I - KB
1189   DO 10 K = KO, I1
1190     IK = KB * K + I - KB
1191     TEMP = A(IK)
1192 10 SUM = SUM - TEMP * B(K)
1193   B(I1) = SUM / A(I1)
1194 20 CONTINUE
1195 C *BACKWARD SUBSTITUTION*
1196 N1 = N - 1
1197 LB = LHS * N - KB
1198 TEMP = A(LB)
1199 B(N) = B(N) / TEMP
1200 DO 40 I = 1, N1
1201   I1 = N - I + 1
1202   NI = N - I
1203   KO = N
1204   IF (I1 .GT. KB) KO = NI + KB
1205   SUM = B(NI)
1206   I1 = LHS * NI - KB
1207   DO 30 K = I1, KO
1208     IK = KB * NI + K - KB
1209     TEMP = A(IK)
1210 30 SUM = SUM - TEMP * B(K)

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1211      B(MI) = SUM / A(II)
1212 40 CONTINUE
1213 RETURN
1214 END
1215
1216 C
1217 SUBROUTINE GENMTX
1218 IMPLICIT REAL*8(A - H, O - Z)
1219 COMMON /B1/ RMOO(19,19), RM22(19,19), RMO2(19,19), RM20(19,19),
1220 1 RM33(19,19), RM66(19,19), RM36(19,19), RM63(19,19),
1221 2 RM44(19,19), RM45(19,19), RM54(19,19), RM55(19,19),
1222 3 RM11(19,19)
1223 COMMON /B2/ AA(19,19)
1224 COMMON /B4/ ETA(6), M(5)
1225 COMMON /B3/ RM(6,19), RM1(6,19)
1226 CALL ZERO
1227
1228 C M0 AND M2 MATRICES
1229 DO 10 I = 1, 6
1230   ETA2 = ETA(I) ** 2
1231   ETA3 = ETA(I) ** 3
1232   ETA4 = ETA(I) ** 4
1233   ETA5 = ETA(I) ** 5
1234   RM(I,1) = ETA2 - 6.00 * ETA3 / 4.00 - ETA4 / 2.00 + 3.00 * ETA5 / 4.
1235 1 DO
1236   RM(I,14) = ETA2 + 5.00 * ETA3 / 4.00 - ETA4 / 2.00 + 3.00 * ETA5 /
1237 1 4.00
1238   RM(I,10) = 1.00 - 2.00 * ETA2 + ETA4
1239   RM(I,2) = (ETA2 - ETA3 - ETA4 + ETA5) / 8.00
1240   RM(I,16) = (-ETA2 - ETA3 + ETA4 + ETA5) / 8.00
1241   RM(I,9) = (ETA(I) - 2.00*ETA3 + ETA5) / 2.00
1242   RM1(I,1) = 2.00 - 15.00 * ETA(I) / 2.00 - 6.00 * ETA2 + 15.00 * ETA3
1243   RM1(I,14) = 2.00 + 15.00 * ETA(I) / 2.00 - 6.00 * ETA2 - 15.00 *
1244 1 ETA3
1245   RM1(I,10) = -4.00 + 12.00 * ETA2
1246   RM1(I,2) = (2.00 - 6.00*ETA(I) - 12.00*ETA2 + 20.00*ETA3) / 8.00
1247   RM1(I,16) = (-2.00 - 6.00*ETA(I) + 12.00*ETA2 + 20.00*ETA3) / 8.00
1248   RM1(I,9) = (-12.00*ETA(I) + 20.00*ETA3) / 2.00
1249
1250 10 CONTINUE
1251 CALL DMAT(1)
1252 DO 20 I = 1, 19
1253   DO 20 J = 1, 19
1254     20 RMOO(I,J) = AA(I,J)
1255   CALL DMAT(2)
1256   DO 30 I = 1, 19
1257     DO 30 J = 1, 19
1258       30 RM22(I,J) = AA(I,J)
1259   CALL DMAT(3)
1260   DO 40 I = 1, 19
1261     DO 40 J = 1, 19
1262       40 RMO2(I,J) = AA(I,J)
1263   CALL DMAT(4)
1264   DO 50 I = 1, 19
1265     DO 50 J = 1, 19
1266       50 RM20(I,J) = AA(I,J)
1267   CALL ZERO
1268
1269 C M3 AND M6 MATRICES
1270 DO 60 I = 1, 6
1271   ETA2 = ETA(I) ** 2
1272   ETA3 = ETA(I) ** 3
1273   ETA4 = ETA(I) ** 4
1274   RM(I,3) = -3.00 * ETA(I) / 4.00 + ETA2 + ETA3 / 4.00 - ETA4 / 2.00
1275   RM(I,16) = 3.00 * ETA(I) / 4.00 + ETA2 - ETA3 / 4.00 - ETA4 / 2.00
1276   RM(I,7) = 1.00 - 2.00 * ETA2 + ETA4
1277   RM(I,4) = (-ETA(I) + ETA2 + ETA3 - ETA4) / 8.00
1278   RM(I,17) = (-ETA(I) - ETA2 + ETA3 + ETA4) / 8.00
1279   RM1(I,5) = -3.00 / 4.00 + 2.00 * ETA(I) + 3.00 * ETA2 / 4.00 - 2.00
1280 1 = ETA3
1281   RM1(I,18) = 3.00 / 4.00 + 2.00 * ETA(I) - 3.00 * ETA2 / 4.00 - 2.00
1282 1 = ETA3
1283   RM1(I,8) = -4.00 * ETA(I) + 4.00 * ETA3
1284   RM1(I,6) = (-1.00 + 2.00*ETA(I) + 3.00*ETA2 - 4.00*ETA3) / 8.00
1285   RM1(I,19) = (-1.00 - 2.00*ETA(I) + 3.00*ETA2 + 4.00*ETA3) / 8.00
1286
1287 60 CONTINUE
1288 CALL DMAT(1)
1289 DO 70 I = 1, 19
1290   DO 70 J = 1, 19
1291     70 RM33(I,J) = AA(I,J)
1292   CALL DMAT(2)
1293   DO 80 I = 1, 19
1294     DO 80 J = 1, 19
1295       80 RM66(I,J) = AA(I,J)
1296   CALL DMAT(3)
1297   DO 90 I = 1, 19
1298     DO 90 J = 1, 19
1299       90 RM36(I,J) = AA(I,J)
1300   CALL DMAT(4)
1301   DO 100 I = 1, 19
1302     DO 100 J = 1, 19
1303       100 RM53(I,J) = AA(I,J)
1304
1305 C M5 AND M4 MATRICES
1306 DO 110 I = 1, 6
1307   RM(I,5) = RM(I,3)
1308   RM(I,3) = 0.000
1309   RM(I,16) = RM(I,16)
1310   RM(I,16) = 0.000
1311   RM(I,8) = RM(I,7)
1312   RM(I,7) = 0.000
1313   RM(I,6) = RM(I,4)
1314   RM(I,4) = 0.000
1315   RM(I,19) = RM(I,17)
1316   RM(I,17) = 0.000
1317   RM1(I,3) = RM1(I,5)
1318   RM1(I,5) = 0.000
1319   RM1(I,18) = RM1(I,18)
1320   RM1(I,18) = 0.000
1321   RM1(I,7) = RM1(I,8)
1322   RM1(I,8) = 0.000
1323   RM1(I,4) = RM1(I,6)
1324   RM1(I,6) = 0.000
1325   RM1(I,17) = RM1(I,19)
1326   RM1(I,19) = 0.000

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1321      110 CONTINUE
1322      CALL DMAT(2)
1323      DO 120 I = 1, 19
1324          DO 120 J = 1, 19
1325      120 RM44(I,J) = AA(I,J)
1326      CALL DMAT(4)
1327      DO 130 I = 1, 19
1328          DO 130 J = 1, 19
1329      130 RM45(I,J) = AA(I,J)
1330      CALL DMAT(3)
1331      DO 140 I = 1, 19
1332          DO 140 J = 1, 19
1333      140 RM54(I,J) = AA(I,J)
1334      CALL DMAT(1)
1335      DO 150 I = 1, 19
1336          DO 150 J = 1, 19
1337      150 RM55(I,J) = AA(I,J)
1338      CALL ZERO
1339      C
1340      M1 MATRIX
1341      DO 160 I = 1, 6
1342          ETA2 = ETA(I) ** 2
1343          ETA3 = ETA(I) ** 3
1344          ETA4 = ETA(I) ** 4
1345      1 RM(1,1) = 2.DO * ETA(I) - 15.DO * ETA2 / 4.DO - 2.DO * ETA3 + 15.
1346      DO = ETA4 / 4.DO
1347      1 RM(1,14) = 2.DO * ETA(I) + 15.DO * ETA2 / 4.DO - 2.DO * ETA3 - 15.
1348      DO = ETA4 / 4.DO
1349      1 RM(1,10) = -4.DO * ETA(I) + 4.DO * ETA3
1350      1 RM(1,2) = (2.DO*ETA(I) - 3.DO*ETA2 - 4.DO*ETA3 + 5.DO*ETA4) / 8.
1351      DO
1352      1 RM(1,15) = (-2.DO*ETA(I) - 3.DO*ETA2 + 4.DO*ETA3 + 5.DO*ETA4) /
1353      1 8.DO
1354      1 RM(1,9) = (1.DO-6.DO*ETA2 + 5.DO*ETA4) / 2.DO
1355      180 CONTINUE
1356      CALL DMAT(1)
1357      DO 170 I = 1, 19
1358          DO 170 J = 1, 19
1359      170 RM11(I,J) = AA(I,J)
1360      RETURN
1361      END
1362      C
1363      SUBROUTINE STFMAS(V, IE, KLO, IN, IK, PI)
1364      IMPLICIT REAL*8(A - H, O - Z)
1365      DIMENSION V(19), AD(19,19)
1366      COMMON /B1/ RM00(19,19), RM22(19,19), RM02(19,19), RM20(19,19),
1367      1 RM33(19,19), RM55(19,19), RM36(19,19), RM53(19,19),
1368      2 RM44(19,19), RM45(19,19), RM54(19,19), RM55(19,19),
1369      3 RM11(19,19)
1370      COMMON /B4/ ETA(6), N(6)
1371      COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL, D, ALPHA, BETA, NJTM,
1372      1 BJ(10), HJ(10)
1373      COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPER,
1374      1 RKROT, RHOC, CP, CNPAL, CNPER, CNROT
1375      COMMON /B7/ GAPX(5), GAPO(5), GAPX(5), GAP(5), ENL, XIN, NGAPS,
1376      1 WAI, WDISCR
1377      COMMON /B8/ DMAS(19,19), STIFF(19,19), DAMP(19,19)
1378      COMMON /B9/ EJT, GJT, RHOJT, PLD, X1, X2, Y1, Y2
1379      IF (IE GT. 1) GO TO 240
1380      IF (KLO .EQ. 1) GO TO 240
1381      P2 = PI ** 2
1382      P4 = PI ** 4
1383      C COVER =
1384      DO 10 I = 1, 19
1385          DO 10 J = 1, 19
1386      10 DMAS(I,J) = 0.000
1387      DAMP(I,J) = 0.000
1388      STIFF(I,J) = 0.000
1389      FAC1 = RKX * (1K**4) * P4 * S / (4.DO*RL**3)
1390      FAC2 = RHOC * [(D*RL*S/4.ODO) + (D**3*(K**2-P2**S/(48.ODO*RL)))]
1391      FAC3 = FAC2 * CP / RHOC
1392      DO 20 I = 1, 19
1393          DO 20 J = 1, 19
1394      20 AD(I,J) = RM00(I,J)
1395      CALL ADD(AD, FAC1, FAC2, FAC3)
1396      FAC1 = RKY * 4.ODO * RL / (S**3)
1397      FAC2 = 0.ODO
1398      FAC3 = 0.ODO
1399      DO 30 I = 1, 19
1400          DO 30 J = 1, 19
1401      30 AD(I,J) = RM22(I,J)
1402      CALL ADD(AD, FAC1, FAC2, FAC3)
1403      FAC1 = -RKV * P2 * IK ** 2 / (S*RL)
1404      FAC2 = 0.ODO
1405      FAC3 = 0.ODO
1406      DO 40 I = 1, 19
1407          DO 40 J = 1, 19
1408      40 AD(I,J) = RM02(I,J)
1409      CALL ADD(AD, FAC1, FAC2, FAC3)
1410      DO 50 I = 1, 19
1411          DO 50 J = 1, 19
1412      50 AD(I,J) = RM20(I,J)
1413      CALL ADD(AD, FAC1, FAC2, FAC3)
1414      FAC1 = RKG * 4.ODO * P2 * IK ** 2 / (S*RL)
1415      FAC2 = RHOC * D ** 3 * RL / (12.DO*S)
1416      FAC3 = FAC2 * CP / RHOC
1417      DO 60 I = 1, 19
1418          DO 60 J = 1, 19
1419      60 AD(I,J) = RM11(I,J)
1420      CALL ADD(AD, FAC1, FAC2, FAC3)
1421      FAC1 = DX * S * P2 * IK ** 2 / (4.ODO*RL)
1422      FAC2 = RHOC * D * RL * S / 4.ODO
1423      FAC3 = FAC2 * CP / RHOC
1424      DO 70 I = 1, 19
1425          DO 70 J = 1, 19
1426      70 AD(I,J) = RM33(I,J)
1427      CALL ADD(AD, FAC1, FAC2, FAC3)
1428      FAC2 = 0.ODO
1429      FAC3 = 0.ODO
1430      FAC1 = DV * RL / S
1431      DO 80 I = 1, 19

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1431      DO 80 J = 1, 18
1432      80 AD(1,J) = RM88(1,J)
1433      CALL ADD(AD, FAC1, FAC2, FAC3)
1434      FAC2 = 0.000
1435      FAC3 = 0.00
1436      FAC1 = -DV * IK = PI / 2.000
1437      DO 80 I = 1, 18
1438      DO 80 J = 1, 18
1439      80 AD(1,J) = RM36(1,J)
1440      CALL ADD(AD, FAC1, FAC2, FAC3)
1441      DO 100 I = 1, 18
1442      DO 100 J = 1, 18
1443      100 AD(1,J) = RM63(1,J)
1444      CALL ADD(AD, FAC1, FAC2, FAC3)
1445      FAC2 = 0.000
1446      FAC3 = 0.00
1447      FAC1 = DG * RL / S
1448      DO 110 I = 1, 18
1449      DO 110 J = 1, 18
1450      110 AD(1,J) = RM44(1,J)
1451      CALL ADD(AD, FAC1, FAC2, FAC3)
1452      FAC1 = IK * PI / 2.000 * DG
1453      FAC2 = 0.000
1454      FAC3 = 0.00
1455      DO 120 I = 1, 18
1456      DO 120 J = 1, 18
1457      120 AD(1,J) = RM45(1,J)
1458      CALL ADD(AD, FAC1, FAC2, FAC3)
1459      DO 130 I = 1, 18
1460      DO 130 J = 1, 18
1461      130 AD(1,J) = RM54(1,J)
1462      CALL ADD(AD, FAC1, FAC2, FAC3)
1463      FAC1 = [DG*RL=S/4.000] * IK = 2 * P2 / [RL=2]
1464      FAC2 = RHOC * D = RL * S / 4.000
1465      FAC3 = FAC2 * CP / RHOC
1466      DO 140 I = 1, 18
1467      DO 140 J = 1, 18
1468      140 AD(1,J) = RM55(1,J)
1469      CALL ADD(AD, FAC1, FAC2, FAC3)
1470      C
1471      * NAILING *
1472      DO 150 I = 1, 18
1473      AD(1,1) = 0.000
1474      AD(2,1) = 0.000
1475      AD(4,1) = 0.000
1476      AD(5,1) = 0.000
1477      150 AD(6,1) = 0.000
1478      AD(1,7) = 1.000
1479      AD(1,11) = -1.000
1480      AD(1,10) = -IK * PI * (HJTM + D) / (2.DO=RL)
1481      AD(2,7) = 1.000
1482      AD(2,11) = -1.000
1483      AD(2,10) = -IN * PI * (HJTM + D) / (2.DO=RL)
1484      AD(3,8) = 1.000
1485      AD(3,12) = -1.000
1486      AD(3,9) = -D / (2.DO=S)
1487      AD(3,13) = -HJTM / (2.DO=S)
1488      AD(4,8) = 1.000
1489      AD(4,12) = -1.000
1490      AD(4,9) = -D / (2.DO=S)
1491      AD(4,13) = -HJTM / (2.DO=S)
1492      AD(5,9) = 1.DO / S
1493      AD(5,13) = -1.DO / S
1494      AD(6,9) = 1.DO / S
1495      AD(6,13) = -1.DO / S
1496      IF (NDISCR.EQ. 0) GO TO 200
1497      SPAR = 0.000
1498      SPER = 0.000
1499      DO 180 I = 1, NAI
1500      X = XIN * [1 - 1] * ENL
1501      IF (NGAPS.EQ. 0) GO TO 180
1502      DO 180 J = 1, NGAPS
1503      X11 = GAPX(J)
1504      X12 = GAPX(J) + GAP(J)
1505      IF (X.GE. X11 .AND. X.LE. X12) GO TO 170
1506      CONTINUE
1507      GO TO 180
1508      170 GO TO 180
1509      180 X = X * PI / RL
1510      SPAR = SPAR + DCOS(IN=X) * DCOS(IK=X)
1511      SPER = SPER + DSIN(IN=X) * DSIN(IK=X)
1512      CONTINUE
1513      GO TO 220
1514      200 IF (IN.NE. IK) GO TO 210
1515      SPAR = RL / (2.0=ENL)
1516      SPER = RL / (2.0=ENL)
1517      GO TO 220
1518      210 SPAR = 0.000
1519      SPER = 0.000
1520      220 SPAR = SPAR * RKPAL
1521      SPER = SPER * RKPER
1522      SROT = SPER * RKROT
1523      DO 230 I = 1, 18
1524      DO 230 J = 1, 18
1525      STIFF(1,J) = STIFF(1,J) * SPAR = AD(1,1) * AD(2,J) + SPER =
1526      1 AD(3,1) * AD(4,J) + SROT = AD(5,1) * AD(6,J)
1527      DAMP(1,J) = DAMP(1,J) * SPAR = CNPAL / RKPAL * AD(1,1) * AD(2,
1528      1 J) + SPER = CNPER / RKPER * AD(3,1) * AD(4,J) + SROT = CNROT /
1529      2 RKROT * AD(5,1) * AD(6,J)
1530      230 CONTINUE
1531      C
1532      * LOAD VECTOR *
1533      240 IF (IN.NE. IK) RETURN
1534      DO 250 I = 1, 18
1535      250 V(1) = 0.000
1536      IF (PLD.EQ. 0.00) RETURN
1537      PINL = PI * IK / RL
1538      PACTR = PLD * (Y2 - Y1) * [DCOS(PINL=X1) - DCOS(PINL=X2)] / [2.DO=
1539      1 PINL]
1540      XIX = 2.DO * Y1 / S
1541      XIY = 2.DO * Y2 / S

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1541      DO 280 I = 1, 5
1542          XI = XIX + (X1Y - XIX) * (1.DO+ETA(I)) / 2.DO
1543          X12 = XI ** 2
1544          X13 = XI ** 3
1545          X14 = XI ** 4
1546          X15 = XI ** 5
1547          V(1) = V(1) + (X12 - 5.DO*X13/4.DO-X14/2.DO+3.DO*X15/4.DO) * H(
1548              1 1)
1549          V(14) = V(14) + (X12 + 5*X13/4.DO-X14/2.DO-3.DO*X15/4.DO) * H(1)
1550          V(10) = V(10) + (1.DO-2.DO*X12 + X14) * H(1)
1551          V(2) = V(2) + (X12 - X13 - X14 + X15) * H(1) / 8.DO
1552          V(15) = V(15) + (-X12 - X13 + X14 + X15) * H(1) / 8.DO
1553      280 V(8) = V(8) + (X1 - 2.DO*X13 + X15) * H(1) / 2.DO
1554          V(1) = V(1) * FACTR
1555          V(14) = V(14) * FACTR
1556          V(10) = V(10) * FACTR
1557          V(2) = V(2) * FACTR
1558          V(15) = V(15) * FACTR
1559          V(8) = V(8) * FACTR
1560      RETURN
1561      END
1562
1563      C
1564      SUBROUTINE ADD(AD, FAC1, FAC2, FAC3)
1565      IMPLICIT REAL*8(A - H, O - Z)
1566      DIMENSION AD(19,19)
1567      COMMON /B6/ DMAS(19,19), STIFF(19,19), DAMP(19,19)
1568      DO 10 I = 1, 19
1569          DO 10 J = 1, 19
1570      10 STIFF(I,J) = STIFF(I,J) + FAC1 = AD(I,J)
1571          IF (DABS(FAC2 - 0.DO) .LT. 1.0E-08) RETURN
1572          DO 20 I = 1, 19
1573              DO 20 J = 1, 19
1574      20 DMAS(I,J) = DMAS(I,J) + FAC2 = AD(I,J)
1575      RETURN
1576      END
1577
1578      C
1579      SUBROUTINE VERDIS(J, NM, NSTEP, IE, XO, XIO, RL, PI)
1580      IMPLICIT REAL*8(A - H, O - Z)
1581      COMMON /B16/ SVEC1(3,136), SVEC2(3,136), RVEC1(5), RVEC2(5),
1582          1 SVEC3(3,136), RVEC3(5)
1583      COMMON /B24/ W1, W2, W3
1584      DIMENSION RMD(19)
1585      IJ = (IE - 1) * 13
1586      J1 = IJ + 1
1587      J2 = IJ + 2
1588      J3 = IJ + 9
1589      J4 = IJ + 10
1590      J5 = IJ + 14
1591      J6 = IJ + 15
1592      CALL SHAPFN(XIO, RMD)
1593      W1 = 0.00
1594      W2 = 0.00
1595      W3 = 0.00
1596      DO 20 I = 1, NM, NSTEP
1597          IK = I
1598          IF (NSTEP .EQ. 1) GO TO 10
1599          IK = (I + 1) / 2
1600      10 W1 = W1 + (SVEC1(IK,J1)=RMD(1) + SVEC1(IK,J2)=RMD(2) + SVEC1(IK,
1601          1 J3)=RMD(9) + SVEC1(IK,J4)=RMD(10) + SVEC1(IK,J5)=RMD(14) +
1602          2 SVEC1(IK,J6)=RMD(15)) * DSIN(I*PI*XO/RL)
1603          W2 = W2 + (SVEC2(IK,J1)=RMD(1) + SVEC2(IK,J2)=RMD(2) + SVEC2(IK,
1604          1 J3)=RMD(9) + SVEC2(IK,J4)=RMD(10) + SVEC2(IK,J5)=RMD(14) +
1605          2 SVEC2(IK,J6)=RMD(15)) * DSIN(I*PI*XO/RL)
1606          W3 = W3 + (SVEC3(IK,J1)=RMD(1) + SVEC3(IK,J2)=RMD(2) + SVEC3(IK,
1607          1 J3)=RMD(9) + SVEC3(IK,J4)=RMD(10) + SVEC3(IK,J5)=RMD(14) +
1608          2 SVEC3(IK,J6)=RMD(15)) * DSIN(I*PI*XO/RL)
1609      20 CONTINUE
1610      WRITE (2,30) J, W1, W2, W3
1611      30 FORMAT (/, 'SOLN AT FLOOR POINT', 5X, 13, /, 5X, 'DISPLACEMENT',
1612          1 15X, 'VELOCITY', 15X, 'ACCELERATION', /, 5X, 3(E13.6,12X),
1613          2 /)
1614      RETURN
1615      END
1616
1617      C
1618      SUBROUTINE SHAPFN(XIO, RMD)
1619      IMPLICIT REAL*8(A - H, O - Z)
1620      DIMENSION RMD(19)
1621      DO 10 I = 1, 19
1622      10 RMD(I) = 0.000
1623          X102 = XIO ** 2
1624          X103 = XIO ** 3
1625          X104 = XIO ** 4
1626          X105 = XIO ** 5
1627          RMD(1) = X102 - 5.000 + X103 / 4.000-X104 / 2.000+3.000 * X105 /
1628              14.000
1629          RMD(2) = (X102 - X103 - X104 + X105) / 8.000
1630          RMD(9) = (X10 - 2.000*X103 + X105) / 2.000
1631          RMD(10) = 1.000-2.000 * X102 + X104
1632          RMD(14) = X102 + 5.000 + X103 / 4.000-X104 / 2.000-3.000 * X105 /
1633              14.000
1634          RMD(15) = (-X102 - X103 + X104 + X105) / 8.000
1635      RETURN
1636      END
1637
1638      C
1639      SUBROUTINE DRPMAS(NEO, NM, NMAX, NSTEP, RL, P1, S)
1640      IMPLICIT REAL*8(A - H, O - Z)
1641      COMMON /B10/ RC(5), RK(5), RM(5), RFORC(5), NDRMAS, NJDR(5),
1642          1 RXO(5), RYO(5)
1643      COMMON /B11/ RSTIF(15,136), RDAMP(15,136)
1644      DIMENSION DRM(19)
1645      DO 40 I = 1, NDRMAS
1646          IE = NJDR(I)
1647          XO = RXO(I)
1648          XIO = RYO(I) * 2.DO / S
1649          J1 = (I - 1) * NMAX + 1
1650          J2 = I * NMAX
1651          DO 10 J = J1, J2
1652          10 DO 10 K = 1, NEO
1653              RSTIF(J,K) = 0.00
1654          END

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1851      10 RDAMP(J,K) = 0.00
1852      CALL SHAPPN(XIO, DRM)
1853      IJ = (IE - 1) = 13
1854      DO 30 L = 1, NM, NSTEP
1855          ILM = L
1856          IF (NSTEP.EQ. 2) ILM = (L + 1) / 2
1857          IM = (I - 1) = NMAX + ILM
1858          FAC1 = -RK(I) = DSIN(L*PI*XO/RL)
1859          FAC2 = -RC(I) = DSIN(L*PI*XO/RL)
1860          DO 20 M = 1, 19
1861              RSTIF(IM,IJ + M) = FAC1 + DRM(M)
1862              RDAMP(IM,IJ + M) = FAC2 + DRM(M)
1863      30 CONTINUE
1864      40 CONTINUE
1865      RETURN
1866      END
1867
1868      C
1869      SUBROUTINE ZERO
1870      IMPLICIT REAL*8(A - H, D - Z)
1871      COMMON /B3/ RM(8,18), RM1(8,18)
1872      DO 10 I = 1, 8
1873          DO 10 J = 1, 18
1874              RM(I,J) = 0.000
1875      10 RM1(I,J) = 0.000
1876      RETURN
1877      END
1878
1879      C
1880      SUBROUTINE EPICK(NJT)
1881      IMPLICIT REAL*8(A - H, D - Z)
1882      COMMON /B12/ YMOD(10)
1883      COMMON /B20/ EO, EM, EK
1884      DO 10 I = 1, NJT
1885          P = PRAND(1.0)
1886          P = DLOG(1.0-P)
1887          P = DLOG(-P) / EK
1888          Z = DEXP(P)
1889      10 YMOD(I) = Z * EM + EO
1890      WRITE (9,20) (YMOD(J),J=1,NJT)
1891      20 FORMAT (10(E10.3,1X))
1892      RETURN
1893      END
1894
1895      C
1896      SUBROUTINE UPDATE(I)
1897      IMPLICIT REAL*8(A - H, D - Z)
1898      COMMON /B5/ NM, NSTEP, NMAX, NJT, S, RL, D, ALPHA, BETA, HJTM,
1899      1 BJ(10), MJ(10), NPLD, INPTE
1900      COMMON /B6/ RKX, RKY, RKV, RKG, DX, DY, DV, DG, RKPAL, RKPER,
1901      1 RKROT, RHDC, CP, CNPAL, CNPER, CNROT
1902      COMMON /B7/ CAPX(5), CAPO(5), CAPX(5), CAP(5), ENL, XIN, NCAPS,
1903      1 NAI, NDISCR
1904      COMMON /B10/ RC(5), RK(5), RM(5), RFORC1(5), NDRMAS, NJDR(5),
1905      1 RXO(5), RYO(5), VEL(5), TIMIMP(5)
1906      COMMON /B12/ YMOD(10), DNSTY(10), CB(10), THETA, GRAVITY
1907      COMMON /B15/ NLOAD, NLU, PLOAD, STORE(10,5), NLJO(10)
1908      COMMON /B19/ ISYM, NTMZN, TIME(10,3), REG, TOL
1909      COMMON /B20/ EO, EM, EK, EMIN, EMAX, SEED, NREPL
1910      COMMON /B21/ NBC, IBC(80,2)
1911      COMMON /B22/ NDEFJT(10), DEFM(10,2), NPNTS
1912      COMMON /B25/ SCALE(3)
1913      S = 16.0
1914      RL = 144.0
1915      DO 10 N = 1, NDRMAS
1916          RM(N) = 0.518
1917          RC(N) = 8.0
1918          RK(N) = 400.0
1919      10 RXO(N) = 72.0
1920          RFORC1(2) = 200.0
1921      DO 20 N = 1, NPNTS
1922          DEFM(N,1) = 72.0
1923      20 DEFM(N,2) = 72.0
1924      DO 30 N = 1, NJT
1925          YMOD(N) = 1.5585
1926          MJ(N) = 7.25
1927      30 CB(N) = 3.83E-3
1928          CP = 4.17E-3
1929          CNPAL = 8.0
1930          CNPER = 8.0
1931          CNROT = 8.0
1932          RKPAL = 8800.0
1933          RKPER = 8800.0
1934          ENL = 8.0
1935
1936      C
1937      MODIFY VALUES OF PARAMETERS FOR DIFFERENT FLOORS
1938      GO TO (40, 50, 60, 70, 80, 90, 110, 130, 150, 170, 200, 230,
1939      1250, 270, 290, 310, 330, 340, 350, 380), I
1940      40 CONTINUE
1941      50 S = 12.0
1942      GO TO 370
1943      60 S = 20.0
1944      GO TO 370
1945      70 RM(1) = 0.382
1946      GO TO 370
1947      80 RM(2) = 0.382
1948          RFORC1(2) = 140.0
1949      GO TO 370
1950      90 DO 100 J = 1, NDRMAS
1951          100 RC(J) = 12.0
1952      GO TO 370
1953      110 DO 120 J = 1, NDRMAS
1954          120 RC(J) = 3.0
1955      GO TO 370
1956      130 DO 140 J = 1, NDRMAS
1957          140 RK(J) = 800.0
1958      GO TO 370
1959      150 DO 160 J = 1, NDRMAS
1960          160 RK(J) = 200.0
1961      GO TO 370
1962      170 RL = 182.0
1963      DO 180 J = 1, NDRMAS
1964          180 RXO(J) = 98.0
1965      DO 190 K = 1, NPNTS
1966          190 DEFM(K,1) = 88.0

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1761      GO TO 370
1762      200 RL = 98.0
1763      DO 210 J = 1, NDRMAS
1764      210 RXO(J) = 48.0
1765      DO 220 K = 1, NPNTS
1766      220 DEFMI(K,1) = 48.0
1767      GO TO 370
1768      230 DO 240 J = 1, NJT
1769      240 MJ(J) = 11.25
1770      GO TO 370
1771      250 DO 260 J = 1, NJT
1772      260 YMOD(J) = 1.6E6
1773      GO TO 370
1774      270 DO 280 J = 1, NJT
1775      280 YMOD(J) = 1.2E6
1776      GO TO 370
1777      290 DO 300 J = 1, NJT
1778      300 CS(J) = 7.66E-3
1779      CP = 8.34E-3
1780      CNPAL = 12.0
1781      CNPER = 12.0
1782      CNROT = 12.0
1783      GO TO 370
1784      310 DO 320 J = 1, NJT
1785      320 CS(J) = 1.92E-3
1786      CP = 2.08E-3
1787      CNPAL = 3.0
1788      CNPER = 3.0
1789      CNROT = 3.0
1790      GO TO 370
1791      330 ENL = 16.0
1792      GO TO 370
1793      340 ENL = 0.5
1794      GO TO 370
1795      350 RKPAL = 1000.0
1796      RKPER = 1000.0
1797      GO TO 370
1798      360 RKPAL = 100000.0
1799      RKPER = 100000.0
1800      370 CONTINUE
1801      RETURN
1802      END

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