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THE SHOCK AND VIBRATION DIGEST

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DIRECTOR NOTES

During the month of September I had the privilege of visiting with a number of distinguished scientists and engineers concerned with shock and vibration research in the United Kingdom. There is not space here to name the persons and organizations contacted, but without exception I found the discussions to be stimulating and rewarding. My only regret is that I did not have enough time at each place and that more organizations could not be included on my itinerary.

From time to time the reader of this Digest will find the work of these UK researchers reported either in the Abstracts section or as review or feature articles. These are valuable contributions and are deeply appreciated. During the face-to-face discussions, however, I feel that I have been able to gain a measure of understanding that goes beyond the published work. It is felt that this understanding gives SVIC a greater capacity to respond to user requests in a meaningful and useful way.

Professor E. J. Richards, the distinguished founder of the Institute of Sound and Vibration Research at Southampton, feels that noise research will continue to be vital "---largely because it is based on application, it is operating in a world of increasing industrialization and is essentially interdisciplinary in concept." I agree completely and suggest that this is equally true for vibration and shock. Communication, both formal and informal, is essential to the advancement of the technology. It is hoped that SVIC can continue to contribute as a mechanism for communication.

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EDITORS RATTLE SPACE

LET'S CONTROL THE PUBLICATION EXPLOSION

Those of you who regularly read this column will recall that I have already expressed my concern about the publication explosion. The opening address of the Rotating Machinery meeting at Churchill College, Cambridge, motivated me to ruminate about this topic yet another time.

In his opening address, Professor Bishop noted that the literature on rotor dynamics has become "flabby" (see Meeting Review in this issue of the **DIGEST**). He's correct--and this flabbiness applys not only to the literature of rotor dynamics but also to that associated with other technologies. Professor Bishop suggests that a unified theory might be one way to slow the seemingly endless proliferation of articles. Perhaps such general theories in the various technical disciplines would allow engineers to concentrate on solving practical problems. Why couldn't publication in society-sponsored journals be restricted to new developments pertaining to theory, techniques, and phenomena? Why couldn't case histories on solved problems be published in some form that would allow for quick distribution?

What must be done to develop a unified theory to rotor dynamics? I believe that one person--perhaps Professor Bishop--should have the responsibility of heading a group to develop such a theory. The proposed theory should then be distributed to technical committees within the various Societies for comments and refinements--because consensus is necessary if the theory is to be widely accepted and used. The work--theory and refinements--also should be distributed to the technical Societies. The procedures used by the international standards organization might provide the foundation for a standard approach to solving practical technical problems.

How can such action be initiated? Why not through the technical committees of the various Societies? Wouldn't the men serving on these committees be the best qualified to decide what the best approach to each technical area would be? The committees could monitor progress, give encouragement and suggestions, and develop necessary financial support. Members of the technical committees could help spread the use of the unified theory by applying it to their own practical problems.

This method of publication control may sound idealistic. But I believe it would work at some level. Further proposals for solving the problem will appear in future editorials.

R.L.E.

SEISMIC AND OPERATIONAL VIBRATION PROBLEMS IN NUCLEAR POWER PLANTS

C. B. Smith*

***Abstract** - This paper presents a brief overview of the following topics: current methods for seismic analysis and design, review of structural and equipment vibration test data, perspective on operational vibration problems, promising new developments, and future research areas.*

The effects of earthquakes and vibrations were considered in the design of the first nuclear reactors. Early design efforts included static analyses, fuel element vibration studies, and calculations of liquid sloshing effects. The state-of-the-art in the 1950s and early 1960s when the first nuclear facilities were designed has been summarized [1]. Many of these early reactors were equipped with vibration or shock operated switches that activated an alarm or shut down the reactor [2]. As the capacity of the plants increased, this approach was no longer appropriate.

With the advent of larger plants, the quantity of radioactive materials in the fuels increased, as did temperature and pressure regimes. In addition, structural materials and power plant components and equipment were put to optimal use. These changes, and the growing number of plants, led to the formulation of increasingly stringent seismic design requirements in the late 1960s and early 1970s. These requirements were outgrowths of basic federal regulations governing nuclear energy [3]. Early in 1970, Oak Ridge National Laboratory (Tenn.) prepared a summary of recent developments in earthquake engineering, soil and site studies, methods for dynamic analysis, and results of some limited testing that had been done on one operational and several decommissioned nuclear power plants[4].

The years since 1970 have been said to exemplify "cascading conservatism" in the seismic design of nuclear power plants: in addition to increasingly strict design requirements, the Nuclear Regulatory Commission (NRC) has issued a series of "Regulatory Guides." The guides regulate all aspects of the plant seismic design, from the seismic instrumentation to analytic methods, and even to fraction of critical damping appropriate for various classes of structures.

Public safety is of course the nuclear industry's foremost goal--and the safety record achieved with commercial nuclear power plants is unparallelled. But there is now widespread concern that certain aspects have been overemphasized: the seismic design and licensing phases of construction add substantially to the cost and time required to bring nuclear power plants into operation. Do these additional expenses make important contributions to public safety, or would it be more cost-effective to put the emphasis elsewhere? Does the emphasis on low-probability events such as major earthquakes receive disproportionate engineering attention compared to high probability events such as thermal expansion and operational vibration problems?

In an effort to establish priorities for research on these and other questions, the nation's electric utilities initiated a study in 1974 [5]. Under the auspices of the Electric Power Research Institute, the utilities proposed to carry out major new seismic research activities, an effort that has not been fully supported by the Energy Research and Development Administration (ERDA). Furthermore, in the last five years, the amount of experimental and test data has increased significantly. It is hoped that the decade of the 1970s will be one of substantial advances in the state-of-the-art of nuclear power plant seismic design.

Earthquake effects on nuclear power plants are of concern not only for reasons of public safety [6] but also because they create risks of loss of capital revenue and of damage to the environment and to electrical generating capacity. Actually, these concerns should apply to ***both*** nuclear and fossil-fuel plants. The design and licensing of nuclear power plants currently require extensive dynamic analysis, testing, and seismic design. Fossil-fuel plants are not

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designed to the same rigorous standards. The public health risk with regard to fossil-fuel plants is thus not negligible, even though public concern has focused on nuclear plants [7].

Study of the seismic response of power plant structures and equipment is a special application of shock and vibration methods. Shock and vibration problems are associated with normal plant operations, however. Such problems can have impact with respect to both economics and safety. Vibration problems are not new to the utility industry, which has accumulated considerable experience in dealing with boiler-caused vibrations, flow-induced vibrations in piping systems, and vibrations caused by turbines and other rotating machinery.

During the last decade the physical size of power plants has increased from a few hundred megawatts electrical (MWe) to single units rated at 1,100 MWe. This rapid increase in the mass and physical dimensions of structures, heavy equipment, and foundations, has introduced new effects that cannot always be accounted for by simple extrapolation. Thus, older design methods that were appropriate for smaller systems are not always successful for larger plants.

CURRENT METHODS FOR DYNAMIC ANALYSIS AND SEISMIC DESIGN

The seismic design of a nuclear power plant begins with site selection, usually five or ten years before the plant is actually built. The plant must be protected against damage by faulting (ground surface displacement) or ground-induced shock or vibrations. The site selection must meet requirements stipulated by the NRC [3]. These regulations specify the minimum acceptable distances that the plants can be located from active faults. Although methods for designing against surface displacement have been studied, they have never been employed in a U.S. plant [8] to my knowledge.

The problem of ground-induced vibrations is approached in a different way. The site is studied by a team of experts in seismology, geology, and soil mechanics. After an extensive review of available data--e.g., recorded earthquakes, local soil conditions, and distance to known faults--these experts establish levels for the most severe earthquake ground motion that can be expected at the site. This so-called maximum design earthquake* is used in the design of the plant. For the protection of the public and for the safe shutdown of the plant, all systems and structures must be designed to withstand the design earthquake and to remain functional, even if nonessential parts of the plant are damaged.

The peak ground acceleration during the design earthquake has ranged as high as 0.67 g's. Present plants located in low seismic areas are designed to at least 0.1 g's peak ground motion. Amplification of the ground motion by structures and equipment--especially on the upper floors of buildings--can result in accelerations of 5 to 10 g's or higher.

NRC regulations also define an "Operating-basis earthquake" (OBE), which is expected to occur one or more times during the life of the plant. During such an earthquake, the plant must remain operational; all equipment and structures must be designed accordingly. The peak accelerations of the OBE are typically 50% those of the SSE. It must be shown that the plant is capable of safe operation if motions exceed the OBE; otherwise, the plant may be required to shut down.

The SSE is generally specified in terms of response spectra for the plant (Fig. 1). An artificial time history is constructed to determine response spectra equal to or greater than the design spectra at all frequencies of interest. Artificial time histories (rather than an actual seismograph record) eliminate any non-site frequencies that might lead to abnormally high or low responses at a particular frequency.

The time history of the reactor containment building is generally applied at the "bedrock" beneath the plant. The bedrock motion is then propagated through the soil layers until it reaches the foundation of the plant. In the dynamic analysis, the designer must include soil-foundation interaction if it is significant. The soil-structure model is used to determine building stresses. In this model, the details of the structure are carefully represented, but the internal components are modeled primarily in terms of the mass they represent.

*Current NRC terminology for this hypothetical earthquake is the "Safe-Shutdown Earthquake" (SSE)

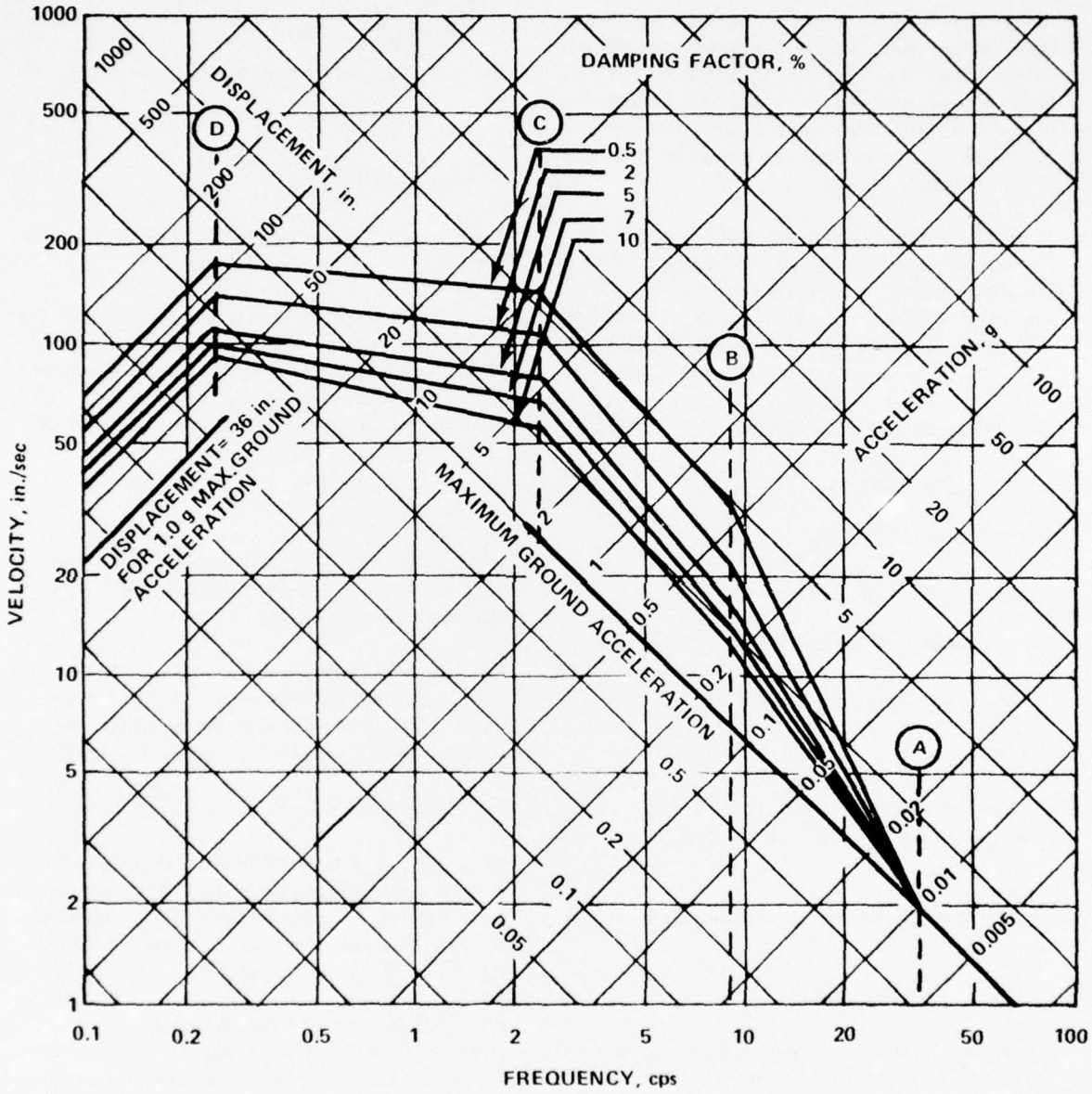


Figure 1. Horizontal Design Response Spectra - Scaled to 1g Horizontal Ground Acceleration

Figure 1 shows a typical two-dimensional plane-strain finite element model for the soil. Either this approach or the lumped mass approach ("continuum" method), is used to model the interaction between heavy power plant structures and the soil. The advantages and disadvantages of the two methods have been discussed [9]. The problem of embedment and the determination of the appropriate strain-dependent soil parameters are major uncertainties in this process.

In a simplified lumped mass (continuum) model, the soil-foundation interaction is modeled by solving for the combined rocking-translation modes of the soil-structure system. The approach can be illustrated with a single-degree-of-freedom system (Fig. 2) that undergoes coupled rocking and translation.

The horizontal force at the base is

$$F_x = -C_x\dot{x}_b - K_x x_b \tag{1}$$

The resistance to rocking is

$$M_\psi = -C_\psi\dot{\psi} - K_\psi\psi \tag{2}$$

The horizontal translation of the foundation is

$$M\ddot{x}_g = Fx = -C_x\dot{x}_b - K_x x_b \tag{3}$$

Note that

$$x_b = x_g - h_o\psi \tag{4}$$

is a coupling term,

$$M\ddot{x}_g + C_x\dot{x}_g + K_x x_g - h_o C_x\dot{\psi} - h_o K_x\psi = 0 \tag{5}$$

The equation of motion for rotation about the C_g is

$$I_o\ddot{\psi} = T_\psi + M_\psi - h_o F_x \tag{6}$$

where T_ψ is the moment applied to the foundation. Substitute equations (2), (3), and (4) in (6)

$$I_o\ddot{\psi} + (C_\psi + h_o^2 C_x)\dot{\psi} + (K_\psi + h_o^2 K_x)\psi -$$

$$h_o C_x\dot{x}_g - h_o D_x x_g - T_\psi = 0 \tag{7}$$

The determinant obtained by solving the coupled equations of motion yields equation (8), which can be solved for the eigenfrequencies of the coupled system:

$$\omega_n^4 - [(K_\psi + K_x h_o^2)/I_o + (K_x/m)]\omega^2 + (K_x K_\psi/mI_o) = 0 \tag{8}$$

The coupling is represented by the h_o term. If $h_o = 0$

$$\omega_1 = \sqrt{K_x/m} \tag{9}$$

$$\omega_2 = \sqrt{K_\psi/I_o} \tag{10}$$

These are the eigenfrequencies for the uncoupled system.

The eigenfrequencies depend on the rocking and translational stiffnesses, which are derived from the soil properties. Modification of the stiffness and addition of a term to represent the effect of embedment provide an approach to the embedment problem.

$$k_x' = k_x + k_{xe}$$

$$k_y' = k_y + k_{ye}$$

This concept can be extended to the finite element method; however, two-dimensional finite element techniques have limitations.

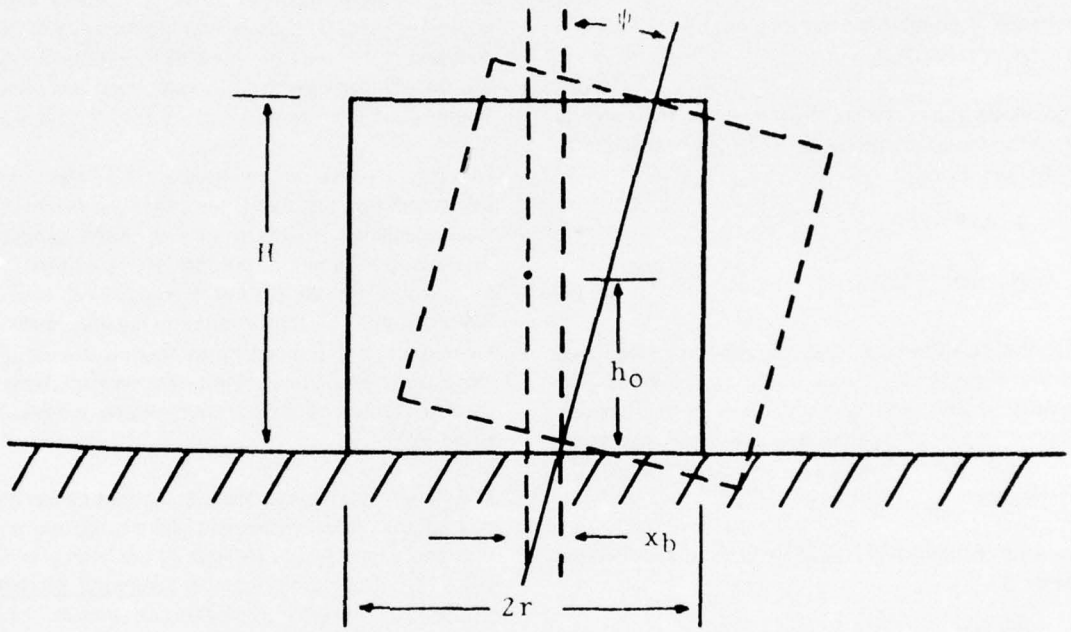
The structural response is frequently analyzed using a lumped mass technique to find floor response spectra. This involves solving the set of coupled differential equations used to model the structure.

$$M\ddot{U} + C\dot{U} + KU = F \tag{11}$$

where K is a real, symmetric; positive definite stiffness matrix, U is the system deflection vector; M is a real, symmetric, positive definite mass matrix; C is a real, symmetric, positive definite damping matrix; and F is a forcing vector.

For this N-degree-of-freedom system there exist N eigenvectors: $A_1, A_2, \ldots, A_N$
N real, positive eigenfrequencies: $\omega_1, \omega_2, \ldots, \omega_N$.

$$\Omega = \begin{bmatrix} \omega_1 & 0 \ldots 0 \\ 0 & \omega_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ 0 \ldots & \omega_N \end{bmatrix} \tag{12}$$



Note: $x_h = x_{tr} - h_o\psi$

Figure 2. Model for Rocking and Translation

N real, positive effective modal masses (eigenmasses):

$$W=\begin{bmatrix} w_1 & 0 \ldots 0 \\ 0 & w_2 \quad . \\ . & \quad . \\ . & \quad\quad . \\ . & \quad\quad\quad . \\ 0 \ldots & \quad\quad\quad w_N \end{bmatrix}$$

Define Φ, a modal shape matrix given by $\Phi = [A_1 A_2 \ldots . A_n]$.

The mode shape matrix Φ, the modal mass matrix W, and the eigenfrequency matrix Ω are related to M and K by

$$\Phi^T M\Phi = W \tag{13}$$

$$\Phi^T K\Phi = W\Omega\Omega \tag{14}$$

The first relation establishes the arbitrary magnitude of the eigenvectors. Some authors set W to the identity matrix and coin the term normal modes. What is important is that W is diagonal, and equation (13) demonstrates the orthogonality of the eigenvectors.

To solve equation (11), define a modal deflection vector Y

$$\Phi Y \equiv U \tag{15}$$

and substitute in equation (11). Premultiply by Φ^T and use the relations in equations (13) and (14) to find

$$\ddot{Y} + 2\beta\Omega\dot{Y} + \Omega\Omega Y = W^{-1}\,\Phi^T F \tag{16}$$

where

$$\beta = (W^{-1}\Omega^{-1}\Phi^T C\Phi/2) \tag{17}$$

is a modal damping matrix. It is assumed that β is diagonal, hence the modal equations are still uncoupled. This assumption is reasonable as structural damping is usually small. In any case, the error associated with this assumption is small in comparison to the assumption that damping is linear in the first place. This set of N uncoupled equations is easily solved for each element of Y, and yields U through equation (15).

After the floor displacements are known, they can be used to determine the response of equipment supported at each level in the building. For simple equipment it is appropriate to use the floor response spectrum with an appropriate damping value and do a quasi-static analysis. For more complex equipment, such as a piping system, the floor time history would be used, and a complete dynamic analysis would be performed. In some cases either method could be used. The designer must weigh the added cost and complexity of a time history analysis against the uncertainties involved in combining the response (determined from response spectra) of several modes.

Dynamic models can be developed in three ways--by closed form analysis, lumped mass methods, or finite element methods--depending on the complexity of the system and the purpose of the analysis. For a typical plant all of the methods will be used. Simple systems can be analyzed directly. Numerical techniques and lumped mass models are used for more complex systems. Finite element methods are used to represent complicated piping systems and structures.

A summary of design standards, current design methods for structures, equipment and piping, and analytical and experimental techniques has been published [5]. The proceedings of the Structural Mechanics in Reactor Technology [10] conferences contain many useful papers on seismic analysis and modeling of nuclear power plant structures and equipment.

FULL-SCALE TESTS OF NUCLEAR POWER PLANT STRUCTURES AND EQUIPMENT

A brief overview of the growing body of literature pertaining to full-scale testing is given in this section. Scale model testing is not included because the greatest need has been for data to confirm present power plant designs and analytical methods. Scale model tests have been of value in some cases, however, particularly for parametric studies. Scaling laws and similitude questions make extrapolation from scale models to full-scale massive structures uncertain (e.g., scaling of gravity effects, material properties with massive concrete walls, inelastic soil properties).

The first step in a field test is to determine soil properties. Both laboratory and in-situ techniques are used; each has disadvantages. Samples for laboratory tests may be atypical, and the sampling procedure itself can disturb soil properties. In-situ tests avoid these difficulties, but it is inconvenient to produce sufficiently high strains during in-situ tests. In addition to measuring soil parameters as a function of strain, it is also necessary to know them as a function of depth, typically to at least 50 or 100 m.

The usual in-situ approach is to measure the shear and compressional wave velocities (Vs and Vp) and the soil specific mass ρ. Then Poisson's ratio and the shear and elastic moduli can be found using the relations below, which apply for linear elastic soils

$$\nu = (r^{-2})\,/2\,(r^2-1) \tag{18}$$

$$G_S = \rho\, V_S^{\,2} \tag{19}$$

$$E = 2G_S(1+\nu) \tag{20}$$

where $r = V\rho/V_S$

Improved methods for measuring strain-dependent soil parameters are urgently needed because they have a dominant effect on the calculated response [5]. The NRC has supported research in this area [11]. The Electric Power Research Institute has also initiated a research program [12].

Experimental measurements of the soil-foundation interaction have been limited to studies on small foundations, models, and embedded concrete cylinders [13]. About ten full-scale nuclear power plants have undergone extensive dynamic testing: one in the Federal Republic of Germany; the others are in Japan and the U.S. Because most of the plants are either old designs or de-commissioned, the results cannot be extrapolated directly to presently operating plants. The chief values of these tests have been data (measured damping values, mode shapes, eigenfrequencies, stiffness values, etc.) and validation of analytical models. Structural vibrators or explosive charges buried in the soil are used to excite the structure; accelerometers, signal conditioners, and recording equipment are used to record the results. Data are processed to obtain the desired characteristics of the structure. The literature contains extensive descriptions of test methods, typical results, costs, and data acquisition and analysis methods [14 - 17].

Similar test methods can be applied to power plant equipment and piping systems. Shake tables can be used in laboratory tests of some smaller pieces of equipment if the support conditions are correctly duplicated [18]. Information concerning equipment responses--ranging from reactor vessels, heavy pumps, turbine generators, steam generators and cranes, to stacks and piping systems--is available [14, 15, 18]. A comprehensive test program was recently conducted at the Humboldt Nuclear Power Plant (Calif.) [19]. This test was unique in that much of the equipment was subjected to high level vibration tests in-situ (for purposes of seismic design qualification). In addition, test data were used in conjunction with analysis to reduce the costs of qualifying equipment that is either too complex, too unreliable, or too expensive to model mathematically. In the Federal Republic of Germany, an extensive program of seismic testing and analysis has been initiated to evaluate computer codes and analytical methods in an effort to increase reliability and reduce conservatism [20, 21].

PERSPECTIVE ON OPERATIONAL VIBRATION PROBLEMS

Vibration is frequently a source of difficulty during normal operation of both conventional and nuclear power plants. Some typical cases, drawn from personal experience are given below.

- Turbulent two-phase fluid flow through a control valve caused vibrations approaching 1 g on a piping system. Piping supports eventually failed.
- Unbalance in a large induced draft fan caused excessive foundation and equipment vibrations.
- Structural modifications to the frame of an emergency diesel generator led to vibration problems.
- Under certain flow conditions a primary coolant pump underwent excessive vibrations.

The NRC requires nuclear power plants to report all "abnormal occurrences" -- equipment failures or operational problems except those of minor importance [22, 23]. Although the most common difficulty is probably valve malfunction, vibration problems and water hammer problems also frequently occur. A typical list from reports for 1974 includes cracks in BWR recirculation piping; excessive BWR jet pump vibrations; damage to pipe hangers and seismic restraints caused by water hammer; vibrations, wear, and movement of reactor core internals; fatigue failure of a main coolant pump shaft; and heat exchanger tube failure due to excessive vibration.

These failures do not have the same consequences as a strong motion earthquake, of course, but public safety could conceivably be involved. Furthermore, plant shutdown to repair even minor equipment failures is expensive due to generally high cost of maintenance work in radiation areas, quality control and documentation required, and revenues lost during shutdown.

Many of the techniques used for seismic analysis and design are applicable to vibration problems that occur during plant operation; experience gained in the aircraft and aerospace industries is also applicable. One possible difference is the frequency spectrum of interest.

Recognizing the importance of operational vibration problems, the NRC has issued a series of "Regulatory Guides" that apply to vibration testing and instrumentation. A vibration assessment program [24], recently revised, is typical of the series. The operational vibration area of operating power plants merits further attention and development, with respect to both theory and practical application.

PROMISING NEW DEVELOPMENTS

Perhaps the most significant recent development has been the rapid expansion of the strong motion seismograph instrumentation grid in the U.S. It has increased the probability of obtaining meaningful data from future earthquakes. Current seismic design efforts are severely limited by the few actual data available. Most of the major decisions pertaining to the seismic design of nuclear power plants are based on "artificial" earthquake time histories; these in turn have been developed from the few dozen earthquakes that have occurred. The San Fernando earthquake (9 February, 1971) produced more moderate--or strong-motion instrumental records than ***all*** previously-recorded historical earthquakes.

Rojahn ([17] pp 40-60) has described the program for installing strong motion instruments in California. In addition, a national standard has been drafted that specifies locations and requirements for seismic instrumentation in nuclear power plants [25]. When earthquakes occur in the future, it is hoped that a greater amount of improved instrumentation will facilitate a better understanding of, and protection against, seismic forces. The performance of operating nuclear facilities during an earthquake will validate design approaches and point out possible conservatism on the one hand or areas where further improvements are needed on the other.

Certainly the growing body of test data, particularly the high-level seismic qualification tests now performed on equipment, creates confidence that the equipment will not only survive but will also remain operational during an earthquake.

Sophisticated dynamic analyses are now done routinely on all major structures and important equipment and piping systems. Although there is admittedly always room for improvement, these analyses are easily several orders of magnitude more expensive, detailed, and comprensive than the dynamic analysis done on a modern high-rise office building.

Significant conservatism and safety margins are introduced in the seismic design at every step, from specification of the ground motion, determination of the models, and selection of stress criteria and damping values to the determination of loads and responses. As a result, nuclear power plants have a margin of conservatism that is 10 to 50 times greater than that for a conventional steel frame high-rise building [26].

Major future developments are likely to be based on better knowledge of earthquakes and their prediction; more accurate and cheaper analytical methods (one interesting possibility is the use of time-dependent

response spectra); wider use of three-dimensional models where appropriate; better values for damping and material properties near failure; and incorporation of nonlinear and inelastic analysis methods.

FUTURE RESEARCH AREAS

Future research areas have been outlined recently in some detail [5]. Choices that reflect a personal sense of priorities are outlined below.

- Develop better methods for in situ determination of strain-dependent soil parameters. Little can be said in favor of current methods except that they do not yield results consistent with laboratory tests
- Develop improved methods for soil-foundation interaction calculations (particularly embedded structures). Validate the results with a large scale field test. This point and the preceding one are vital because errors here are multiplied in the subsequent steps of design, and overconservatism leads to excessive construction costs.
- Current damping values used in design (legislated by the NRC) are too low and should be modified. Better understanding of damping mechanisms is needed.
- Until the above steps are completed, there is little benefit in trying to improve analytical techniques since the computer models are only as good as the input data--"garbage in, garbage out"[27]. Eventual goals are to improve running time, reduce costs, improve accuracy in modeling, and incorporate nonlinear methods where needed.
- Additional high-level tests on full-scale, current generation plants should be conducted. These tests should produce DBE-type ground motions to demonstrate the adequacy of current designs. The most likely test will be a California earthquake or buried explosive charges. The latter technique is preferred, so that the date and place of the test can be selected in advance.
- The types, locations, and numbers of seismic instruments in nuclear power plants should be reviewed. For the same cost, better placement of instrumentation would substantially increase the probability of obtaining useful information following an earthquake.
- A nuclear facility will eventually be damaged during an earthquake. No procedures exist for determining whether the plant will be shut down or continue operating. This is an important area for future research.

In conclusion, nuclear power plants present unique dynamic problems because they have large masses, interact with the supporting soil, and contain many different types of piping and equipment. Furthermore, they must be designed to withstand the combined forces of many different types of loads. From a seismic point of view, they are today among the most thoroughly analyzed and designed structures. Undoubtedly this is appropriate in view of their overall importance to society; however, further improvements are possible, and researchers interested in dynamics can find many rewarding opportunities for interesting work in this field.

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27. This is a technical expression from the computer sciences field: if you start with bad data, the computer will trust you and automatically assume your data are valid.

ACKNOWLEDGEMENT: I thank my colleagues G.E. Howard and P. Ibáñez for suggestions and comments related to this review.

LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critque and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

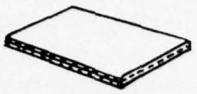
Dr. Charles Bert of the University of Oklahoma continues his review article, Damping of Composite and Sandwich Panels, in this issue of the DIGEST. Small deflection motions of panels; effects of thickness-shear flexibility and of large deflections on panel vibrations and the concepts of forced vibration, dynamic stability and wave propagation for panels are discussed.

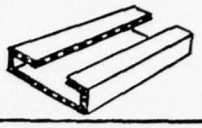
An article on modeling of vibrating systems emphasizing force balance and energy methods is presented by A.J. Hannibal of Lord Kinematics. In this article, modeling techniques rather than details are presented.

DAMPING OF COMPOSITE AND SANDWICH PANELS

PART II

CHARLES W. BERT*





Abstract - This article surveys the literature pertaining to the dynamics of composite and sandwich panels and emphasizes flexural motion. It is limited to elastic and viscoelastic behavior of materials. Free vibration work since 1969 is emphasized. Plates stiffened with attached stiffeners (stringers) and curved panels (as opposed to flat ones) are beyond the scope of the survey. The author has concentrated on references available from the National Technical Information Service.

SMALL-DEFLECTION MOTION OF CYLINDRICALLY-ORTHOTROPIC AND CYLINDRICALLY-ANISOTROPIC PANELS

In the panels described in the first part of the article all fibers in a given layer were assumed to be oriented at the same angle. In some cases, such as built-up reinforcing bosses at holes and in rotating disks (compressor disks and flywheels), however, the fibers are arranged in a circumferential direction by filament winding. If the fibers in a given layer are arranged either circumferentially or radially, the macroscopic behavior of the layer is said to be cylindrically orthotropic (sometimes called polar orthotropic). In some instances, perhaps due to manufacturing limitations, it is necessary to orient the fibers at some acute angle with the radial direction. Such a layer is said to have a cylindrically-anisotropic fiber arrangement.

An inherent difficulty in conducting static or dynamic analyses of solid circular plates of cylindrically orthotropic material is the singularity at the origin (radius r=0). It can be shown that, although the strain-energy density at r=0 is infinite if $D_\theta \neq D_r$, the total strain energy in a finite-radius disk is finite. At r=0, however, radial and circumferential directions cannot be distinguished. This fact has been used as the argument for inserting a very small concentric isotropic-material region, called a core, at the center of a cylindrically-orthotropic plate [80, 81]. An alternative is to assume that a very small hole exists at the center [82]; this approach has the disadvantage of introducing the inherent stress-concentrating effect of a hole.

In a series of papers on the free vibration of cylindrically orthotropic annular plates, Vijakumar and Ramaiah [83-85] used the Ritz technique in conjunction with a new coordinate defined as

$$y \equiv (r^2 - a^2)/(b^2 - a^2) \tag{12}$$

where a and b are respectively, the inside and outside radii. It was then possible to use polynomial functions of y as the radial modal functions. In one case, only axisymmetric modes were considered [83]; in another, unsymmetric modes with up to two nodal diameters were treated [84]. The assumption that the radial bending moment is zero at a nodal diameter was used in an analysis of higher modes having many nodal diameters [85]. Free vibration of annular plates has also been treated [86].

Stiffness matrices have been derived for solid circular and circular annular finite elements [87]. They were applied to the analysis of free vibrations of an annular plate simply supported at both the inside and outside edges. Other work on circular annular plates has been reported [88-89]. The case of a circular plate continuous over an arbitrary number of concentric circular supports, either rigid or elastic, has been studied [90]. The effect of in-plane uniform edge loading was included.

It is sometimes desirable -- for example, in compressor disks -- to taper the plate by decreasing its thickness as the radius is increased. Free vibrations of such a plate have been studied [91]. Thickness distribution was given by

$$h = h_o - (h_o - h_a)(r/a)^n \tag{13}$$

Some results were presented for clamped and simply supported edges.

The case of a non-circular planform shape has been analyzed using a series solution for free vibrations of a cylindrically-orthotropic plate having a planform of a sector of a circular annulus [92]. The two curved

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edges were assumed to be simply supported; the two straight edges were permitted to have arbitrary boundary conditions.

The orthogonality conditions for forced vibration, including unsymmetric modes, have been derived, but no numerical results were presented [93]. Only one dynamic analysis of a cylindrically anisotropic plate has been done [94]. The inherent difficulty caused by the presence of the cross-elasticity terms (uneven number of derivatives with respect to both r and θ) was avoided by noting the deflections' periodicity in θ and using an exponential series in θ.

EFFECTS OF THICKNESS-SHEAR FLEXIBILITY

In the work mentioned thus far, thin plate theory -- based on the Kirchhoff hypothesis that plane sections remain plane and are normal to the deflected midplane -- has been used. This theory is adequate for determining gross characteristics, such as natural frequencies. It is sometimes necessary, however, to include the effects of thickness-shear deformation, i.e., to discard the Kirchhoff hypothesis. This is especially necessary in composite-material plates, since practical composite materials have a much lower ratio of shear modulus to in-plane elastic moduli than do isotropic ones. In sandwich panels having lightweight, highly flexible cores, thickness-shear deformation is the price that must be paid to enhance flexural rigidity.

Thickness-shear deformation must be considered in four dynamic situations:

- Free vibrations of moderately thick plates
- Forced vibration amplitude and stress distribution (including damping effects)
- High-frequency, short-wavelength wave propagation
- Localized impact

For certain problems, including those involving laminated plates, it has been possible to solve the three-dimensional dynamic elasticity equations. These equations provide more accurate solutions than do the shear-flexible plate theory equations and can be used to determine the range of parameters for which solutions using the less exact theories are sufficiently accurate for engineering purposes.

Sandwich Panels

References on vibrations of sandwich plates have been selected primarily on the basis of their applicability to sandwich panels having orthotropic (composite material) facings or an orthotropic core (many sandwich core materials are orthotropic). The effects of orthotropic cores on natural frequencies of simply supported sandwich panels have been investigated [95]. A core with a ratio of longitudinal to transverse shear moduli of 1.5 to 1.7 (typical of hexagonal-cell honeycombs) increased the natural frequency of the panel by about 3 percent compared with a panel having an isotropic core.

A general theory of the dynamics of sandwich panels with anisotropic facings has been developed [96]. Free vibrations of panels with orthotropic facings and core have been investigated [97], and the effect of in-plane axial compression has been considered [98].

Few experiments on sandwich panel dynamics have been carried out. Panels with glass-reinforced plastic facings in air and in a vacuum have been considered [99], as have graphite-reinforced plastic facings [100].

Response of sandwich panels to random excitation has been studied [101], and the effects of a fluid medium have been analyzed [102]. In an analysis of supersonic panel flutter [103], the effects of core orthotropy and various edge conditions were investigated.

Multicore sandwich panels have facings stiffer than the core that lies between each core. Various dynamic analyses of multicore panels, including orthotropic effects have been made: closed-form solution [104], finite-strip analysis [105], finite-element analyses [106, 107], and dynamic stability under time-dependent in-plane loading [108].

Moderately Thick Laminated Panels

In analysis of moderately thick laminated panels shear thickness flexibility is included. Free vibrations of symmetrically laminated rectangular-orthotropic panels of rectangular planform have been analyzed [109], as have the axisymmetric modes of cylindrically orthotropic panels of circular planform [110].

Harmonic wave propagation of symmetrically laminated composite panels has been studied [111] as has transient wave propagation such as that resulting from impact loads [112-117].

Numerous theoretical approaches have been developed for arbitrarily laminated plates: Mindlin-type shear-corrected theory [118], microstructural theory [119], Biot's theory [120-121], and various higher order theories [122-124]. Many of these theories have been discussed [7, Section VI.A].

Various analyses of free vibration of moderately thick, laminated composite rectangular panels have appeared [125-128]. Finite-element analyses of moderately thick, laminated composite panels involve rectangular orthotropic materials [129, 130], the effect of in-plane loadings [130], and cylindrically orthotropic materials [131].

Exact solutions of the three-dimensional dynamic theory of elasticity have been obtained for specific laminated panel configurations. Simply supported plate strips of cross-ply and angle-ply layups have been considered [132, 133], as have rectangular panels laminated of orthotropic materials [134, 135]. If the natural frequencies associated with the flexural, thickness-twist, and thickness-shear modes corresponding to each set of mode numbers (m, n) are sought, the Mindlin-type shear-corrected theory (SPT) is adequate. If the full spectrum of modes (an infinite number of doubly infinite spectra) -- including symmetric thickness modes, for example, -- is required, solutions for the three-dimensional theory are necessary.

The effects of damping have been considered using both the three-dimensional theory and SPT for free vibrations [136] and SPT for sinusoidally forced vibration [137]. In the latter study, micromechanics predictions of the composite layer properties and laminated plate SPT were used to predict free-edge plate resonant frequencies and damping ratios for off-axis-oriented rectangular plates. The predictions were in good agreement with experimental results [138].

Dynamic response of laminated SPT panels undergoing cylindrical bending has been considered [139 - 141]. Dynamic load factors (ratio of dynamic deflection or stress to the corresponding value for the same loading applied statically) have been presented for plates subjected to sudden pressure loading only [140] and sudden pressure loading plus steady in-plane loading [141]. Impact loading by a point mass has been investigated [142], and a finite-element modal analysis of impact has been carried out [143]. Numerous analyses of wave propagation in laminated composite-material plates with shear flexibility have appeared [144-151].

EFFECTS OF LARGE DEFLECTIONS

The most important effect of large deflections (geometric nonlinearity) occurs when the panel edges are restrained from in-plane motion. As the deflection increases, membrane forces develop in the panel. Their net effect is to increase the mean stress in the panel and limit the deflection attained in a panel subjected to a given excitation. Thus, the panel has a mechanical action analogous to that of a spring-mass system with a "hardening" type of spring -- specifically, a linear spring in parallel with a cubic spring.

Free Vibration

Nonlinear vibrations of rectangular sandwich panels with isotropic facings have been analyzed [152, 153]. The effects of thickness shear flexibility and edge conditions have been studied [153].

Large-amplitude vibrations of orthotropic rectangular plates with either simply supported or clamped edges have been investigated [154]. The simplifying hypothesis originated by Berger [155] for large static deflections of isotropic plates was used. Berger's hypothesis is that the second invariant of the mid-plane strains in the strain-energy expression can be neglected. The hypothesis permits convenient decoupling of in-plane and flexural equations. An orthotropic version of Berger's hypothesis and the familiar characteristic modal shape for a clamped slender beam were used to study orthotropic rectangular panels with all edges clamped [156]; experiments with glass-fiber reinforced epoxy panels were also reported. The same general analytical approach, but including thickness shear flexibility, has been used to analyze rectangular plates having various combinations of clamped and simply supported edges [157].

Vendhan [158] made a detailed study of Berger's hypothesis as applied to orthotropic rectangular panels and used a higher-order Galerkin approximation to handle the in-plane action [159]. The Galerkin method has been used without the Berger hypothesis for orthotropic rectangular plates having elastic rotational supports at the edges [160].

Skew plates of rectangularly orthotropic material have been investigated [161-164]; tapered thickness was considered [164]. Triangular-planform plates have also been considered [165, 166]. Circular plates with rectangular orthotropy have been treated [167], as have circular plates with circular cylindrical orthotropy [168-171]. In one instance, the effects of heating and both clamped and simply supported edge conditions were included [171].

Nonlinear vibrations of unsymmetrically laminated rectangular plates were first analyzed by Bennett [172, 173]. An approximate Galerkin approach without the Berger hypothesis has been reported [174]. Rectangular sandwich panels with unequal facings have been considered [175] as well as cross-ply and angle-ply laminated plates [176, 177].

Forced Vibration, Dynamic Stability, and Wave Propagation

Relatively little work has been directed to the nonlinear vibration of composite-material or sandwich plates under conditions other than free vibration. Sinusoidal excitation has been considered for cylindrically-orthotropic circular plates [169], and for multi-layered rectangular sandwich plates [178].

Pulse- and shock-type excitations of rectangular sandwich panels have been studied [179], and dynamic stability has been analyzed [180]. In an investigation of the flutter of arbitrarily laminated rectangular panels undergoing large deflections, the hardening-spring-type membrane action limited the flutter amplitude [181]. Proper design will ensure that the stresses induced during the limit cycle are below the fatigue strength of the panel material; thus, a lighter weight panel can be used than would be required to prevent initiation of flutter. The effects of large dynamic deflections and of large initial static deflections on flexural have propagation in plates have been studied. [182-184].

SUGGESTIONS FOR FUTURE RESEARCH

The following suggestions are pertinent to investigations involving composite-material panels.

- Numerical results should be presented in forms more useful to structural designers.
- More attention should be directed toward the optimal design of composite-material panels so that specific dynamic and static criteria are satisfied. Criteria include stresses under various loadings, buckling load, and panel flutter speeds. Consideration should be given to the interaction of stiffness, damping, and fatigue strength.
- More attention should be given to the effects on vibration of non-uniformly distributed in-plane loadings; for example, the author is not aware of any published analysis of the flexural vibrations of a cylindrically-orthotropic (filament-wound) circular plate subjected to centrifugal, Coriolis, or rotational accelerational loadings. Yet such an analysis could play an important role in the development of a successful filament-wound composite-material flywheel for a hybrid automotive vehicle.
- More attention should be paid to experimental verification of dynamic analyses.

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MODELING OF VIBRATING SYSTEMS - AN OVERVIEW

Part I. Force Balance and Energy Methods

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Abstract - A number of prominent modeling methods are presented in capsule form. The "type" of modeling technique is emphasized rather than details of the method. The references have been divided into sections relating to the modeling methods.

In a general sense, modeling (excluding scale modeling) may be defined as the art of representing a real physical system in mathematical terms. A representation that will yield valuable results depends upon a judicious choice of assumptions. It takes substantial insight -- normally accumulated through study and experience -- to cast a system into proper perspective; that is, to avoid "over analysis" where unimportant aspects cloud the issue and "under analysis" where important aspects are lost. The approach used for modeling depends on the system in question, the type and purpose of the analysis, and the best available representation of the system components. It is the intent of this article to discuss the more common approaches and to shed light on their advantages and disadvantages.

The modeling of physical dynamic systems can be divided into the following:

- Physical idealization and reduction to mathematical equations
- Identification of system parameters
- Definition of the loading mechanisms

Each step plays an important role in the accurate prediction of system response. However, this article deals only with the first, which involves:

- The identification of the operating mechanisms or components in the physical system and the development of a definitive mathematical expression, usually in terms of force, pressure, energy, impedance, etc...
- The assembly of the components into a representation of the system

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The identification process begins with a pictorial representation of the physical system, which is idealized into such components as masses, springs, dampers, beams, plates, shells, and servo-valves. In many cases, representation in straightforward or can be ascertained experimentally. On the other hand, component definition -- for example, in hydrodynamic and gas-lubricated journal bearings or wave effects on drilling platforms -- can be complex and time consuming. This article is a review of some of the most common methods available for modeling vibrating systems. The methods include:

- Force Balance -- Newton's Second Law
- Energy Methods (Hamilton's Principle, Lagrange's Equations)
- Approximate Methods
- Impedance and Mobility Methods
- Transfer-Matrix Method
- Finite Element Methods
- Bond Graphs

The assumptions that must be made before a system is modeled deserve some attention. Assumptions concerning most physical mechanisms are representative over a limited range of the variables on which they are dependent. For example, at low frequencies, beams (foundation structures in general) can usually be considered rigid; at higher frequencies, their response is governed by the Bernoulli-Euler beam theory. At even higher frequencies, as Timoshenko [9] first noted, the Bernoulli-Euler theory is inadequate. In other words, assumptions must be coordinated with the purpose of the analysis, or errors will result. This is particularly true of finite element methods and other so-called "canned programs," in which the user may not be familiar with the assumptions used to develop the elements. Karnopp and Rosenberg [10] have presented an interesting expose on the assumption process.

FORCE BALANCE

Equilibrium in Newtonian mechanics is expressed by equating the sum of the applied forces and moments acting on each mass element (ith) in the system and the inertia force as in equations (1) and (2)

$$\frac{d}{dt}(m_i\dot{\vec{x}}_i) = \vec{F}_i \tag{1}$$

$$\frac{d}{dt}(\vec{J}_i) = \vec{L}_i \qquad i = 1, 2, 3, \ldots, n \tag{2}$$

In the equations $\vec{x}_i$ is the translatory motion of the ith mass element, $\vec{F}_i$ is the sum of the applied forces, $\vec{J}_i$ is the angular momentum, and $\vec{L}_i$ is the sum of the applied moments. If the vectors $\vec{x}_i$ do not represent independent motion (that is, they are not generalized coordinated), equations (1) and (2) must be modified by constraints of the form in equation (3). In mechanics, this type of constraint is referred to as holonomic. For the more general pfaffian form, the reader is referred to Chapter 2 of Meirovitch's book [11].

$$f_j(\vec{x}_1, \vec{x}_2, \ldots, \vec{x}_n) = 0 \qquad j = 1, 2, \ldots, m \tag{3}$$

Equations (1) and (2) assume a coordinate system whose origin either in not accelerating or is the center of mass. Although not usually desirable, it is possible to choose an accelerating point as the origin, in which case equations (1) and (2) must be modified to include inertia coupling. For a rigid body whose orientation in space is described by counterclockwise rotations about the x^1, y^1 and z^1 axes (see Fig. 1) -- referred to as roll (α), pitch (β) and yaw (γ) respectively -- and which are assumed small so that

$$\sin\theta \approx \theta \qquad \cos\theta \approx 1 \qquad \theta = \alpha, \beta, \gamma \tag{4}$$

equation (1) becomes

$$\frac{d}{dt}(m\dot{\vec{x}}_a) - m(\vec{u} \times \ddot{\vec{\theta}}) = \vec{F} \tag{5}$$

In this equation m is the mass of the rigid body, $\vec{x}_a$ is the motion of the arbitrary origin (depicted by point "a" on Fig. 1) with respect to an inertial reference frame, $\vec{u}$ is the vector from "a" to the center of gravity and $\vec{\theta} = (\alpha, \beta, \gamma)$.

Equation (2) becomes

$$\frac{d}{dt}(I^1\dot{\vec{\theta}}) + m(\vec{u} \times \ddot{\vec{x}}_a) = \vec{L} \tag{6}$$

where I^1 is the inertia tensor with respect to point "a", the arbitrary origin.

As an example of the usefulness of Equations (5) and (6), consider the vibrating body in Figure 2.

For this example,

$$\vec{x}_a = \begin{Bmatrix} 0 \\ y \\ 0 \end{Bmatrix}; \quad \vec{u} = \begin{Bmatrix} u \\ 0 \\ 0 \end{Bmatrix}, \quad \vec{\theta} = \begin{Bmatrix} 0 \\ 0 \\ \gamma \end{Bmatrix}, \quad I' = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & I_a \end{bmatrix}$$

$$\vec{F} = \vec{F}_{Applied} + \vec{F}_{Springs} = \begin{Bmatrix} 0 \\ F_y \\ 0 \end{Bmatrix} + \begin{Bmatrix} 0 \\ -k(y + (b+u)\gamma) - k(y - (b-u)\gamma) \\ 0 \end{Bmatrix} \tag{7}$$

By substitution, equation (5) becomes

$$m \begin{Bmatrix} 0 \\ \ddot{y} \\ 0 \end{Bmatrix} - m \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ u & 0 & 0 \\ 0 & 0 & \ddot{\gamma} \end{vmatrix} = \vec{F}$$

or,

$$m\ddot{y} + mu\ddot{\gamma} = F_y - k(y+(b+u)\gamma) - k(y - (b-u)\gamma) \tag{8}$$

Equation (6) becomes

$$I_a\ddot{\gamma} = L_a + m \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & \ddot{y} & 0 \\ u & 0 & 0 \end{vmatrix}_z = L_a - mu\ddot{y}$$

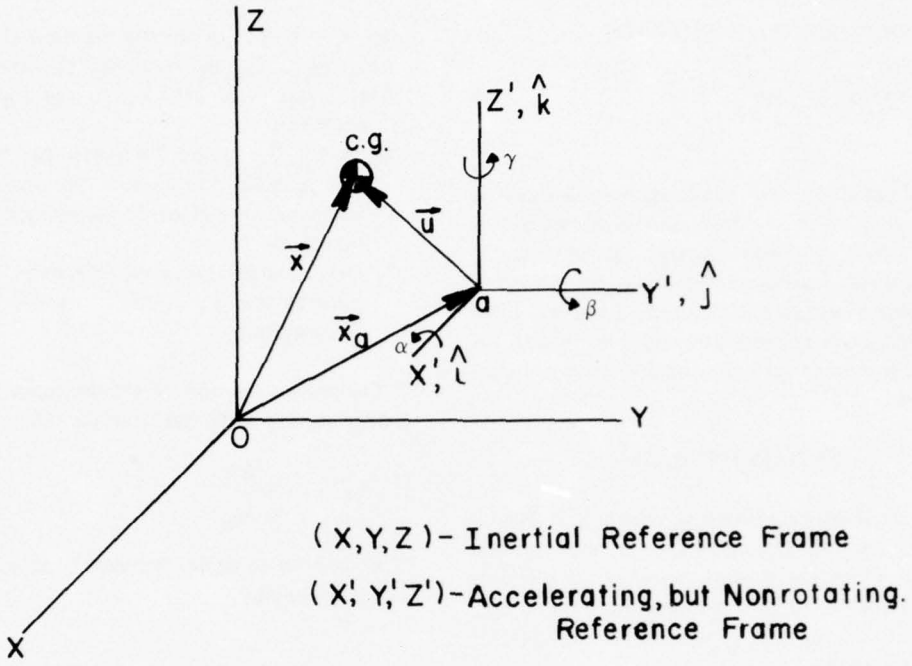


Figure 1. Accelerating Reference Frame

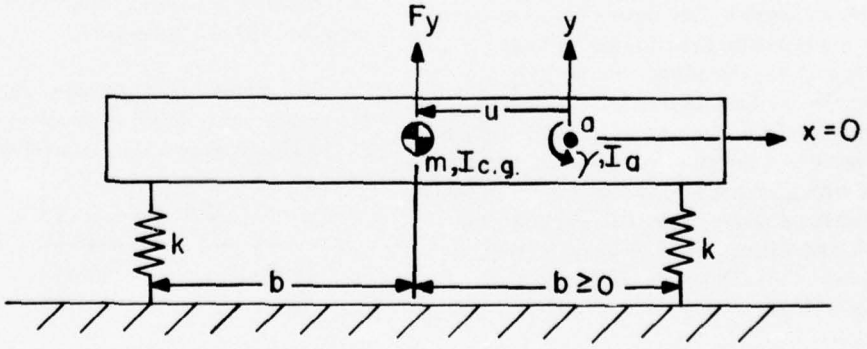


Figure 2. Two Degree-of-Freedom Sample Problem

or

$$I_a\ddot{\gamma} + mu\ddot{y} = F_y u - k(b+u)(y+(b+u)\gamma)$$

$$+ k(b-u)(y-(b-u)\gamma) \qquad (9)$$

Modeling based on the force balance approach is generally limited to relatively simple vibratory systems for which free-body diagrams can be drawn -- for example, an assemblage of rigid masses connected by a series of springs and dampers. Although force balance has been applied sucessfully to distributed systems, Hamilton's principle provides a more elegant derivation.

ENERGY METHODS

The two most important energy methods are Hamilton's principle and Lagrange's equations of motion. The latter, which is expressed as a system of differential equations, is usually derived from Hamilton's principle. Equation (10) is Hamilton's principle for holonomic systems.

$$\delta I = \delta \int_{t_1}^{t_2} L(\dot{q}_1, \dot{q}_2, \ldots, \dot{q}_n, q_1, q_2, \ldots, q_n, t)dt = 0 \qquad (10)$$

The Lagrangian, L, is given by T - V, T and V being the kinetic and potential energies of the system respectively. In essence, Hamilton's principle states that of all the geometrically admissible motions that vanish at t_1 and t_2, the actual motion (or path) of the system in configuration space $(q_1, q_2, \ldots, q_n)$ renders equation (10) stationary. In analytical mechanics, Hamilton's principle is the basic postulate and, along with Lagrange's equations, has the advantage of invariance under coordinate transformation. For insight and discussion of variational principles, see Meirovitch [11], Goldstein [12], and Crandall, Karnopp, et al [13].

Lagrange's equations of motion can be written in the following form

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_k}\right) - \frac{\partial L}{\partial q_k} = Q_k + \sum_{j=1}^{m} \lambda_j \frac{\partial f_j}{\partial q_k}$$

$$k = 1, 2, \ldots, n \qquad (11)$$

where

q_k, k = 1, 2,..., n are the generalized coordinates
$L(\dot{q}_1, \dot{q}_2, \ldots, \dot{q}_n, q_1, q_2, \ldots, q_n, t)$ is the Lagrangian
$f_j(q_1, \ldots, q_n) = 0$, j=1, 2,...,m are the constraint equations
Q_k, k = 1, 2,..., n are the generalized forces due to the applied forces and the nonconservative forces which cannot be represented as potential functions
λ_j, j=1,..., m are Lagrange multipliers which when summed as in equation (14) represent the forces of constraint

If the nonconservative forces are linear and viscous, the generalized force can be written as

$$Q_k = -\frac{\partial R}{\partial \dot{q}_k} \qquad (12)$$

R is referred to as the Rayleigh dissipation function and is defined by

$$R = \frac{1}{2}\sum_{r=1}^{n}\sum_{s=1}^{n} C_{rs}\,\dot{q}_r\dot{q}_s \qquad (13)$$

When Lagrange's equations of motion are used, a dynamic system is represented as a finite number of degrees of freedom and therefore, are not suitable for modeling distributed systems unless the system is discretized as a lumped parameter model or motion is represented as a finite series.

As an example of Lagrange's equations, consider the two-degree-of-freedom sample problem in Figure 2. The kinetic energy of the system is

$$T = \underbrace{\frac{1}{2}m(\dot{y} + u\dot{\gamma})^2}_{\substack{\text{translation}\\ \text{of c.g.}}} + \underbrace{\frac{1}{2}I_{c.g.}\,\dot{\gamma}^2}_{\substack{\text{rotation}\\ \text{about c.g.}}} \qquad (14)$$

The stored energy in the springs is

$$V = \frac{1}{2}k(y + (b+u)\gamma)^2 + \frac{1}{2}k(y - (b-u)\gamma)^2 \qquad (15)$$

Let

$$Q_y = F_y$$

$$Q_\gamma = F_y u \tag{16}$$

and apply equation (11). By invoking the Theorem of Parallel Axes to show that

$$I_a = I_{c.g.} + mu^2 \tag{17}$$

the equations of motion expressed by equations (8) and (9) are derived.

Energy methods provide a straightforward approach to the dynamic equations of motion, even of complex vibratory systems. After the energy of each component in the system has been formulated in terms of generalized coordinates, Lagrange's equations assemble them into a mathematical expression of the system model. A further advantage of energy methods is that forces of constraints and boundary conditions flow naturally from their use.

CONCLUDING REMARKS

In this article, the "type" of modeling technique has been emphasized over the details of the method. For these, the reader is encouraged to refer to the references, which for convenience have been divided into sections by modeling method. In this regard, **FORCE BALANCE** has been ignored as any good book in the mechanics of vibration can satisfy the readers quest for understanding. Furthermore, the references have purposely been limited to avoid confusion and are to be thought of as a "point of departure" for further investigation.

The remaining methods mentioned early in this article will be discussed in Part II.

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BOOK REVIEWS

DAMAGE TOLERANCE IN AIRCRAFT STRUCTURES

ASTM Special Technical Publication 486, 1971
Philadelphia, Pennsylvania

This publication contains 12 papers that were presented at the Symposium on Damage Tolerance in Aircraft Structures in June, 1970. The specific objectives of the symposium were

- To review the state of aircraft structural analysis for structures with propagating cracks
- To present recent advancements in research into basic mechanisms of crack propagation and residual strength of aircraft structures
- To provide a review of fracture mechanics as applied to the assessment of structural vulnerability and residual strength of materials and structures

The papers presented can be separated into four categories

- Basic concepts in fatigue crack propagation
- Effects of panel geometry
- Influence of panel stiffeners
- Application of fracture mechanics and crack propagation to the design and test of aircraft structures

Three of the papers fall in the first category, three in the second category, two in the third, and the rest in the fourth. The papers are of good quality, and the conclusions are based on both analysis and testing. This book will be of value to aircraft designers and those conducting research in this area. Advances have been made in this field since 1970, some by the authors. This book is thus a record of the state-of-the-art during 1969-1970.

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GYRODYNAMICS

P.Y. Willems, Editor

Springer-Verlag, Berlin-Heidelberg-New York, 1974

This volume contains the papers presented at the *European Mechanics Colloquim on* Gyrodynamics - EUROMECH 38 - at the University of Louvain, Belgium, in September 1973. It is a survey of current activities in the broad field of rotor dynamics.

A variety of problems of rotor dynamics, including theoretical and practical aspects, are dealt with in the 35 papers. The papers are classified into four areas: instruments, about 25%, rotating mechanisms, 15%, application of system theory to rotational dynamics, 20%, and spacecraft attitude dynamics, 40%.

In the area of instrumentation attention is given to the dynamically-tuned gyroscope, the vibrating gyro, and the error-modeling of imperfect gyro-rotor bearings. A tidbit for experts is a survey on effects of friction on the kinetics of gyros. Rotating mechanisms is concerned mostly with rotating shafts. The influence of shear deformation on critical speeds, the nonlinear behavior of slightly curved shafts, and the dynamics of a two-stage centrifuge are of interest. A report on actively controlled magnetic bearings for fly-wheels apparently is indicative of a further step toward industrial application of this kind of bearing.

In the area application of system theory to rotational dynamics the concept of nonlinear estimation is described, and some connections to control theory are shown. It also includes an investigation of the rotation of a satellite about a body-fixed axis with minimal energy consumption and the balancing of a crankshaft using parameter-optimization techniques. Spacecraft attitude dynamics involve dynamics and control of flexible or multibody spacecraft. Some of the algorithms used to set up equations of motion are also well suited for land applications. One paper discusses rotor dynamics problems with reference to ESRO-satellites. Two authors are concerned with the dynamics of fuel-filled satellites.

The papers are usually short but self-contained, and the references are adequate. Readers interested in special subjects may find that most of the papers have been published elsewhere in more comprehensive form. The book is an excellent survey of actual problems in rotor dynamics, however, and should be of value to research workers or lecturers in this field.

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NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

NEW STANDARD METHOD FOR SPECIFYING THE CHARACTERISTICS OF AUXILIARY EQUIPMENT FOR SHOCK AND VIBRATION MEASUREMENTS PUBLISHED BY ASA

A revision of American National Standard S2.4-1960 has been published by the Acoustical Society as ASA STANDARD 8-1976 (S2.4-1976). It was approved by the American National Standards Institute on 4 August 1976.

This American National Standard provides suggestions on subject matter and format for describing auxiliary equipment for mechanical shock and vibration measurements, so there will be a clear understanding by both the user and the manufacturer. It is intended to outline, in standardized form, what data should be presented to enable the person experienced in making such measurements to specify this type of equipment correctly. Also, the standard defines terminology in a further effort to ease the problem of communication between user and manufacturer.

This standard relates directly to International Electrotechnical Commission, Methods for Specifying the Characteristics of Auxiliary Equipment for Shock and Vibration Measurement, IEC Publication 222, 1966, and it is recommended that they be used conjunctively.

This standard--ASA STANDARD 8-1976--is available from the Back Numbers Department, American Institute of Physics, 335 East 45th Street, New York, New York 10017.

COMPOSITE MATERIALS COMPUTATION WORKSHOP

A five day "Composite Materials Computation Workshop" to provide users and producers of composites with a practical guide to solving problems in design and testing will be held March 28 to April 1, 1977, at the University of California at Berkeley.

The workshop co-chairmen and principal instructors will be Stephen W. Tsai, of the Air Force Materials Laboratory at Wright-Patterson AFB; Edward M. Wu, of the University's Lawrence Livermore Laboratory; and H. Thomas Hahn, of the University of Dayton Research Institute.

Lectures, practice sessions and drills will be devoted to demonstrating advanced methods that can be applied to everyday problem solving. Whenever possible, available methods will be condensed to an easily used formula or chart, or to a format that can be implemented readily on a programmable pocket calculator. Participants will be provided with calculators for use during the workshop, and also will be given preprogrammed magnetic cards containing pertinent formulas; the cards may be retained for later use.

For program details write to Continuing Education in Engineering, University of California Extension, 2223 Fulton St., Berkeley, CA 94720, or call (415) 642-4151.

SHORT COURSES

DECEMBER

INTRODUCTION TO VIBRATION AND SHOCK TESTING, MEASUREMENT, ANALYSIS AND CALIBRATION

Dates: December 6 - 10, 1976
Place: San Diego, California
Objective: The course will benefit plant engineers and maintenance personnel responsible for on-line condition analysis of rotating machinery. Electronic techniques for analysis of vibration and sound signatures in terms of specific machinery faults will be discussed. This course will concentrate upon equipments and techniques rather than upon theory.

Contact: Mr. Wayne Tustin, Tustin Institute of Technology, Inc., 22 E. Los Olivos St., Santa Barbara, CA 93105 Tele. (805) 963-1124

MACHINERY VIBRATION ANALYSIS

Dates: December 7 - 9, 1976
Place: Sheraton Inn
New Orleans, LA
Objective: This seminar is devoted to the measurement and analysis of machine vibrations. Topics to be discussed include machine excitation; vibration measurement; transducer placement; vibration monitoring; failure analysis; vibration reduction and control; vibration analysis; and computer data management.

Contact: Mr. Bob Kiefer, Spectral Dynamics Corp. of San Diego, P. O. Box 671, San Diego, CA 92112 Tele. (714) 565-8211

JANUARY

PREVENTIVE MAINTENANCE AND FAULT DIAGNOSIS

Dates: January 31, February 1 & 2, 1977
Place: University of Houston Hotel
Houston, Texas
Objective: This seminar is devoted to the understanding and application of vibration technology to machinery preventive maintenance programs and fault diagnosis problems. Basic and advanced techniques with illustrative case histories and demonstrations will be discussed by industrial experts and consultants. Topics to be covered in the seminar include development of preventive maintenance programs; measurements, analysis, and data reduction; shock pulse techniques for bearing analysis; computer monitoring; and acoustic techniques. An instrumentation show will be held in conjunction with this seminar.

Contact: Dr. R. L. Eshleman, Vibration Institute, Suite 206, 101 W. 55th St., Clarendon Hills, IL 60514 Tele. (312) 654-2254/654-2053

MARCH

CORRELATION AND COHERENCE ANALYSIS FOR ACOUSTICS AND VIBRATION PROBLEMS

Dates: March 7 - 11, 1977
Place: UCLA
Objective: This course covers the latest practical techniques of correlation and coherence analysis--ordinary, multiple and partial--for solving acoustics and vibration problems in physical systems.

Contact: Continuing Education in Engineering and Mathematics, Short Courses, 6266 Boelter Hall, UCLA Extension, Los Angeles, CA 90024 Tele. (213) 825-1047

AERODYNAMIC NOISE

Dates: March 14 - 18, 1977

Place: University of Tennessee
Tullahoma, Tennessee

Objective: This course is designed to introduce the fundamentals of acoustics and aerodynamic noise to engineers and scientists with a background in fluid dynamics. Topics to be covered are: elements of sound sources and sound propagation, acoustics of a moving medium, generation of sound by aerodynamic forces, jet noise theory, interaction with solid surfaces, experimental techniques and facilities, and noise suppression techniques.

Contact: Mr. Jules Bernard, Manager of Short Course Program, The University of Tennessee Space Institute, Tullahoma, TN 37388 Tele. (615) 455-0631

DIGITAL TIME SERIES METHODS

Dates: March 21 - 25, 1977

Place: UCLA

Objective: This course is for users of digital time series who require modern methods of data analysis using the fast Fourier transform, digital filtering, power spectral densities and correlational functions.

Contact: Continuing Education in Engineering and Mathematics, Short Courses, 6266 Boelter Hall, UCLA Extension, Los Angeles, CA 90024 Tele. (213) 825-1047

REVIEWS OF MEETINGS

CONFERENCE ON

VIBRATIONS IN ROTATING MACHINERY
15-17 September 1976
Churchill College
University of Cambridge, UK

Many vibration conferences in recent years have contained little new material. For the most part papers pertaining to applications of technology and case histories on solved problems are rare; rather, most presentations are merely reworkings of previously published material. It was therefore refreshing to attend the Institution of Mechanical Engineers' conference on Vibrations in Rotating Machinery; new technology was introduced, not only in rotor dynamics and shaft and blade vibration, but also in preventive maintenance and fault diagnosis.

The conference was sponsored by the Applied Mechanics, Steam Plant, and Tribology groups of the Institution of Mechanical Engineers. Co-sponsors included the Japan Society of Mechanical Engineers and the Verein Deutscher Ingenieure. Conspicuously absent as a co-sponsor was the American Society of Mechanical Engineers, several members of which participated in the conference.

Introductory remarks were made by the chairman of the conference planning panel, Mr. Paul. G. Morton of GEC Power Engineering Limited. In the opening address Professor R.E.D. Bishop acknowledged early work in rotor dynamics, including that by H.H. Jeffcott, D.C. Johnson, D.M. Smith, and K.G.Federn. Smith and Federn attended the conference. Bishop noted that, until 20 years ago, research in rotor dynamics was sporadic. Since the mid 1950s, however, a vast literature has accumulated, to the extent that the literature has become "flabby". Professor Bishop expressed his strongly held opinion that a unified rotor dynamics theory should be developed to take the place of the seemingly endless publication of special cases having simple and predictable results. My own scanning of the literature over the past five years forces me to agree. It is not my intention to downgrade the good case histories and solutions of practical engineering problems that have been published; it is the publication of solutions to contrived problems and the reworking of results already published that should stop. In fact, during the past 20 years, the technology of rotor dynamics has not advanced as far as the more than 500 publications would indicate.

A highpoint of the conference was a series of papers on the analysis and balancing of nonconservative rotor-bearing systems. It has been noted earlier in the literature that rotor systems having real fluid film-bearing representations, applied axial torque, and cross-coupled damping are nonconservative. To my knowledge, however, this is the first time that the nonconservative nature of such systems has been explicitly stated. The reason is, perhaps, that engineers have been forced to seek mathematical solutions and thus have had to meet head on the issue of nonconservative systems.

An interesting series of papers concerned the application of probabilistic methods to balancing problems. Such methods show promise of widespread use -- especially for balancing mass-produced equipments.

Another interesting session, having to do with blade vibration and vibration of cracked rotating shafts grew out of concern for new problems being introduced by industry.

Worthy of special mention were the practical papers on preventive maintenance and fault diagnosis given by members of the British engineering community. The work reported in four papers represented many years experience in machine vibration problems in British industry. New techniques, measures, and acceptance levels were also introduced.

Mr. Morton, his planning panel, and the Institution of Mechanical Engineers are to be congratulated for organizing and smoothly executing a valuable conference. More than 250 engineers from 13 countries attended. Proceedings containing the papers and conference discussions are available from the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London SW1 H9JJ UK.

R.L.E.

SPECTRUM

I have just completed reading the lead article of the July 1976 issue of the Shock and Vibration Digest entitled "Vibration Isolating Mountings for Sensitive Equipment - New Design Criteria," by J. A. Macinante. He states, in part, "It is remarkable that so many investigators of such a variety of systems continue to represent the equipment as a single lumped mass, thereby eliminating from the dynamic model the significant feature of the equipment - its nonrigidity."

I can only assume that the author is not very familiar with American literature on the subject. The one paper that immediately comes to mind is the now classic paper by R.D. Mindlin entitled, "Dynamics of Package Cushioning," published, I believe, in 1945 in the Bell System Technical Journal. Mindlin considered the identical problem as Macinante, namely the response of a component inside of a piece of equipment mounted on isolators. The paper contains numerous response curves for the component for various values of the component damping and resonant frequency as a function of isolator damping and resonant frequency. The only difference is that Mindlin used a half-sinusoid forcing function rather than a damped sinusoid or sinusoidal forcing function.

On several occasions over the years I have found Mindlin's paper a handy design guide when I had to consider the response of a critical component inside of an isolated piece of equipment and the forcing function could be approximated as a half-sinusoid. For other forcing functions, Mindlin's paper was helpful in providing assistance in formulating the analytical approach. Other engineers that I have worked with during the last 20 years also have used Mindlin's paper when the need arose to worry about the response of a critical component.

Of course, for many problems, that need may not exist. I could level a similar criticism of Macinante's paper, namely, if he measured the motion of the foundation prior to the installation of the equipment, the foundation motion will change after the equipment has been installed, if the foundation is not rigid as he assumed, thereby invalidating his results. That particular problem has also been extensively covered in the literature for those cases where the consideration of a nonrigid foundation has a significant effect on the solution of the isolation problem under consideration.

In summary then, Macinante's "Design Criteria" are certainly not "new", and should probably be credited to Mindlin. Incidentally, in looking over Harris and Crede's Shock and Vibration Handbook, I came across a subsection of Chapter 31 entitled "Response of Equipment with a Flexible Component." Macinante's point is of course well taken and brings us to the subject of my recent editorial. One must always consider the system engineering approach. The solution of a partial problem is often not sufficient to determine the overall system performance. If a critical component cannot be assumed as rigid, its dynamic characteristics must be taken into consideration. If, in addition, the foundation is nonrigid, possibly a three-degree-of-freedom model should be used, taking into account the change of the motion of the unloaded foundation due to the installation of the isolated equipment.

At the same time, I do not want to detract from the usefulness of the many design curves presented in the paper, which 30 years ago would have been a major task to generate. They will save the design engineer, faced with a problem that fits the model under discussion, many hours of computational time.

Taking a philosophical turn, in reading over the comments I made above, it makes me wonder how often I and many others keep "re-inventing the wheel," i.e., attacking problems that have been solved before. I would gladly use previous results if I only knew that they existed, and if so, where to find them. Computer search facilities such as offered by SVIC, DDC, USC's "WESRAC," and others, are helpful, but they leave a lot to be desired, particularly in the indexing of older technical papers. I have used such facilities in the past and often missed one or two critical papers because I did not use the proper key words, or the key words assigned to the paper were not sufficiently complete or were not contained in the title or the abstract. I often have to rely on my own memory and those of old acquaintances. A few phone calls sometimes bring surprising results in finding old solutions to apparently new problems. It makes one marvel about the human brain, if one realized that its memory capacity is still greater than the combined memory capacity of all computers in the entire world (excuse me, at least on earth). Unfortunately the same cannot be said about the brain's memory accuracy.

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Newbury Park, CA 91320

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, Va., 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM). 313 N. Fir St., Ann Arbor, MI. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

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ANALYSIS AND DESIGN

ANALYTICAL METHODS

(Also see Nos. 1757, 1849)

76-1722

Dynamics and Stability of Sequential Systems

P.A. Erickson

Ph.D. Thesis, Univ. of Texas at Austin, 1975, 79 pp

UM 76-14, 444

Key Words: Automated transportation systems, Lyapunov approach

Car following models have been proposed as a possible control for vehicles on automated highways. In these models the control force on a following vehicle is a function of the relative motion with respect to the preceding vehicle and the absolute motion of the vehicle itself. In previous studies of car following models, the response of a sequence of linear differential equations has been analyzed using a transfer function method. In this dissertation an alternate approach utilizing Lyapunov theory is introduced and developed for a general class of linear sequential systems. The method is extended to certain types of nonlinear systems.

76-1723

Formulation of the Global Equations of Motion of a Deformable Body

T.B. McDonough

Aeronautical Research Associates of Princton, Inc., Princeton, NJ, AIAA J. 14 (5), pp 656-660 (May 1976) 11 figs, 10 refs

Sponsored by AFOSR Contract No. F44620-74-C-0045

Key Words: Equations of motion

The global equations of motion for a deforming body are cast in a new form that is attractive for many studies. The deforming body is assumed a continuum, but its constitutive behavior is left totally general. Equations treated represent the conservation of linear and angular momenta and kinetic energy. The motion (including deformation) of the body is of unrestricted magnitude. A translating and rotating reference frame is defined in terms of the linear and angular momenta of the body, and the global equations of motion are transformed in terms of parameters that are defined relative to this reference frame.

NUMERICAL ANALYSIS

(Also see No. 1753)

76-1724

Studies on the Spring-Pendulum

J. Koiller

Ph. D. Thesis, Univ. of California, Berkeley, 1975, 185 pp

UM 76-15, 263

Key Words: Mass-spring systems, Two-degree of freedom systems, Natural frequencies

In this work mechanical systems possessing two degrees of freedom are studied. A numerical method to study pendulum motions away from the equilibrium is reported.

PERTURBATION METHODS

(See No. 1784)

STATISTICAL METHODS

(Also see No. 1729)

76-1725

Stochastic Linearization of Multi-Degree-of-Freedom Non-Linear Systems

T.S. Atalik and S. Utku

Bechtel Power Corp., Los Angeles, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 411-420 (Apr - June 1976) 16 refs

Key Words: Equivalent linearization technique, Nonlinear systems, Multidegree of freedom systems, Stochastic processes, Random excitation

The response of non-linear multi-degree-of-freedom dynamic systems to stationary gaussian excitation is developed using an equivalent linearization technique. The non-linearities are assumed to be single-valued functions of accelerations, velocities and displacements. Using a property of gaussian vector processes, the closed forms of the coefficients of the equivalent linear system are obtained by the direct application of partial differentiation and expectation operators to the non-linear terms.

VARIATIONAL METHODS

76-1726

Variational Methods of Analysis

C.L. Dym

Dynamics & Structural Group, Bolt Beranek and Newman, Inc., 50 Moulton St., Cambridge, MA., Shock and Vibration Digest, 8 (7), pp 27-29 (July 1976) 68 refs

Key Words: Variational methods, Reviews

This paper briefly reviews some of the recent literature on variational methods that were abstracted in the Shock and Vibration Digest during 1975. The review is aimed at delineating the current use of variational principles, as well as the development of such principles. The paper begins with a summary and listing of available books on variational methods.

FINITE ELEMENT MODELING

(Also see Nos. 1804, 1813, 1814)

76-1727

A Note on Mass Lumping and Related Processes in the Finite Element Method

E. Hinton, T. Rock and O.C. Zienkiewicz

Dept. of Civil Engrg., The Univ. of Wales, Swansea, Wales, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 245-249 (Jan - Mar 1976) 3 figs, 13 refs

Key Words: Lumped parameter method, Finite element technique, Dynamic structural analysis

The general problem of lumping mass and related processes in the finite element method are discussed. A scheme to lump mass is presented for parabolic isoparametric elements. Examples are presented to show the good accuracy which can be obtained in linear and non-linear dynamic problems using the scheme.

76-1728

Postprocessing of Finite Element Transient Response Calculations by Digital Filters

N. Holmes and T. Belytschko

Univ. of Illinois at Chicago Circle, Box 4348, Chicago, IL., 60680, Computers and Struc., 6 (3), pp 211-216 (June 1976) 10 figs, 9 refs

Sponsored by the Dept. of Transportation

Key Words: Transient response, Finite element tec...

A method of postprocessing output from linear transient response calculations by a nonrecursive digital filter is presented. The method is applied to postprocess a series of calculations performed with an explicit temporal integration and a lumped mass matrix; both one dimensional and two dimensional meshes are considered. It is shown that the digital filter is quite effective in eliminating spurious frequencies.

MODELING

76-1729

Response of Coupled Dynamic Systems

G. Maidanik

David W. Taylor Naval Ship Research and Development Ctr., Bethesda, MD., 20084, J. Sound Vib., 46 (4), pp 561-583 (June 22, 1976) 1 fig, 17 refs

Key Words: Mathematical modeling, Coupled response, Coupled systems, Statistical energy analysis

A complex dynamic system can often be modeled in terms of coupled basic dynamic systems. A basic dynamic system is a system whose response can be specified in terms of a scalar quantity. A general formalism, dealing with the response of a complex dynamic system, is developed. The formalism spans several previous formalisms and encompasses new material that has not been previously considered, e.g., direct couplings between the ribs on a panel. The format is chosen so that it provides for consideration of elements of the statistical energy analysis (SEA). Thus, for example, the expression for the frequency spectral power flow between two basic dynamic systems is derived and cast in a modal form. In particular, various conditions and approximations under which cross modal terms vanish in the expression are specified and interpreted. Modal densities are defined and used to obtain further reductions in the expression for the power flow between two multimodal basic dynamic systems.

76-1730

Variations in the Boundary Conditions of Coupled Dynamic Systems

G. Maidanik

David W. Taylor Naval Ship Research and Development Ctr., Bethesda, MD., 20084, J. Sound Vib., 46 (4), pp 585-589 (June 22, 1976) 2 refs

Key Words: Mathematical modeling, Coupled response, Coupled systems

The paper is a sequel to 76-1729. In that paper, isolation of the basic dynamic systems was achieved by imposing uncoupled boundary conditions in which the coupling impedances were removed. It is illustrated that alternate isolations, involving different boundary conditions, can be imposed. In particular, the modification introduced in the formalism when blocked boundary conditions are substituted for the uncoupled boundary conditions is discussed in some detail.

DIGITAL SIMULATION

(See No. 1832)

PARAMETER IDENTIFICATION

76-1731

Identification of Viscous Damping in Structures from Modal Information

J. Beliveau

Dept. of Civil Engrg., Universite de Sherbrooke, Sherbrooke, Quebec, Canada, J. Appl. Mech., Trans. ASME, 43, Ser. E (2), pp 335-339 (June 1976) 2 figs, 9 refs

Key Words: Parameter identification, Viscous damping, Multistory buildings

The identification of damping, stiffness, and mass parameters from modal information is formulated within a general Bayesian framework. A modified Newton-Raphson scheme is used to modify parameter estimates, given natural frequencies, associated damping constants, mode shapes, and phase angles. Actual data from a nine-story steel structure are used in an application of the method.

DESIGN INFORMATION

(See No. 1741)

CRITERIA, STANDARDS, AND SPECIFICATIONS

76-1732

Procedures for Developing Vibratory Ground Motion Criteria at Nuclear Plant Sites

S.D. Werner

Nucl. Engr. Des., 36 (3), pp 411-441 (Mar 1976) 24 figs, 54 refs

Sponsored by the U.S. Nuclear Regulatory Commission

Key Words: Nuclear power plants, Ground vibration

This paper describes how vibratory ground motion criteria at nuclear plant sites can be developed to meet requirements set forth by the United States Nuclear Regulatory Commission (USNRC). The description and assessment of the current technology for carrying this out includes site-independent procedures and site-dependent techniques. Site-independent procedures (such as these used in the development of the Regulatory Guide 1.60 spectrum shapes) are not dependent on the particular characteristics of the site under investigation; in contrast, site-dependent techniques (such as the use of site-matched records or site-response analyses) are influenced by the geologic and local soil conditions at the site. This assessment of current technology is used as a basis for a recommended procedure for developing vibratory motion criteria. An example application of the procedure illustrates how it can be applied to an actual site.

SURVEYS

76-1733

Results of Inquiries Passenger Car Vibration Data

M. Mitschke and H. Helms

Braunschweig, Germany, Automobiltech. Z., 78 (5), pp 227-228 (May 1976) 6 figs, 2 refs

(In German)

Key Words: Automobiles, Surveys, Vibration response

In the article the results of a survey of major German vehicle manufacturers on vibration data of passenger cars are presented. The results show that body natural frequencies range between 0.9 and 1.7 Hz, the damping rate is 0.15 to 0.45 and the natural frequencies of the axles are 10 to 11 Hz. From these results it was concluded that it is safer and more comfortable to drive at top speeds on good roads, than at 100km/hr. on average roughness country roads. The survey was conducted by the Motor Vehcile Institute of the Technical University, Braunschweig.

TUTORIAL

76-1734

Putting a Value on Noise. The Development of an Index Which is Fair to Both Airport Operators and the Public

E.J. Richards

Inst. of Sound and Vibration Research, Univ. of Southampton, Southampton, England, Aeronaut. J., 80 (785), pp 193-204 (May 1976) 13 figs, 18 refs

Sponsored by Directorate of Operations Res. & Analysis of Civil Aviation Authority

Key Words: Aircraft noise

The paper discusses the issues involved in setting up a system of planning and a method of measuring the environmental effects of existing airports on the local communities. Some suggestions are presented.

COMPUTER PROGRAMS

GENERAL

(Also see Nos. 1752, 1855, 1866)

76-1735

Extensions and Refinements of the Crash Computer Program. Part II. User's Manual for the Crash Computer

R.R. McHenry

Calspan Corp., Buffalo, NY., Rept. No. CALSPAN-ZQ-5708-V-3, DOT-HS-801 838, 68 pp (Feb 1976) (see also part 1, PB-252 114 and part 2, PB-252 116) PB-252 115/1GA

Key Words: Collision research (automotive), Computer programs

The report contains detailed instructions for users of the CRASH computer program. It also outlines the analytical basis of calculations within the program.

76-1736

Extensions and Refinements of the Crash Computer Program. Part III. Evaluation of the Accuracy of Reconstruction Techniques for Highway Accidents

R.R. McHenry and I.S. Jones

Calspan Corp., Buffalo, NY., Rept. No. CALSPAN-ZQ-5708-V-1, DOT-HS-801-839, 45 pp (Feb 1976) (see also part 2, PB-252 115) PB-252 116/9GA

Key Words: Collision research (automotive), Computer programs

An analytical study was performed with the objectives of development of an 'obstacle course' of well documented, staged collisions representative of frequently occurring accident configurations and determination of the reconstruction accuracies of the automatic iteration version of the SMAC and of the simplified CRASH computer programs. It had been initially estimated that twenty staged collisions could be selected for this purpose. It is concluded that an urgent need exists for realistic staged collision experiments to permit quantitative determinations of the accuracies of reconstruction techniques. The limited results achieved within the present study are considered to be indicative of very attractive levels of attainable accuracies.

76-1737

Truck Design Optimization Project Field Test Data. Series 1, 2, 3 and 4.

A.J. Bang

Federal Railroad Admn., Office of Res. and Dev., Washington, D.C. (Mar - Sept 1975) Series 1: PB-250 183. Series 2: PB-250 194 through PB-250 227. Series 3: PB-250 230 through PB-250 266. Series 4: PB-250 267 through PB-250 310

Key Words: Freight cars, Dynamic tests, Bearings, Shock absorbers, Suspension systems (vehicles), Magnetic tapes

The data files on this magnetic tape include acceleration, force, and displacement measurements at critical points on a freight car and truck. Each file includes detailed alphanumeric descriptions of test conditions. Source tape is in *ADCII* and *BINARY* character set. Character set restricts preparation to 9 track one-half inch tape only. Identify recording mode by specifying density only.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 1722, 1760, 1775, 1777, 1833, 1844, 1855, 1856, 1858)

76-1738

Multidimensional Analyses of Judgments About Traffic Noise

G.W. Cermak and P.C. Cornillon

Research Labs., General Motors Corp., Warren, MI., 48090, J. Acoust. Soc. Amer., 59 (6), pp 1412-1420 (June 1976) 5 figs, 19 refs

Key Words: Traffic noise, Human response

In a report on a laboratory experiment where human subjects were presented pairs of recorded 1-min traffic sounds, subjects chose whichever sound of each pair they thought they would rather be exposed to on a regular basis; they also judged the relative dissimilarity of the sounds in each pair. The data were analyzed using multidimensional scaling techniques.

76-1739

Theorem on the Scattering and the Absorption Cross Section for Scattering of Plane, Time-Harmonic, Elastic Waves

T.H. Tan
Dept. of Electrical Engineering, Div. of Electromagnetic Research, Delft Univ. of Technology, Delft, The Netherlands, J. Acoust. Soc. Amer., 59 (6), pp 1265-1267 (June 1976) 1 fig, 9 refs

Key Words: Elastic waves, Wave diffraction, Wave absorption

In a homogeneous, isotropic, perfectly elastic medium a scattering obstacle of finite extent is present. When a plane, time-harmonic, elastic compressional (P) or shear (S) wave is incident on it, the extinction cross-section (i.e., the sum of the scattering and the absorption cross-section) of the obstacle is directly related to the far-zone amplitude of the particle displacement of the scattered wave, observed exactly behind the obstacle. This relationship is discussed.

RANDOM

(See No. 1725)

SEISMIC

(Also see Nos. 1761, 1762, 1763, 1767, 1770, 1796, 1828, 1830, 1832, 1834, 1835, 1836, 1837, 1838, 1839 1841, 1843, 1860, 1861, 1862, 1863)

76-1740

Ductility of Reinforced Concrete Sections with Confined Compression Zones

P. Desayi, K.T.S.R. Iyengar and K.N. Reddy
Civil Engrg. Dept., Indian Institute of Science, Bangalore, India, Intl. J. Earthquake Engr. Struc. Dynam., 4 (2), pp 111-118 (Oct - Dec 1975) 10 figs, 6 refs

Key Words: Beams, Seismic design, Earthquake resistant structures, Reinforced concrete, Energy absorption

Concrete confinement in circular spiral steel binders increases strength and ductility. This property can be utilized in designing concrete structures to withstand seismic forces where the members are required to possess not only strength but also energy absorbing capacity. Assuming the stress-strain behavior of confined concrete as elastic-plastic, the ductility factor for strain and the strength factor (denoting increase in strength) have been determined for concrete confined to different degrees. Similarly, assuming the moment-curvature behavior of reinforced concrete sections with confined compression concrete to be elastic-plastic, the ductility factor for curvature has been determined for such beams. The computed moment-curvature plots have been found to compare satisfactorily with tests on 18 beams. Ductility factors for curvature of singly and doubly reinforced concrete sections with compression concrete confined to different degrees have been determined and presented for certain typical cases. Such plots would be of use in designing reinforced concrete beam sections for required ductility.

76-1741

Earthquake Simulator Study of a Steel Frame Structure

D.T. Tang
Ph.D. Thesis, Univ. of California, Berkeley, 1975, 203 pp
UM 76-15, 386

Key Words: Earthquake resistant structures, Frames, Test models, Mathematical models

This study presents the development of mathematical models and the verification of response predictions for a three-story single-bay moment-resistant frame structure, using the experimental results observed for the structure tested on a 20 ft x 20 ft shaking table.

76-1742

Earthquake Response of a Steel Frame Building

J.H. Wood
Central Laboratories, Ministry of Works and Development, Lower Hutt, New Zealand, Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 349-377 (Apr - June 1976) 21 figs, 7 refs
Sponsored by the National Science Foundation

Key Words: Earthquake damage, Buildings, Seismic response

A study has been made of the response of the nine-story steel frame Building 180, located at the California Institute of Technology, Jet Propulsion Laboratory, Pasadena, during the San Fernando earthquake 9 February 1971. The analysis shows actual dynamical properties of the building during the

earthquake, and also demonstrates that it is possible, when the ground motion is specified, to make accurate predictions of building motions during moderate earthquakes by using a linear viscously damped model. Methods of evaluating the lower mode periods and damping ratios from the earthquake records are described and the values obtained are compared with results from dynamic testing before and after the earthquake and with the periods computed from computer models of the building.

76-1743
Horizontal Ground Motion in Los Angeles During the San Fernando Earthquake

C.B. Crouse
Fugro Consulting Engineers and Geologists, Long Beach, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 333-347 (Apr - June 1976) 10 figs, 11 refs
Sponsored by the National Science Foundation

Key Words: Earthquake damage, Ground motion, Seismic response spectra, Interaction: soil-structure

Accelerograms, Fourier amplitude spectra and response spectra from ground motion recorded in the San Fernando earthquake at selected sites in Los Angeles were examined and compared. Although differences exist in the data from the bases of a group of six tall buildings close together near the intersection of Wilshire Boulevard and Normandie Avenue, the differences are not significant from the standpoint of design. A single design spectrum is most appropriate for this area, even though there exists a variety of foundation conditions, building properties and basement configurations for the six sites.

76-1744
Earthquake Response Analysis Considering Non-Proportional Damping

R.W. Clough and S. Mojtahedi
Univ. of California, Berkeley, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 489-496 (July - Sept 1976) 2 figs, 10 refs

Key Words: Earthquake response, Non-proportional damping, Viscous damping, Interaction: soil-structure

Non-proportional damping may be defined as a form of linear viscous damping which introduces coupling between the undamped modal co-ordinate equations of motion. The standard mode superposition method of earthquake response analysis therefore cannot be employed with non-proportionally damped structures. In this paper, several methods for analyzing the dynamic response of non-proportional damped structures are outlined. It is concluded that the most efficient procedure is to express the response in terms of a truncated set of undamped modal co-ordinates and to integrate directly the resulting coupled equations. The effectiveness of the method is demonstrated by a numerical example.

76-1745
Observations and Estimation of Long-Period Strong Ground Motion in the Los Angeles Basin

T.C. Hanks
Office of Earthquake Studies, U.S. Geological Survey, Menlo Park, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 473-488 (July - Sept 1976) 6 figs, 26 refs

Key Words: Earthquakes, Ground motion, Amplitude data, Seismic data

While the accurate estimation of ground-motion amplitudes across the entire frequency band of engineering interest is not possible at the present time, the excitation and propagation of long-period strong ground motion can be understood with existing seismological methodology. In the Los Angeles Basin, the long-period strong ground motion excited by the San Fernando earthquake is dominated by the presence of surface waves, whose gross amplitude and frequency content are easily attributable to physical properties of the earthquake source and source-station propagation paths. Observed measures of the long-period strong ground motion of the Kern County earthquake relative to the San Fernando earthquake at two sites in the Los Angeles Basin which recorded both shocks can be predicted with considerable accuracy by a simple earthquake source model. This source model is extrapolated to represent the maximum credible earthquake likely to affect the Los Angeles area, taken to be a repeat of the Fort Tejon (1857) earthquake along the San Andreas fault.

76-1746
Correlations of Peak Acceleration, Velocity and Displacement with Earthquake Magnitude, Distance and Site Conditions

M.D. Trifunac and A.G. Brady
Earthquake Engrg. Research Lab., California Inst. of Technology, Pasadena, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 455-471 (July - Sept 1976) 8 figs, 29 refs

Key Words: Earthquakes, Amplitude data

A brief review of proposed correlations between peak accelerations and earthquake magnitude and distance has been presented. It has been found that most investigators agree favourably on what should be the amplitude of peak accelerations for the distance range between about 20 and 200 km. For distances less than 20 km, there is significant disagreement in the predicted peak amplitudes, reflecting the lack of data there and the uncertainties associated with the extrapolation.

76-1747

Ground-Motion Modelling at Regional Distances for Earthquakes in a Continental Interior. 1. Theory and Observations

R.B. Herrmann and O.W. Nuttli
Univ. of Colorado, Boulder, CO., Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 49-58 (July - Sept 1976) 8 figs, 17 refs
Sponsored by the National Science Foundation

Key Words: Ground motion, Seismic excitation, Mathematical models

To understand the ground-motion contribution by multiple-mode surface-wave arrivals, the surface-wave theory required for predicting ground-motion time histories is discussed. The adequacy of the theory in accounting for observed earthquake ground motion is tested by comparing theoretically predicted long-period seismograms with real seismograms for two earthquakes in the central United States. The agreement between the predicted and observed maximum vertical component L_g ground velocities and acclerations in the 2- to 3-sec period range is excellent over a distance range of 100 to 2,000 km.

76-1748

Ground-Motion Modelling at Regional Distances for Earthquakes in a Continental Interior. II. Effect of Focal Depth, Azimuth and Attenuation

R.B. Herrmann and O.W. Nuttli
Univ. of Colorado, Boulder, CO., Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 59-72 (July - Sept 1975) 12 figs, 8 refs
Sponsored by the National Science Foundation

Key Words: Ground motion, Seismic excitation, Mathematical models

Multiple-mode surface-wave signals are used to model ground motion at distances of 50 to 500 km for an earthquake source in a continental interior. Motion on a thrust fault is used as the earthquake model. Theoretical ground-motion time histories are generated for this source for various focal depths, receiver azimuths and medium-attenuation models. A shallow source will generate greater values for the ground motion than the same source at a greater depth. Two anelastic attenuation models are considered, one appropriate to the central and eastern United States and the other to southern California. The effects of the difference in the attenuation models are seen at distances greater than 100 km for periods greater than 1.5 sec.

76-1749

A Line-Source Model for Seismic Risk Analysis

A. Der Kiureghian
Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 1976, 145 pp
UM 76-16, 118

Key Words: Seismic design

A line-source model for the analysis of seismic risk at a site is developed. The model assumes that earthquakes originate as slips along geologic faults and considers the proximity of a structure to the nearest slipped zone as the significant distance in determining the level of seismic hazard. The application of the model for a site requires the statistical, geological and seismological data of the region; however special provisions are provided for considering regions with limited geological information.

76-1750

The Haicheng, China, Earthquake of 4 February 1975; The First Successfully Predicted Major Earthquake

R.D. Adams
Geophysics Div., Dept. of Scientific and Industrial Res., Seismological Observatory, Wellington, New Zealand, Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 423-437 (July - Sept 1976) 11 figs

Key Words: Earthquake prediction

The earthquake of magnitude 7.3 that occurred near the town of Haicheng in north-east China on 4 February 1975 was the first major earthquake anywhere in the world known to have been predicted with enough certainty for people to have been warned, and measures taken for civil protection. These steps were successful in keeping the number of casualties small. This paper describes a visit to the affected area seven and a half months after the earthquake, and discussions with Chinese scientists about their successful prediction methods. The prediction resulted from the synthesis of many types of investigation, but the main methods used for long-, mid- and short-term prediction appear to have been based on studies of seismicity, deformation and foreshocks respectively.

76-1751

A Deterministic Approach to the Prediction of Free Field Ground Motion and Response Spectra from Stick-Slip Earthquakes

J.T. Cherry, E.J. Halda and K.G. Hamilton
Systems, Science and Software, La Jolla, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 315-332 (Apr - June 1976) 18 figs, 26 refs
Sponsored by ARPA & Air Force Office of Scientific Research

Key Words: Earthquake prediction, Ground motion, Seismic response spectra

Theoretical and experimental results from computational physics and non-linear rock mechanics have been merged in order to obtain a deterministic model of a stick-slip earthquake. The model has been exercised to uncover the dependence of peak ground motion and response spectra on fault length, rupture velocity and dynamic stress drop during rupture. A particular method for generating a design spectrum has been tested against results from the model. Utilization of this deterministic technique seems especially appropriate when design information is required at sites located near the epicentre.

SHOCK

(Also see No. 1805)

76-1752

Development of a Computer Program for the Dynamic Nonlinear Response of Reinforced Concrete Slabs Under Blast Loading

J.M. Ferritto
Civil Engineering Lab., (Navy), Port Hueneme, CA., Rept. No. CEL-TN-1434, 51 pp (Apr 1976)
AD-A024 050/7GA

Key Words: Reinforced concrete, Blast response, Explosion effects, Computer programs

A computer program was developed to determine the nonlinear dynamic response of reinforced concrete slabs subjected to blast pressure loading. Given the explosive parameters and geometry of the slab, the program computes the blast environment and the structural resistance, mass, and stiffness of the slab and solves for the dynamic response. The program will assist engineers in the design and analysis of facilities intended to contain the effects of accidental explosions. The report gives a user's guide and sample problems with data input and program output.

76-1753

Iteration Process for the Determination of the Head Injury Criterion, HIC

R. Wagner
Ingolstadt, Germany, Automobiltech. Z., 78 (5), pp 231-233 (May 1976) 5 figs, 3 refs
(In German)

Key Words: Collision research (automotive), Heads (anatomy), Iteration

A simple method for calculating the Head Injury Criterion is presented. It requires a single integration of the deceleration of head center of gravity (e.g., on an analog computer). The rest can be performed graphically.

TRANSPORTATION

76-1754

Proceedings of the Interagency Symposium on University Research in Transportation Noise (3rd) Held at University of Utah, Salt Lake City, Utah on Nov. 12-14, 1975

Utah Univ., Salt Lake City, UT., Rept. No. DOT/TST-76-58, 648 pp (Nov 14, 1975)
PB-252 075/7GA
Sponsored in part by DoD, EPA, and NSF, Washington, D.C.

Key Words: Transportation noise, Combustion noise, Aerodynamic noise, Ducts

The Symposium dealt with research in basic and applied noise problems related to transportation. Papers presented cover surface transportation noise generation, noise propagation and transmission, community reaction, combustion noise, aerodynamic noise, turbulence, rotor noise, jet noise, duct acoustics.

PHENOMENOLOGY

COMPOSITE

76-1755

Elastic and Dissipative Properties of Fiber-Reinforced Composite Materials in Flexural Vibration

R.F. Gibson
Ph.D. Thesis, Univ. of Minnesota, 1975, 203 pp
UM 76-14, 892

Key Words: Composite materials, Fiber composites, Flexural vibration, Internal damping, Mathematical models

The shock and vibration response of any structure is governed by the elastic stiffness and the internal damping of its constituent materials. This report presents the results of an analytical and experimental effort to find the internal damping and the elastic stiffness of typical fiber-reinforced composite structural materials under flexural vibration. The variables considered during the study were material configuration, vibration frequency, and vibration amplitude. The effects of material configuration and vibration frequency were studied analytically and experimentally for small amplitudes. The effects of large amplitudes and resulting structural damage in the materials were found experimentally.

DAMPING

(See Nos. 1731, 1744, 1768)

ELASTIC

76-1756

Huygens' Principle, Radiation Conditions, and Integral Formulas for the Scattering of Elastic Waves

Y. Pao and V. Varatharajulu
Dept. of Theoretical and Appl. Mechanics, Cornell Univ., Ithaca, NY., 14853, J. Acoust. Soc. Amer., 59 (6), pp 1361-1371 (June 1976) 2 figs, 23 refs
Sponsored by the National Science Foundation

Key Words: Elastic waves, Wave propagation

Helmholtz- and Kirchhoff-type integral formulas are presented for elastic waves in isotropic and anisotropic solids. The displacement vector field at points interior and exterior to a region bounded by a closed surface is expressed in terms of a volume integral of the body sources and a surface integral of the sources on the closed surface, namely the traction and the displacement. The kernels of these integrals are the well-known Green's displacement dyadic and a third rank Green's stress tensor. The latter is related to the former by generalized Hooke's law. From these formulas radiation conditions for both steady-state and transient elastic waves are established in terms of the traction, displacement, and particle velocity. In the Kirchhoff-type formula, the retardation in time for the surface and volume sources is made with respect to the travel times for dilatational and shear waves, respectively. This clearly illustrates Huygens' principle for the two wave fronts of the elastic wave field.

76-1757

High Frequency Cylindrical and Spherical Elastic Waves in a Heterogeneous Half-Space

S.H. Zemell
Foundation of Canada Engrg. Corp., Ltd. (FENCO), Toronto, Ontario, Canada, SIAM J. Appl. Math., 31 (1), pp 1-15 (July 1976) 18 refs
Sponsored by the National Res. Council of Canada

Key Words: Elastic waves, Wave propagation, Half-space, Inhomogeneous sphere

A high-frequency asymptotic representation of the displacement field in an inhomogeneous elastic half-space is secured for periodic normal line or point loading. It is assumed that the constitutive moduli of the medium depend solely, and analytically, on distance from the solid's plane boundary. This technique involves a transformation of the linearized elastodynamic equations in order to recast these as a first order system of ordinary differential equations, the utilization of an asymptotic theory of Birkhoff and inversion by means of the method of stationary phase and the geometrical theory of diffraction. If the solid is homogeneous, the leading term of our asymptotic expansion in inverse powers of frequency is identically equal to the known displacement vector. In a half-space whose wavespeeds decrease monotonically, the formation of shadow zones and the functional dependence of the field on the material parameters are discussed.

FATIGUE

(See No. 1832)

FLUID

(Also see Nos. 1806, 1864)

76-1758

The Locking-on of Vortex Shedding Due to the Cross-Stream Vibration of Circular Cylinders in Uniform and Shear Flows

P.K. Stansby
Atkins Research and Development, Ashley Rd., Epsom, Surrey, England, J. Fluid Mech., 74 (4), pp 641-665 (Apr 22, 1976) 19 figs, 11 refs

Key Words: Vortex shedding, Circular cylinders

The frequencies of vortex shedding from circular cylinders forced to oscillate transversely in low-turbulence uniform and shear flows were investigated. The stream velocity in the shear flow varied linearly with spanwise distance.

76-1759

Surface Waves Normally Incident on a Submerged Horizontal Cylinder

A.M.J. Davis and M.J. Hood
Dept. of Mathematics, Univ. College London, London WC1E 6BT, United Kingdom, SIAM J. Appl. Math., 31 (1), pp 16-30 (July 1976) 6 refs

Key Words: Underwater structures, Cylinders, Wave diffraction

When small amplitude surface waves on infinitely deep water are normally incident on a submerged circular cylinder whose axis is horizontal, there is zero reflection at all frequencies and an exponentially small phase shift at high frequency. Here the latter result is generalized to finite depth and cylinders of arbitrary cross section, after which it is shown that zero reflection at all frequencies only occurs when the cross section of the fluid region can be mapped by a bilinear transformation into a concentric circular annulus.

76-1760

Spectral Analysis of the PEKERIS Operator in the Theory of Acoustic Wave Propagation in Shallow Water

C. Wilcox
Dept. of Mathematics, Univ. of Utah, Salt Lake City, UT., Archive Rational Mech. Anal., 60 (3), pp 259-300 (June 1976) 9 refs
Sponsored by the Office of Naval Research

Key Words: Underwater sound, Sound transmission, Spectrum analysis

The PEKERIS differential operator arises in the study of acoustic wave propagation in a layer of water having sound speed c_1 and density ρ_1 which overlays a bottom having sound speed c_2 and density ρ_2. In this paper it is shown that the operator acting on a class of functions which are defined for positive space and vanish at zero defines a self-adjoint operator on the Hilbert space. The spectral family of the operator is constructed and the spectrum is shown to be continuous. Moreover an eigenfunction expansion for the operator is given in terms of a family of improper eigenfunctions.

SOIL

(Also see Nos. 1743, 1744, 1761, 1860, 1867)

76-1761

Seismic Wave Effects on Soil-Structure Interaction

R.H. Scanlan
Dept. of Civil Engrg., Princeton Univ., Princeton, NJ., Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 379-388 (Apr - June 1976) 7 figs, 10 refs

Key Words: Interaction: soil-structure, Seismic waves, Nuclear power plants

The present paper discusses some of the effects which will inevitably be entrained by the introduction of any information or hypotheses regarding the spatial distribution of earthquake motions. This analysis tends to suggest why higher frequencies are of lesser importance for a structure having a large rigid foundation.

76-1762

A Note on the Dynamic Response of Rigid Embedded Foundations

J.E. Lucco, H.L. Wong and M.D. Trifunac
Earthquake Engrg. Research Lab., California Inst. of Technology, Pasadena, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (2), pp 119-127 (Oct - Dec 1975) 6 figs, 24 refs
Sponsored by the National Science Foundation

Key Words: Rigid foundations, Seismic response, Interaction: soil-structure

The problem of the dynamic response of rigid embedded foundations subjected to the action of external forces and seismic excitation is analyzed. It is shown that to calculate the response of rigid embedded foundations, or the response of flat rigid foundations subjected to non-vertically incident seismic waves, it is necessary to obtain not only the impedance matrix for the foundation, but also the forces induced by the incident seismic waves. Under these general conditions, rocking and torsional motion of the foundation is generated in addition to translation. The case of a two-dimensional rigid foundation of semi-elliptical cross-section is used as an example to illustrate the effects of the embedment depth and angle of incidence of the seismic waves on the response of the foundation.

76-1763

Earthquake Response of Non-Linear Hysteretic Soil Systems

E. Faccioli and J. Ramirez
Instituto de Ingenieria, Universidad Nacional Autonoma de Mexico, Mexico, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 261-276 (Jan - Mar 1976) 10 figs, 27 refs

Key Words: Soils, Seismic response, Random vibration, Hysteretic damping

The seismic amplification response of horizontally stratified soil deposits with Ramberg-Osgood stress-strain behavior is analyzed by a random-vibration method. The deposit is modeled by a discrete shear beam system with radiation damping at the base. Parameters of an equivalent system are obtained by a harmonic linearization technique in which the actual relative displacement response at the surface is represented by a suitable sinusoidal motion. Despite the simplifications introduced, results for a number of different soil profiles and material description parameters are in good agreement with those given by numerical simulation techniques. Due to the much greater computational effort required by the latter, the proposed method seems preferable for predicting spectral amplification characteristics over a broad range of excitation intensities.

76-1764
Soil-Pile Interaction in Vertical Vibration

T. Nogami and M. Novak
Dept. of Engrg. Science, The Univ. of Western Ontario, London, Canada, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 277-293 (Jan - Mar 1976) 12 figs, 8 refs
Sponsored by the National Res. Council of Canada

Key Words: Interaction: soil-structure, Pile structures, Hysteretic damping

The interaction between a soil layer and an end bearing pile is theoretically investigated. The pile is assumed to be vertical and elastic, the soil is considered as a linear visco-elastic layer with hysteretic type damping. The layer alone is solved first and the wave modes of the layer are used in the analysis of the pile response. The pile response to a harmonic load is obtained in a closed form and used to define stiffness and damping at the level of the pile head. The dimensionless parameters of the problem are identified. A parametric study is conducted to determine the main features of the response and of the equivalent stiffness and damping. The validity of equivalent viscous damping is examined. A comparison is made with the simpler plane strain theory used previously and its accuracy is assessed.

76-1765
Modal Analysis of Coupled Motion of Horizontally Excited Embedded Footings

Y.O. Beredugo
Dept. of Civil Engrg., College of Science and Technology, Port Harcourt, Nigeria, Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 403-410 (Apr - June 1976) 4 figs, 15 refs
Sponsored by the National Res. Council

Key Words: Footings, Modal analysis

A modal analysis formulation of the equations of motion of horizontally excited embedded footings is presented. Numerical solutions obtained with these equations are compared with the results obtained from direct solutions. It is shown that the two methods of solution are in good agreement for frequencies near to the first resonance.

76-1766
Dynamic Response of a Horizontally Buried Cylinder Above a Soil/Rock Interface. Results of a Finite-Element Analysis

R.N. Murtha
Civil Engineering Lab. (Navy), Port Hueneme, CA., Rept. No. CEL-TR-838, 40 pp (Mar 1976)
AD-A024 052/3GA

Key Words: Cylinders, Underground structure, Interaction: soil-structure, Finite element technique, Computer programs

Static and dynamic two-dimensional finite element computer structural analyses were performed on cylinders, horizontally buried above a rigid concrete bottom (simulating a soil/rock interface), for correlation with laboratory experimental test data. Both linear and nonlinear constitutive models were used to mathematically describe the behavior of the soil medium. A mesh parameter study was performed to optimize mesh size and time increment without degradation of the results. The computer results compared favorably with the experimental data.

76-1767
Shear Modulus and Damping Characteristics of Soils

E.A.C. Palaniappan
Ph.D. Thesis, Georgia Inst. of Technology, 1976, 175 pp
UM 76-16, 450

Key Words: Soils, Seismic response, Viscous damping, Coulomb friction, Hysteretic damping, Mathematical models

In this dissertation, the mathematical models and reported experimental data regarding the nature of damping in soils have been analyzed. These models include viscous damping, Coulomb damping, and hysteretic damping. For hysteretic damping, certain concepts regarding the critical damping coefficient and damping ratio have been proposed by the author. A method which equates energy input and energy dissipation at resonance has been suggested by the author for use in interpreting the torsional shear test.

76-1768

Vibrations of a Rigid Disc on a Layered Viscoelastic Medium

J.E. Luco

Dept. of Appl. Mechanics and Engrg. Sciences, Univ. of California, San Diego, La Jolla, CA., 92093, Nucl. Engr. Des., 36 (3), pp 325-340 (Mar 1976) 10 figs, 14 refs

Key Words: Disks, Viscoelastic medium, Foundations, Interaction: soil-structure, Material damping, Internal damping

A method of obtaining the dynamic impedance functions for a rigid circular foundation placed on a layered viscoelastic half-space is presented. Both hysteretic and Voigt models of internal damping are considered. The results obtained indicate that the presence of internal damping introduces important changes in the dynamic response of the foundation for vertical, rocking and horizontal steady-state excitation.

76-1769

Acoustic Emission Behavior of Granular Soils

R.M. Koerner, A.E. Lord, W.M. McCabe and J.W. Curran

Dept. of Civil Engrg., Drexel Univ., Philadelphia, PA., ASCE J. Geotech. Engr. Div., 102 (GT7), pp 761-773 (July 1976)

Key Words: Soils, Acoustic properties

The study is subdivided into three phases: granular soils, cohesive soils, and field monitoring; the present paper addresses itself to the first phase of the overall project. Acoustic emissions are internally generated sounds that occur when a soil sample is stressed and subsequently deforms.

76-1770

Torsional Response of Structures to Obliquely Incident Seismic SH Waves

J.E. Luco

Dept. of Appl. Mechanics and Engrg. Sciences, Univ. of California, San Diego, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 207-219 (Jan - Mar 1976) 9 figs, 17 refs

Sponsored by the National Science Foundation

Key Words: Seismic excitation, Torsional response, Interaction: soil-structure, Rigid foundations

A study is made of the torsional response of an elastic structure placed on a rigid circular foundation supported on an elastic half-space and subjected to the action of obliquely incident plane SH waves. The problem is solved by considering first the steady-state response of a massless rigid foundation excited externally by a harmonic torque and through the soil by an obliquely incident plane SH wave. In a second stage the coupling between the structure and the soil is considered to obtain the torsional response at the base and top of the superstructure. The results obtained indicate a range of conditions under which the torsional effects will be most pronounced.

76-1771

Vertical Vibration of Rigid Bodies with Rectangular Bases on Elastic Media

A.O. Awojobi and P.H. Tabiowo

Dept. of Mech. Engrg., Univ. of Lagos, Nigeria, Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 439-454 (July - Sept 1976) 5 figs, 10 refs

Key Words: Rectangular bodies, Elastic foundations, Resonant frequency, Amplitude data

Dual double integral equations completely representing the mixed boundary-value problem of the vertical vibration of rigid bodies with rectangular bases on semi-infinite elastic media are exactly formulated. An exact solution of these equations - even for the static case - is at present formidable, but an approximate solution is given by reducing the pair of dual double integral equations to another pair which shows an approximate relation between the three-dimensional and axi-symmetric systems. This new method is used to generate response curves for Poisson's ratio 0.25 and side ratios 1, 2, 3, 4 and 5, from known results for circular bases, for the dynamic problem.

THERMOELASTIC

(See No. 1772)

VISCOELASTIC

76-1772

Variational Principles for Linear Coupled Dynamic Theory of Thermoviscoelasticity

J.N. Reddy

School of Aerospace, Mechanical and Nuclear Engrg., Univ. of Oklahoma, Norman, OK., 73069, Intl. J. Engr. Sci., 14 (7), pp 605-616 (1976) 19 figs

Key Words: Thermoviscoelasticity theory

Variational principles for linear coupled dynamic theory of thermoviscoelasticity are constructed using variational theory of potential operators. The functional derived herein gives, when varied, all the governing equations, including the boundary and initial conditions, as the Euler equations. The procedure shown herein does not require, in contrast to Gurtin's method, the transformation of field equations into an equivalent set of integro-differential equations, and includes the initial conditions of the problem explicitly. Gurtin's variational principle for dynamic theory of thermoviscoelasticity is also derived and compared with the present one. Variational principles for elastodynamics, visco-elasticity, etc. are derived as special cases of the variational principle derived herein.

EXPERIMENTATION

DIAGNOSTICS

76-1773

Machinery Health Monitoring -- The Use of Vibration and Other Operating Characteristics in a Comprehensive Engineered Monitoring System

J.S. Mitchell

Machinery Health Monitoring Div., ENDEVCO, Rancho Viejo Road, San Juan Capistrano, CA., 92675, In: 22nd International Instrumentation Symposium, Tutorial Proceedings, May 25-27, 1976, San Diego, CA., B.W. Washburn (ed.), pp 29-36, 5 figs, 9 refs

Key Words: Diagnostic techniques, Machinery

Of the commonly measured machinery parameters, vibration is generally the most complex and difficult to interpret. Financial impact of lost production and an increased awareness of the potential of vibration as a prime indicator of mechanical condition is providing the incentive for rapid advancement in equipment and methods for vibration measurements, display, and analysis. Although most of the technological developments for using broad band vibration have been applied to periodic off line analysis, the resulting knowledge of machinery characteristics may be used advantageously in the design of on line continuous monitoring systems.

EQUIPMENT

(See No. 1847)

FACILITIES

(Also see No. 1807)

76-1774

Impedance-Tube Calibration of a Reverberant Room for the Measurement of Sound Power in Tones

D.A. Bies and C.H. Hansen

Dept. of Mechanical Engrg., Univ. of Adelaide, South Australia, 5001, J. Acoust. Soc. Amer., 59 (6), pp 1393-1398 (June 1976) 5 figs, 11 refs

Key Words: Reverberation chambers, Calibrating

The use of an impedance tube and horn for the absolute calibration of a 180-m^3 reverberant room for the measurement of sound power in tones is discussed and demonstrated. The results of the calibration procedure are found to compare quite favorably with results obtained using a one-third-octave-band decay method. For a modal overlap index greater than 5, corresponding to frequencies greater than 400 Hz, the difference in the predictions of the two methods is less than 0.8 dB while at a modal overlap index as low as 1.9, corresponding to a frequency of 264 Hz, the difference is less than 1.6 dB.

76-1775

Studies of Impulsive Sound Level Response Statistics in a Reverberant Enclosure

E.K. Dunens

Ph.D. Thesis, Univ. of Minnesota, 1975, 139 pp *UM 76-14, 886*

Key Words: Reverberation chambers, Shock excitation, Acoustic response, Mathematical models

This study is devoted to an experimental investigation of an impulse sound source in a reverberant enclosure. The influence on the pressure response of such factors as source-microphone location, amount and placement of sound absorbing material, and shielding by barriers is assessed. A simple, analytical model is developed on the basis of the experimental observations. The formulation of the model is subdivided into analytically modeling the source, obtaining the RMS sound pressure, and obtaining the shape of the EPD. The essential source parameters needed in the model are peak amplitude probability density, impulse duration and shape, average occurrence rate, and directivity. An energy partition model is used to obtain the RMS sound pressure. The energy is divided in time into an early energy component and a reverberant component. A method of images is used to calculate the early energy and a cutoff time t_e.

INSTRUMENTATION

76-1776
A Test Stand for the Determination of the Dynamic Response of Rotating Elastic Power Transmission Components

R. Mehner and D. Peschel
Technische Universität Dresden, Sektion Grundlagen des Maschinenwesens, Bereich Dynamik u. Datenverarbeitung, Maschinenbautechnik, 25 (3), pp 105-108 (Mar 1976) 8 figs, 3 refs
(In German)

Key Words : Test stands, Power transmission systems, Couplings, V-belts

A test stand for the determination of stiffness and damping of power transmission elements, particularly couplings and V-belts, is described. The dynamic response is calculated by means of linear theory from the experimental input and output values of the multimass oscillation system into which the test sample is mounted and subjected to various test conditions, including rotation.

76-1777
Acoustic Measurement System for Use in Phase Transition Experiments

E.M. Alexander and G.E. Friedman
Naval Research Lab., Washington, D.C., Rev. Sci. Instr., 47 (6), pp 662-666 (June 1976) 6 figs, 2 refs

Key Words: Measuring instruments, Acoustic measurement

An electronic system has been developed whereby the relative velocity and attenuation of an acoustic wave can be measured simply, dynamically, automatically, and simultaneously. The best application for this system is in certain phase transition experiments where acoustic quantities undergo large changes, i.e., the attenuation changes by several dB and the velocity by a factor of two or more. The unique feature of this sytem is that the output pulse signal is fed into gates that track the changing position of the signal with time. Attenuation is determined from the integral of the signal in one of the gates while velocity information is determined from the time positioning of one of the gate edges.

76-1778
Evaluation of Transducer Window Materials

E.E. Mikeska and J.A. Behrens
Appl. Research Labs., The Univ. of Texas at Austin, Austin, TX., 78712, J. Acoust. Soc. Amer., 59 (6), pp 1294-1298 (June 1976) 10 figs, 10 refs

Key Words: Absorbers (materials), Acoustic absorption

Acoustic measurements of insertion loss and echo reduction at normal incidence were made for thin plates of eight materials for evaluation of their use in underwater sound transducers in the frequency range 50-500 kHz. Materials tested included Lucite; silicone rubber RTV-560; the commercial polyurethane products PRC-1527, CPC-19, Scotchcast 8, and Scotchcast 221; and two of these materials with talc added during curing to vary the properties. Values of longitudinal sound velocity, attenuation constant, and characteristic impedance are derived from comparison of theoretical and measured characteristics.

TECHNIQUES
(Also see No. 1783)

76-1779
A Human Model for Measuring Ride Quality

J.C. Wambold and W.H. Park
The Pennsylvania Transportation Institute, The Pennsylvania State Univ., University Park, PA., Mech. Engr., 98 (7), pp 30-34 (July 1976)

Key Words: Ride dynamics, Measurement techniques, Anthropomorphic dummies

A means for measuring vehicle ride quality that can be used with all types of transportation systems is discussed. It is based on absorbed power, a method developed in the late 1960s but not extensively utilized. Recent developments for handling random data have cast a new light on its use as a comfort criterion. Because amplitude of motion as well as frequency are identified, it is easy to recognize what is causing ride deterioration. The system consists of a dummy which carries instrumentation to measure comfort parameters in three axes, although only the vertical axis presently simulates human response.

76-1780
Resonance Test of a Structure with Damping Coupling and Frequency Neighborhood

H. Wittmeyer
Fredriksbergsvagen 13, S-582 58 Linkoping, Sweden, Z. Flugwiss., 24 (3), pp 139-151 (May/June 1976) 15 refs
(In German)

Key Words: Mathematical models, Resonance tests

Mathematical models for structures are obtained from ground resonance tests. The proposed procedure combines the advantages of the classical method with adapted excitation with the advantages of the newer "analytical" procedures with not adapted excitation and complementary computation. The force groups needed for the approximated excitation of the complex natural vibration modes are calculated, where a computation with a greater precision is only required in case of a frequency neighborhood. Therefore, comprehensive analytical eliminations of disturbing natural vibration modes are not necessary and the procedure is not sensitive to small nonlinearities. Special averaging gives good accuracy. The damping is supposed to be small and can be either structural or viscous.

76-1781
Acoustic Emission Testing for Structural Applications

K. Ono and A.T. Green
Dept. of Materials, California Univ., Los Angeles, CA.
(presented at ASCE Specialty Conference/UCLA Extension, 30-31 Mar 1976, Los Angeles, CA) 12 pp (Mar 1976)
AD-A024 064/8GA

Key Words: Nondestructive tests, Acoustic techniques, Bridges, Dams, Pressure vessels

General introduction of acoustic emission testing is given. While little practical experience has been accumulated in many applications involving civil engineering structures, the potential of this technique in structural integrity assessment has been well demonstrated in aerospace and nuclear fields.

76-1782
Acoustic Emission Behavior of Concrete Laboratory Specimens

W.M. McCabe, R.M Koerner and A.E. Lord
Drexel Univ., Philadelphia, PA., J. Amer. Concrete Inst., 73 (7), pp 367-371 (July 1976) 7 figs, 28 refs

Key Words: Nondestructive-testing technique, Acoustic techniques, Concretes, Concrete construction

Acoustic emission monitoring of concrete represents a potentially rapid, economic, and reliable method to nondestructively test full scale concrete structures. Since the technique is relatively new, however, considerable laboratory work of a fundamental nature is first required before field work commences. To this end a study to monitor the acoustic emissions which are generated by placing test specimens under load was initiated. The major findings of this study are reported.

COMPONENTS

SHAFTS

76-1783
The Determination of Elastic Properties of Crankshafts

I. Gantschev
Universität Rostock, Wissenschaftsbereich Mechanik fester Körper, Rostock, Germany, Maschinenbautechnik, 25 (3), pp 122-124 (Mar 1976) 3 figs, 7 refs (In German)

Key Words: Crankshafts, Elastic properties, Testing techniques

For the calculation of the coupled torsional-longitudinal vibrations of a propulsion system with reciprocating engines, the elastic characteristics of the crankshaft are needed. In the article an experimental technique for the determination of influence coefficients of crankshafts is described.

BEAMS, STRINGS, RODS

(Also see Nos. 1740, 1814, 1828)

76-1784
Fourth-Order Dispersion of Free Longitudinal Waves in a Long Orthotropic Bar of Rectangular Cross Section

A.J. Zuckerwar
Old Dominion Univ. Research Foundation, Norfolk, VA., 23508, J. Acoust. Soc. Amer., 59 (6), pp 1372-1378 (June 1976) 2 figs, 5 refs

Key Words: Bars, Wave propagation, Perturbation theory

A perturbation technique described previously is applied to find the dispersion of free longitudinal waves of fourth order of approximation in a long orthotropic bar of rectangular cross section. Measurements of the first two frequencies of two potassium chloride specimens, having different major orientations, are compared with theoretical predictions; the percent differences are 0.06%, 0.12%, 0.07%, and $< 0.01\%$, all of which lie well within the bounds permitted by the uncertainties in the governing parameters.

76-1785

Optimization of Beam Type Structures Under Dynamic Input

T.T. Feng and J.S. Arora

Intertech Corp., Iowa City, IA., Rept. No. 22, 13 pp (Feb 1976)

(see also report dated May 1975, AD-A012 212)

AD-A023 976/4GA

Key Words: Cantilever beams, Optimum design

This report presents optimal design of cantilever beams subjected to dynamic input. The beams have radial ribs, and the depth of the ribs are considered as design variables. A lumped mass is placed at the free end of the cantilever beams and its effect on the dynamic response is studied. Numerical results for two examples are obtained and discussed.

76-1786

Numerical Calculation of Large Elastic-Plastic Deformation of Beams Due to Dynamic Loading

A. Sperling and Y. Partom

Material Mechanics Lab., Technion-Israel Inst. of Tech., Haifa, Israel, Rept. No. MML-50, Scientific-8, AFOSR-TR-76-0478, 43 pp (Dec 1975)

AD-A023 948/3GA

Key Words: Beams, Elastic-plastic properties

Numerical calculations were performed for two examples of the response of elastic-plastic beams subjected to dynamic loads. These were a simply supported, axially restrained beam under suddenly applied uniform pressure, and an axially restrained, clamped beam with a central mass that is impacted by a projectile. Large elastic-plastic deflections were considered, and the method of finite differences was used. Two different constitutive equations were assumed: the elastic-perfectly plastic relation, and a special elastic-visco-plastic strain hardening model. Analysis of the results included examining the interaction between the bending moment and the axial force, the variation of the axial force, bending moment and deflection with time, and the propagation velocities of the various phenomena during motion. Experiments were carried out in which a rifle projectile hit a central mass which had been fastened to a clamped beam. Comparison between the theoretical and experimental dynamic deflections shows good agreement for relatively short response times.

76-1787

Numerical Determination of Minimum Mass Structures with Specified Natural Frequencies

A. Miele

Dept. of Mechanical Engineering, Rice University, Houston, TX., Rept. No. AFOSR-TR-76-0275, 20 pp (1976)

AD-A023 655/4GA

Key Words: Cantilever beams, Natural frequencies, Minimum weight design, Quasilinearization technique

The problem of the axial vibration of a cantilever beam was investigated numerically. The mass distribution that minimizes the total mass for a given fundamental frequency constraint is determined using both the sequential gradient-restoration algorithm and an ad hoc modification of the modified quasilinearization algorithm.

76-1788

Elastic-Plastic Large Deformation Static and Dynamic Analysis

K. Bathe and H. Ozdemir

Dept. of Mechanical Engrg., Massachusetts Inst. of Technology, Cambridge, MA., 02139, Computers and Struc., 6 (2), pp 81-92 (1976)

Key Words: Beams, Shells, Finite element technique, Elastic-plastic properties, Dynamic response

The problem of formulating and numerically implementing finite element elastic-plastic large deformation analysis is considered. In general, formulations can use different kinematic descriptions and assumptions in the material law, and analysis results can vary by a large amount. In this paper, starting from continuum mechanics principles, two consistent formulations for elastic-plastic large deformation analysis are presented in which either the initial configuration or the current configuration is used for the description of static and kinematic variables. The differences between the formulations are clearly identified and it is established that, depending on the elastic-plastic material description, identical numerical results can be obtained. The formulations have been implemented and representative sample analyses of large deformation response of beams and shells are presented.

76-1789

Dynamic Beam Model with Internal Damping, Rotatory Inertia and Shear Deformation

C.W. De Silva

Univ. of Cincinnati, Cincinnati, OH., AIAA J., 14 (5), pp 676-680 (May 1976) 1 fig, 9 refs

Key Words: Beams, Internal damping, Rotatory inertia effects, Transverse shear deformation effects, Mathematical models

A simple and straightforward technique that makes use of the state space method of modern control theory to include the effects due to internal damping, rotatory inertia, and shear deformation in the dynamic analysis of beams is proposed. It is shown how the resulting beam model which is valid even for high frequencies of vibration, can be used in design situations such as vibration control using linear dampers and dynamic absorbers. A method to include hysteretic internal damping as well as viscoelastic damping is indicated. A numerical example is given to illustrate the use of the proposed beam model in an elementary problem.

76-1790

Non-Linear Forced Vibrations of a Beam Carrying Concentrated Mass Under Gravity

H. Saito, K. Sato and T. Yutani
Dept. of Mechanical Engrg., Tohoku Univ., Sendai, Japan, J. Sound Vib., 46 (4), pp 515-525 (June 22, 1976) 6 figs, 11 refs

Key Words: Beams, Forced vibration, Harmonic excitation

The non-linear dynamic behavior of a simply supported beam, with ends restrained to remain a fixed distance apart, carrying a concentrated mass and subjected to a harmonic exciting force at an arbitrary point under the influence of gravity is analyzed. By using the one mode approximation and applying Galerkin's method, the governing equation of motion is reduced to the well known Duffing type equation. The effects of the weight, the location, and the vibratory amplitude of the concentrated mass on the natural frequency are discussed.

76-1791

Response of Beams to Propagating Boundary Excitation

S.F. Masri
Dept. of Civil Engrg., Univ. of Southern California, Los Angeles, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (5), pp 497-509 (July - Sept 1976) 10 figs, 13 refs

Key Words: Beams, Bernoulli-Euler method, Viscous damping, Supports, Shock response

An exact solution is presented for the transient response of viscously damped Bernoulli-Euler beams with arbitrary boundary conditions that are subjected to directly applied dynamic loads in addition to arbitrary support motion. It is shown that, for certain system characteristics, the wave-like progression of the disturbance may have a significant influence on the structural response of such beams.

76-1792

Transverse Vibrations of Tapered Beams

R.P. Goel
Dept. of Mechanical Engineering, North Carolina Agricultural and Technical State Univ., Greensboro, NC, 27411, J. Sound Vib., 47 (1), pp 1-7 (July 8, 1976) 7 refs

Key Words: Beams, Flexural vibrations

Transverse vibrations of linearly tapered beams, elastically restrained against rotation at either end, have been investigated. Results for the first three eigenfrequencies, with different values of stiffness ratios (ratio of spring stiffness and beam stiffness at either end) and taper ratio are presented. Cases of a tapered cantilever beam with a concentrated mass at the free end and spring hinged at the other end have also been presented.

76-1793

Inelastic Response of Beam-Plate Assemblages Subjected to Static and Dynamic Loads

K. Khozeimeh
Ph.D. Thesis, The George Washington Univ., 1974, 150 pp
UM 76-16, 262

Key Words: Beam-plate systems

An analytical study is made of the inelastic behavior of structural systems consisting of beam-plate assemblages and subjected to static and dynamic loads. Such structures are idealized as a collection of finite elements. The governing differential equations of motion for the system are derived through the application of Hamilton's Principle. In case of static loading, the above equations are specialized by neglecting temporal terms. In both cases, the governing equations are solved numerically. In the analysis, the effect of both material and geometric nonlinearities are taken into account by utilization of the "Initial Stress" method and by introduction of a geometric stiffness matrix to account for large displacements. Numerical examples demonstrating the applicability of the proposed method are presented and the results are compared, when applicable, with the work of other investigators, both of experimental and theoretical nature.

76-1794

Free Vibrations of a Beam-Mass System with Elastically Restrained Ends

R.P. Goel
Dept. of Mechanical Engrg., North Carolina Agricultural and Technical State Univ., Greensboro, NC., 27411, J. Sound Vib., 47 (1), pp 9-14 (July 8, 1976) 3 refs

Key Words: Beams, Mass-beam systems, Free vibration, Laplace transformation

The vibration problem of a beam with an arbitrarily placed concentrated mass and elastically restrained against rotation at either end is solved by using Laplace transforms. The effects on eigenfrequencies of the system produced by varying the ratios of the concentrated mass to the mass of the beam, stiffness of the end spring to the stiffness of the beam and position of the mass to the total length of the beam are presented. The effect of neglecting the mass of the beam is considered.

76-1795

The Motion of the Bowed String

R. H. Johns
Ph.D. Thesis, Temple Univ., 1976, 114 pp
UM 76-15, 844

Key Words: Strings, Musical instruments, Test equipment

A new model for understanding the motion of the bowed string is proposed, new apparatus for displaying string vibrations on the oscilloscope is reported, and new demonstrations for showing bowed and plucked vibrations to large groups are described.

76-1796

On the Dynamic Response of a Suspended Cable

H. M. Irvine and J. H. Griffin
Univ. of Auckland, Auckland, New Zealand, Intl. J. Earthquake Engr. Struc. Dynam., 4 (4), pp 389-402 (Apr-June 1976) 2 figs, 3 refs

Key Words: Cables, Geometric effects, Elastic properties, Seismic excitation

Linearized equations are derived to account for the additional tensions and deflections induced by dynamically exciting a suspended cable. Wave-type and modal solutions are presented to explore the influence of a fundamental geometric and elastic parameter, λ^2.

76-1797

An Energy Method Determination of Large Cable Dynamics

W. W. Carson and A. F. Emery
Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture, Seattle, WA, J. Appl. Mech., Trans. ASME, 43 (2), pp 330-334 (June 1976) 10 figs

Key Words: Cables (ropes), Catenaries, Energy methods

The free and forced vibrations of cable segments typical of a skyline logging cable system are analyzed by assuming that the vibrating cable segment maintains a catenary shape. Energy expressions are derived to implement the Lagrange equation of motion. The results of this method are compared with finite-difference results, and, the accuracy and usefulness of the approach applied to more complex cable configurations are discussed.

76-1798

An Investigation on the Break-Down of Solutions of Models of Nonlinear Vibrating Strings

P. H. Chang
Ph.D. Thesis, Univ. of Minnesota, 1975, 183 pp
UM 76-14, 875

Key Words: Strings, Nonlinear response, Mathematical models

The mixed initial boundary value problem of the quasilinear wave equation $w_{tt} - Q^2(w_x)w_{xx} = 0$ is considered. A local existence theorem, cases satisfying some convexity conditions, and the existence of a local weak solution are shown.

BEARINGS

76-1799

Satellite Bearing Torque Noise

H. Greer and R. A. Mack
The Aerospace Corp., El Segundo, CA, ASLE Transactions, 19 (3), pp 232-238 (July 1976) 8 figs, 17 refs

Key Words: Ball bearings, Spacecraft components, Spectral energy distribution

Many spin-stabilized spacecraft use precision ball bearings to support and to align an antenna or instrument platform relative to the rotor. The pointing accuracy of the instrument platform is affected by the dynamic fluctuations in running torque or torque noise of the bearings. Although many previous investigations have been concerned with average (or dc) torque, there is a lack of information on the spectral distribution of the torque noise of lightly loaded, large-diameter bearings at slow speeds. This paper summarizes experiments performed on seven pairs of bearings of two bore sizes. Limited measurements of bearings profilometry were made. A special fixture was used to measure torque noise over a range of preload, rotational speed, and temperature. The bearing torque noise was processed by a computer to obtain torque spectral density and rms. On the basis of this experimental data, an ad hoc model was developed to estimate torque spectral density for use in control system preliminary design and feasibility studies.

BLADES

(Also see No. 1851)

76-1800

Mathematical Programming Methods for the Optimal *Design of Turbine Blade Shapes*

B.M.E. DeSilva, B. Negus and J. Worster
Univ. of Technology, Loughborough LE11 3TU, England, J. Sound Vib., 46 (4), pp 501-514 (June 22, 1976) 3 figs, 22 refs

Key Words: Turbine blades, Rotor blades (turbomachinery), Optimum design, Timoshenko theory, Mathematical programming

This paper describes some optimization techniques for the design of turbine blade profiles with a vibration constraint. The vibration characteristics were modelled by a Timoshenko beam with idealized boundary conditions permitting the system dynamics to be simulated by differential equations. Elliptical cross-sectional shapes were assumed, resulting in an optimization problem in a finite number of variables. This paper includes a numerical study of these methods and their implementation together with a discussion of results.

76-1801

Composite Inlays Increase Flutter Resistance of Turbine Engine Fan Blades

W. Troha and K. Swain
Wright Patterson AFB, OH, ASME Paper No. 76-GT-29

Key Words: Rotor blades (turbomachinery), Fans, Flutter, Vibration control

A method for improving turbine engine blade flutter stability was recently demonstrated on a TF41 fan rig and engine. The concept uses the high strength and stiffness properties of B/SiC-titanium composite, bonded into the leading edge tip section of a titanium fan blade to control the blade vibrational characteristics. Comparisons are made between the blade response characteristics with and without the composite inlay for blade natural frequency, untwist due to rotational speed, and shift in flutter boundary. Engine performance improvements due to shroud removal are also shown.

76-1802

Coupled Bending-Torsion Vibrations of Rotating Blades

S. Banerjee and J. S. Rao
Indian Inst. of Technology, Kharagpur, India, ASME Paper No. 76-GT-43

Key Words: Rotor blades (turbomachinery), Coupled response, Galerkin method

Analytical and experimental investigations are presented to determine the coupled bending-torsion natural frequencies of cantilever blades mounted on a rotating disk. The Galerkin method is applied to solve the coupled differential equations of motion for an aerofoil cross-section blade with asymmetry about only one principal axis. The blade is considered to be mounted with the axis of symmetry in the plane of disk rotation. Results obtained are presented in nondimensional form, showing the effects of rotation, disk radius, and asymmetry on the lowest three-coupled bending and lowest three-coupled torsion frequencies. An experimental rig was designed and fabricated to test rotating blades using piezoelectric crystals to excite the blades and also pick up the response.

76-1803

Prediction of Modal Damping of Jet Engine Stator Vanes Using Finite Element Techniques

P. Trompette, M. Paulard, M. Lalanne, D.I.G. Jones, and M. L. Parin
Institut National des Sciences Appliquees, Villeurbanne, France, ASME Paper No. 76-GT-60

Key Words: Stators, Compressors, Jet engines, Modal damping, Natural frequencies, Finite element technique

A finite element analysis utilizing isoparametric elements is used to predict the modal damping and resonant frequencies of a jet engine high pressure compressor stator vane with a damping treatment in the form of an enamel coating applied to the surface. The results of the finite-element analysis are shown to agree well with experimentally measured data. The ultimate advantage of this particular finite-element approach is that it can be applied at very low cost to predicting the effect of many types of damping treatment on modal damping and resonant frequencies of practically any structural component, as well as stress levels if the excitation forces are known.

COLUMNS

76-1804
Stability of Tapered Cantilever Columns Subjected to Follower Forces

G. V. Sankaran and G. V. Rao
Structural Engineering Div., Vikram Sarabhai Space Centre, Trivandrum-695022, India, Computers and Struc., 6 (3), pp 217-220 (June 1976) 1 fig, 7 refs

Key Words: Columns, Cantilever beams, Follower forces, Finite element technique, Galerkin method

Accurate estimates of critical loads of tapered cantilever columns with fixed or spring hinged ends subjected to follower forces are obtained in this paper. A Galerkin finite element method was used to solve the governing differential equation with variable coefficients. The effect of the stiffness of the spring hinge on the critical load was studied.

76-1805
Combined Analysis and Test of Earthquake-Resistant Circuit Breakers

E. G. Fischer and W. M. Daube
Westinghouse Electric Corp., Pittsburgh, PA, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 231-244 (Jan-Mar 1976) 11 figs, 10 refs

Key Words: Columns, Electric power plants, Seismic response, Earthquake resistant structures

Following the severe earthquake damage at San Fernando in 1971, it became of technical and perhaps psychological importance to demonstrate that properly re-designed electrical equipment is able to withstand even worse transient vibration phenomena which can be produced in an earthquake simulator laboratory. This has been accomplished for one column of a 500 kV gas circuit breaker and the test results are used to qualify the much larger original 3-column assembly by means of a computer-aided structural analysis. Since the equipment exhibited some closely spaced, cross-coupled modes of vibration, a valuable comparison could be obtained between the effects produced by El Centro 1940 ground acceleration and those for a more purposeful sine beat vibration input. The latter can be adjusted to produce definite stresses and fatigue effects in specific parts of the equipment due to quasi-resonance response.

CYLINDERS

(Also see Nos. 1758, 1759)

76-1806
Whispering Gallery Wave Modes on Elastic Cylinders

J. W. Dickey, G. V. Frisk and H. Überall
Naval Ship Research and Development Center, Annapolis, MD, 21402, J. Acoust. Soc. Amer., 59 (6), pp 1339-1346 (June 1976) 8 figs, 14 refs
Sponsored by the Office of Naval Res.

Key Words: Cylinders, Fluid-induced excitation

An analytic and numerical study of Whispering Gallery-type surface-wave modes on solid elastic cylinders imbedded in a fluid is presented. The complex wave numbers of these waves are obtained for the case of high frequencies ($ka \gtrsim 15$), including both their attenuation and dispersion curves for the phase velocities.

DUCTS

76-1807
Acoustic Pulse Propagation in a Duct with Flow

J. E. Cole
Dept. of Mech. Engrg., Tufts Univ., Medford, MA, 02155, J. Sound Vib., 47 (1), pp 95-105 (July 8, 1976) 9 figs, 13 refs

Key Words: Ducts, Wind tunnels, Sound transmission

The effect of a mean flow on acoustic pulse propagation in a wind tunnel of rectangular cross-section is considered both experimentally and theoretically. Pulse shapes in the wind tunnel are recorded by microphones located upstream and downstream of a source. A theoretical model of pulse propagation from a point source located in an infinitely-long rectangular duct carrying a uniform flow is considered. The convective wave equation with boundary conditions appropriate to hard walls is solved by using the Laplace transform.

76-1808

Double Eigenvalues of Soft Circular Ducts Containing Uniform Flow and Sheared Flow

G. G. Tseo
Rohr Industries, Inc., Chula Vista, CA, 92012, J. Acoust. Soc. Amer., 59 (6), pp 1386-1392 (June 1976) 7 figs, 17 refs

Key Words: Ducts, Fluid-induced excitation, Eigenvalue problems

Numerical methods to compute double eigenvalues for circular ducts containing uniform and sheared flow are presented. A technique to verify both the maximum exponential decay and the double eigenvalue, impedance, and attenuation in ducts of different sizes are presented and discussed. For well cut-on modes in a uniform-flow duct, the impedance velocity by a simple relationship suggested in a previous study. However, in a sheared-flow duct, optimum impedances are found to have much smaller values than in the uniform-flow case.

76-1809

Sound Transmission between Enclosures--A Study Using Plate and Acoustic Finite Elements

A. Craggs and G. Stead
Dept. of Mech. Engrg., Univ. of Alberta, Canada, Acustica, 35 (2), pp 89-98 (May 1976) 11 figs, 12 refs
Sponsored by National Res. Council, Canada

Key Words: Enclosures, Sound transmission, Natural frequencies, Mode shapes, Finite element technique

In this paper the free vibrations of two enclosures coupled through a flexible panel are studied by using plate and acoustic finite elements. The three dimensional problem is reduced to one of two dimensions by prescribing the solution in one direction, so while there is a restriction to have enclosures and panels of equal depth the geometry in the remaining plane problem can be irregular.

GEARS

(See No. 1776)

PIPES AND TUBES

76-1810

Experiments on Parametric Resonance of Pipes Containing Pulsatile Flow

M. P. Paidoussis and N. T. Issid
Dept. of Mech. Engrg., McGill Univ., Montreal, Quebec, Canada, J. Appl. Mech., Trans ASME, 43 (2), pp 198-202 (June 1976) 6 figs, 7 refs

Key Words: Piping systems, Stability, Flow-induced excitation, Pulse excitation, Resonance, Parametric response

This paper describes an experimental investigation of the stability of elastic pipes containing water flow, the velocity of which is perturbed harmonically about a mean value. Parametric and combination resonances were found to occur over specific ranges of pulsation amplitudes and frequencies, and of flow rates. The critical values of pulsation frequency and amplitude for the onset of instability are compared with theory, and agreement is found to be generally fairly good.

PLATES AND SHELLS

(Also see Nos. 1752, 1788, 1793)

76-1811

The Dynamic Transient Analysis of Axisymmetric Circular Plates by the Finite Element Method

E. Hinton
Dept. of Civil Engrg., Univ. of Swansea, Swansea SA2 8PP, Wales, J. Sound Vib., 46 (4), pp 465-472 (June 22, 1976) 9 figs, 11 refs

Key Words: Circular plates, Flexural vibration, Rotatory inertia effects, Transverse shear deformation effects, Finite element technique

The linear elastic, dynamic transient, analysis of some circular plate bending problems is considered by using axisymmetric, parabolic isoparametric, elements with an explicit time marching scheme. The effects of rotatory inertia and transverse shear deformation are included. A special mass lumping scheme and the use of a reduced integration technique allow the treatment of thin as well as thick plates. Several numerical examples are presented and compared with results from other sources.

76-1812

Finite Deflections of an Impulsively Loaded Fully Clamped Viscoplastic Plate by an Extension of the Mode Approximation Technique

C. T. Chon
Ph. D. Thesis, Brown Univ., 1975, 65 pp
UM 76-15, 617

Key Words: Circular plates, Viscoelastic properties, Shock response

This paper is concerned with the extension of the "mode approximation technique" to the dynamic plastic response with finite deflections of a circular plate. The problem of a fully clamped circular sandwich plate, composed of strain rate sensitive material, subjected to uniform initial impulsive pressure is solved.

76-1813

A Finite Element Formulation for Large Amplitude Flexural Vibrations of Thin Rectangular Plates

G.V. Rao, I.S. Raju and K.K. Raju
Vikram Sarabhai Space Centre, Trivandrum-695022, India, Computers and Struc., 6 (3), pp 163-167 (June 1976) 3 figs, 7 refs

Key Words: Plates, Flexural vibration, Finite element technique

Large amplitude flexural vibrations of rectangular plates are studied in this paper using a direct finite element formulation. The formulation is based on an appropriate linearization of strain displacement relations and uses an iterative method of solution. Results are presented for rectangular plates with various boundary conditions using a conforming rectangular element. Some solutions are compared with those of earlier work. This comparison brings out the superiority of the proposed formulation over the earlier finite element formulation.

76-1814

Finite Element Formulation for the Large Amplitude Free Vibrations of Beams and Orthotropic Circular Plates

G. V. Rao, K. K. Raju and I. S. Raju
Vikram Sarabhai Space Centre, Trivandrum-695022, India, Computers and Struc., 6 (3), pp 169-172 (June 1976) 3 figs, 6 refs

Key Words: Beams, Circular plates, Free vibration, Finite element technique

A finite element formulation for the large amplitude free oscillations of beams and orthotropic circular plates is presented in this paper. The present formulation does not need the knowledge of longitudinal inplane forces developed due to large displacements and thus avoids the use of corresponding geometric stiffness matrices, which were used in earlier finite element formulations. The convergence of the results obtained by using the present formulation is very good. Comparison of the present results with the earlier work wherever possible confirms the reliability and effectiveness of the present finite element formulation.

76-1815

The Effect of Self-Equilibrating Stresses on the Natural Frequencies of a Free-Free Rectangular Plate

R. F. D. P. Goff
Dept. of Engrg., Univ. of Cambridge, Cambridge CB2 1PZ, England, J. Sound Vib., 47 (1), pp 85-94 (July 8, 1976) 7 figs, 7 refs

Key Words: Rectangular plates, Natural frequencies, Torsional vibration, Flexural vibration

A rectangular plate supported with all edges free vibrates in both torsional and flexural modes. A self-equilibrating stress system, induced by running a weld on the longitudinal centre-line, reduces the natural frequencies of the plate. The effect is more marked in the torsional than in the flexural modes. It becomes less significant with increase in frequency. The paper describes an experimental and theoretical study of this effect and seeks to suggest a physical interpretation of the phenomenon.

76-1816

Approximate Natural Frequencies for Coupled Shear Walls

A. Rutenberg
Dept. of Civil Engineering, Technion-Israel Inst. of Technology, Haifa, Israel, Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 95-100 (July-Sept 1975) 2 figs, 14 refs
Sponsored by the National Res. Council of Canada

Key Words: Walls, Natural frequencies, Cantilever plates

An approximate yet accurate formula is proposed for the natural frequencies of coupled shear walls under continuous medium assumptions. First the deflected shape of the structure is represented as the sum of two components: one due to flexural cantilever action and one due to shear-flexure cantilever action. The natural frequencies of the latter two systems are then combined in Dunkerley's formula to yield the approximate frequency of the structure.

76-1817

Vibrations of Nearly Annular and Circular Plates

A.H. Nayfeh, D.T. Mook, D.W. Lobitz and S. Sridhar
Dept. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA., 24061, J. Sound Vib., 47 (1), pp 75-84 (July 8, 1976) 10 refs

Key Words: Circular plates, Rings, Natural frequencies, Mode shapes, Perturbation theory

A general procedure is presented to determine the natural frequencies and mode shapes of nearly annular and circular plates. A straightforward perturbation procedure is used with a transfer of the boundary conditions to obtain solutions given by simple expressions. As well as yielding good accuracy quantitatively, the method accurately predicts qualitative behavior. Numerical results are presented for clamped elliptical and square plates.

76-1818

Transmissibility Across Clamped Circular Plates with Central Loading Masses and Various Rib Configurations

J. B. Ochs, J. C. Snowdon and R. L. Kerlin

Engrg. Acoustics Program, The Pennsylvania State Univ., University Park, PA, J. Acoust. Soc. Amer., 59 (6), pp 1347-1360 (June 1976) 17 figs, 16 refs

Sponsored by the U.S. Naval Sea Systems Command and Office of Naval Research

Key Words: Plates, Transmissivity

The transmissibility between the midpoint and the boundary of thin, symmetrically vibrating, circular, aluminum plates of identical dimensions has been determined experimentally in the frequency range 16-2000 Hz. The plates were clamped at their boundaries and loaded symmetrically by concentrated masses or by distributed masses (ribs) of various configurations. The loading masses were always equal to the plate mass, so that their effectiveness in reducing transmissibility could be evaluated as a function of their geometry. Consideration was given to continuous and segmented circular ribs and to triangular, radially directed, square and crossed ribs. The transmissibilities across plates loaded centrally by cylindrical masses of small and intentionally large contact areas, and by continuous and segmented circular ribs of small and large diameters, agreed closely with prediction, encouraging belief in the validity of the experimental results obtained for the remaining plates loaded by noncircular ribs, which had theoretically intractable geometries. The transmissibilities across an unloaded plate and a plate plus damping tile also agreed satisfactorily with prediction, even though the transmissibility across the damped plate was calculated from an expression developed for a homogeneous plate with internal damping. The greatest overall reductions in transmissibility were provided by the central loading masses, particularly by the mass having small contact area. By comparison, the reductions provided by the various rib configurations were disappointing; only the performance of the triangular rib and of the small circular rib approached that of the central masses, suggesting use of these ribs when access to the plate center is necessary.

76-1819

Nonlinear Waves Generated by a Steadily Moving Line Load on an Elastic Plate

D. H. Y. Yen and S. Tang

Michigan State Univ., East Lansing, MI, Intl. J. Solids Struc., 12 (7), pp 467-477 (1976) 5 figs, 9 refs

Key Words : Plates, Moving loads, Periodic response

The steady-state response of an infinite plate to a steadily moving line load is studied. The nonlinear plates theory of Herrmann is used. The plate response is governed by a set of nonlinear differential equations and, in addition, must satisfy the "radiation" conditions. Appropriate radiation conditions for the present nonlinear problem are developed. Exact solutions representing nonlinear waves generated by the moving load are constructed.

76-1820

Stress, Buckling and Vibration of Hybrid Bodies of Revolution

D. Bushnell

Lockheed Missiles and Space Co., Inc., Palo Alto Research Lab., Palo Alto, CA, Rept. No. LMSC-D501503, (Mar 1976) 28 pp (presented at the 17th AIAA/ASME/SAE Structures, Structural Dynamics and Materials Conf.)

AD-A023 656/2GA

Key Words: Shells, Bodies of revolution, Rings, Finite difference theory, Finite element technique, Computer programs

The analysis is applicable to bodies of revolution composed of thin shell segments, thick segments, and discrete rings. The thin shell segments are discretized by the finite difference energy method and the thick or solid segments are treated as assemblages of 8-node isoparametric quadrilateral finite elements of revolution. Plasticity and primary or secondary creep are included. Axisymmetric prebuckling displacements may be moderately large. The nonlinear axisymmetric problem is solved in two nested iteration loops at each load level or time step. In the inner loop the simultaneous nonlinear equations corresponding to a given tangent stiffness are solved by the Newton-Raphson method. In the outer loop the plastic and creep strains and tangent stiffness are calculated by a subincremental procedure.

76-1821

Analysis of Self-Excited and Forced Vibrations of a Cylindrical Shell in Supersonic Flow

Z. Dżygadlo, I. Nowotarski and A. Olejnik
Polish Academy of Sciences, Inst. of Fundamental Technological Res., Warszawa, Poland, J. Technical Physics, 17 (1), pp 37-58 (1976) 12 figs, 23 refs

Key Words: Cylindrical shells, Forced vibration, Self-excited vibrations

In the present paper a complex analysis has been made of self-excited and forced vibrations of a cylindrical shell of finite length in supersonic flow. Conditions have been established for the occurrence of self-excited vibrations, depending on the form of the deformation of the shell, its parameters and the Mach number of flow. The singularities of the resonance characteristics of forced vibration have been investigated in the neighborhood of critical states, as well as the vibration modes in a number of typical cases. The solution has been obtained by the method of expansion in series of eigenfunctions of the self-adjoint boundary-value vibration problem of the same shell in vacuum, on the assumption that the conditions of simple support are satisfied at both edges of the shell. The convergence of the solution of the equations of motion has been studied. The equation of frequency of autonomous vibrations has been determined together with the expressions for stationary forced vibration of the system. The results of numerical analysis of self-excited vibrations have been presented as well as the resonance characteristics and modes of forced vibration of the shell under consideration.

76-1822

The Dynamic Response of Spinning Cross-Ply Laminated Circular Cylindrical Shells

S. S. Gassel
Ph.D. Thesis, Univ. of Wisconsin-Madison, 1976, 152 pp
UM 76-10, 659

Key Words: Cylindrical shells, Laminates, Transverse shear deformation effects, Rotatory inertia effects, Viscous damping, Mathematical models

A new dynamic shell theory is developed to study cross-ply laminated circular cylindrical shells. The analytical model is an improved theory which includes the effects of heterogeneous shear deformation and rotary inertia as well as constant spin, a uniform initial membrane state of stress and viscous damping. The character of the derivation is such that the basic equations, although applicable to laminates with diverse material and geometric properties, possess a desirous simplicity. In fact, for a shell consisting of an arbitrary number of layers only five displacement variables are required to describe the response. In addition, the equations may be reduced to the equations of generally accepted shell models.

76-1823

Radial Oscillations of Nonhomogeneous, Thick-Walled Cylindrical and Spherical Shells Subjected to Finite Deformations

E. Ertepinar and H. U. Akay
Depts. of Engrg. Science and Civil Engrg., Middle East Technical Univ., Ankara, Turkey, Intl. J. Solids Struc., 12 (7), pp 517-524 (1976) 4 figs, 14 refs

Key Words: Spherical shells, Cylindrical shells, Tubes, Vibration response

The infinitesimal breathing motions of long cylindrical tubes and hollow spherical shells of arbitrary wall thickness subjected to a finite deformation field caused by uniform internal and/or external pressures are investigated. A neo-Hookean material with a material constant varying continuously along the radial direction is used. The shell is first subjected to finite static deformations and is then exposed to a secondary dynamic displacement field. Based on the theory of small deformations superposed on large deformations, closed form expressions are obtained for the frequency of small oscillations about the highly prestressed state. Frequency versus initial deformation parameter curves are given for several nohomogeneity functions and for various wall thicknesses.

76-1824

Radial Vibrations of a Perturbed Spherical Shell

J. P. Cambou
Institut Universitaire de Technologie de Saint-Nazaire, 44606 Saint-Nazaire, France, Acustica, 35 (2), pp 137-140 (May 1976) 6 refs
(In French)

Key Words: Spherical shells, Vibration response

This paper deals with the free radial vibrations of a thin spherical shell. A perturbation parameter based on thickness (ratio of thickness to outer radius) is employed in the solution for radial natural frequency.

76-1825

Bifurcation and Snap-Through Phenomena in Asymmetric Dynamic Analysis of Shallow Spherical Shells

N. Akkas
Dept. of Civil Engrg., Middle East Technical Univ., Ankara, Turkey, Computers and Struc., 6 (3), pp 241-251 (June 1976) 15 figs, 28 refs

Key Words: Spherical shells, Dynamic buckling, Eigenvalue problems

The asymmetric dynamic behavior of clamped shallow spherical shells under a uniform step pressure of infinite duration is investigated. The solution of a linear eigenvalue problem yields the bifurcation paths and also the lower bound for the asymmetric dynamic snap-through buckling pressure. The asymmetric dynamic response of shells with a shape imperfection is studied. The asymmetric dynamic snap-through buckling load is defined to be the threshold value of the step pressure at which the asymmetric response shows significant growth rate. The snap-through buckling loads are obtained for a few shell parameters. The numerical results are compared with the available experimental results and they are in good agreement. Finally, a preliminary study of the phase planes is presented.

76-1826
Axisymmetric Membrane and Flexural Vibrations of Spherical Shells

J. Hammel
Fachbereich Mechanik, Technische Hochschule, Darmstadt, BRD, Mech. Res. Comm., 3, pp 113-118 (1976) 7 figs, 3 refs
(In German)

Key Words: Spherical shells, Flexural vibration

The calculation of the frequencies of free vibrations of spherical shells is based on modes of vibration which are made up of two types of vibrations: natural frequency with a superimposed higher frequency vibration. In order to clarify these modes of vibration, membrane and flexural vibrations of spherical shells with various parameters and boundary conditions are examined.

76-1827
The Finite Amplitude Motion of an Incompressible Composite Hollow Sphere

Y. Benveniste
Dept. of Solid Mechanics, Materials and Structures, Tel-Aviv Univ., Ramat-Aviv, Tel-Aviv 69978, Israel, J. Sound Vib., 46 (4), pp 527-535 (June 22, 1976) 5 figs, 4 refs

Key Words: Spheres, Composite structures, Cavity containing media, Laminates

The finite dynamic deformations of a composite hollow sphere made of an arbitrary number of layers is treated. The layers are assumed to be made of a non-linearly elastic incompressible material. The cavity wall is subjected to a spatially uniform radial pressure and the spherically symmetric motions of the layered hollow sphere are considered. A nonlinear ordinary differential equation governing the motion of the cavity wall is obtained and solved by a numerical method.

RINGS
(See No. 1817)

STRUCTURAL
(Also see No. 1816)

76-1828
Repaired R/C Members Under Cyclic Loading

E. P. Popov and V. V. Bertero
Dept. of Civil Engrg., Univ. of California, Berkeley, CA., Intl. J. Earthquake Engrg. Struc. Dynam., 4 (2), pp 129-144 (Oct - Dec 1975) 20 figs, 5 refs
Sponsored by the National Science Foundation

Key Words: Structural members, Reinforced concrete, Seismic response

The seismic behavior of repaired reinforced concrete members (severely cracked test specimens) was studied. The repair was made using either epoxy resin or concrete. In this paper a comparison of the performance of the original specimens with their performance after the repair is given. The repaired specimens were found to behave in a very satisfactory manner except where the injected epoxy had to restore a large region of destroyed bond between the concrete and the reinforcing steel. This condition was found to be particularly prevalent at the interior beam-column joints of moment-resisting frames. In such joints the bottom reinforcing steel of a beam tends to slip through a column due to the gradual bond degradation under cyclic loading.

76-1829
A Joint Relaxation Technique for the Receptance Solution of Structural Vibration Problems

S. Mahalingam
Dept. of Mech. Engrg., Univ. of Sri Lanka, Peradeniya, Sri Lanka, J. Sound Vib., 47 (1), pp 115-124 (July 8, 1976) 4 figs, 11 refs

Key Words: Structural elements, Vibration response, Joint relaxation technique

A well-established technique for the analysis of a complex vibrating system is to cut it into a convenient number of simpler subsystems. An alternative approach, suggested by recent studies of displacement excitation, is to convert the system into a set of independent subsystems by clamping it at a sufficient number of co-ordinates. Exact solutions for free and forced vibration are then obtained by considering the relaxation of the clamps. Published data were used for the numerical solution of framed structures by this method. This displacement approach is in some cases simpler than the standard methods and leads to smaller frequency determinants.

SYSTEMS

ABSORBER

76-1830

An Extrusion Energy Absorber Suitable for the Protection of Structures During an Earthquake

W. H. Robinson and L. R. Greenbank
Dept. of Scientific and Industrial Res., Materials Science Section, Physics and Engrg. Lab., Private Bag, Lower Hutt, New Zealand, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 251-259 (Jan-Mar 1976) 8 figs, 9 refs

Key Words: Earthquake resistant structures, Energy absorption

A structure moving under the influence of an earthquake is normally required to absorb its own energy of motion. However, in many cases it is possible to attach to the structure energy absorbing devices which absorb most of its energy of motion. One such device is an energy absorber which works by extruding lead back and forth through an orifice. On being extruded the deformed lead recrystallizes immediately, thereby recovering its original mechanical properties before the next extrusion or stroke. Accordingly, the amount of energy absorbed is not limited by work hardening or fatigue of the lead, but rather by the heat capacity of the device, the melting point of lead being the upper limit to the operating temperature. Furthermore, the device is able to absorb energy during a large number of earthquakes.

ACOUSTIC ISOLATION

76-1831

Influence of the Room Parameters on Sound Insulation According to Statistical Energy Analysis

A. von Elmallawany
Building Research Centre, Giza, Egypt, Acustica, 35 (2), pp 107-110 (May 1976) 4 figs, 9 refs
(In German)

Key Words: Acoustic insulation, Rooms, Statistical energy methods

For the calculation of the sound insulation, when using the method of statistical energy analysis, the volumes of the receiving room and the transmission room are required as well as the reverberation time of the receiving room. This article deals with the degree of influence of the room parameters upon the calculated results of the sound insulation and if these can be eliminated. A relation is deduced between the sound insulation for single walls obtained by this method and the sound insulation with respect to the mass law for a diffuse sound field. An approximate expression is obtained for the sound insulation of single walls above the critical frequency.

NOISE REDUCTION

(See Nos. 1778, 1868, 1869)

AIRCRAFT

(Also see Nos. 1803, 1852)

76-1832

Digital Generation of Random Forces for Large-Scale Experiments

M. Shinozuka, R. Vaicaitis and H. Asada
Modern Analysis, Inc., Ridgewood, NJ, J. Aircraft, 13 (6), pp 425-431 (June 1976) 15 figs, 12 refs
Sponsored by the U.S. Air Force Materials Lab.

Key Words: Aircraft wings, Spectral energy distribution, Fatigue tests, Random excitation, Digital simulation

Response cross spectral density is determined for a wing structure represented by a discrete system of masses subject to a stationary gust field. Response cross spectral density due to jack loads to be imposed for fatigue testing in a laboratory is then obtained. By employing equivalence relation between these cross spectral densities and simulation techniques of multivariate random processes, time histories of jack loads are produced. To illustrate the application of this method, two numerical examples for an idealized wing-gust interaction model are presented.

76-1833

Effect of Air Flow, Panel Curvature, and Internal Pressurization on Field-Incidence Transmission Loss

L. R. Koval
Univ. of Missouri-Rolla, Rolla, MO, 65401, J. Acoust. Soc. Amer., 59 (6), pp 1379-1385 (June 1976) 5 figs, 24 refs
Sponsored by NASA

Key Words: Aircraft, Sound transmission loss, Panels

In the context of sound transmission through aircraft fuselage panels, equations for the field-incidence transmission loss (TL) of a single-walled panel are derived that include the effects of external air flow, panel curvature, and internal fuselage pressurization. These effects are incorporated into the classical equations for the TL of single panels, and the resulting double integral for field-incidence TL is numerically evaluated for a specific set of parameters. Flow is shown to provide a modest increase in TL that is uniform with frequency up to the critical frequency.

BRIDGES

76-1834
Seismic Response of Long Multiple-Span Highway Bridges

W. S. Tseng and J. Penzien
Bechtel Power Corp., San Francisco, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 25-48 (July-Sep 1976) 22 figs, 6 refs
Sponsored by the U.S. Dept. of Transportation

Key Words: Bridges, Reinforced concrete, Seismic response

Non-linear seismic responses are described for three prototype long, multiple-span, reinforced concrete, modern highway bridge structures, namely the 5/14 South Connector Overcrossing and the curved Figueroa Street Undercrossing as designed by the California Department of Transportation, and a straight version of the Figueroa Street Undercrossing. The analytical seismic responses are discussed and are correlated with the apparent prototype behavior experienced during the San Fernando, California, earthquake of 9 February 1971. In particular, the causes of collapse of the 5/14 South Connector Overcrossing are identified and examined. Finally, based on parameter studies of the seismic responses of these structures, general conclusions and recommendations related to seismic design methodology are presented.

76-1835
Seismic Analysis of Long Multiple-Span Highway Bridges

W.S. Tseng and J. Penzien
Bechtel Power Corp., San Francisco, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 3-24 (July - Sep 1976) 19 figs, 13 refs
Sponsored by the U.S. Dept. of Transportation

Key Words: Bridges, Seismic response, Reinforced concrete, Mathematical models

Mathematical models and three-dimensional non-linear dynamic analysis procedures are described for determining the seismic response of long, curved (or straight), multiple-span, reinforced concrete highway bridges. Under the action of strong earthquakes, the columns (or piers) of such structures may experience large cyclic inelastic deformations of a coupled form. Also, cyclic slippage of the Coulomb type can take place in the expansion joints of the deck causing multiple impacts and separations to occur. These separations may be sufficiently large to cause tensile yielding of the longitudinal expansion joint restrainer bars (or cables) and, if not controlled, can permit deck spans to fall off their supports resulting in partial or total collapse of the structure. In this paper, a three-dimensional elasto-plastic mathematical model suitable for representing the coupled inelastic flexural behavior of reinforced concrete columns under cyclic deformations is presented along with a non-linear mathematical model for simulating the non-linear discontinuous behavior of expansion joints. The procedures used for non-linear seismic response analysis are described and a numerical example is given to illustrate the method.

BUILDING

(Also see Nos. 1731, 1742)

76-1836
Non-Linear Models for Simulating the Dynamic Damaging Process of Low-Rise Reinforced Concrete Buildings During Severe Earthquakes

H. Takizawa
Hokkaido Univ., Sapporo, Hokkaido, Japan, Intl. J. Earthquake Engr. Struc. Dynam., 4 (1), pp 73-94 (July-Sep 1975) 15 figs, 26 refs

Key Words: Buildings, Reinforced concrete, Earthquake damage, Mathematical models

This paper describes a study of idealizing a planar reinforced concrete frame as a non-linear dynamic system for the purpose of simulating its inelastic behavior during severe earthquakes. After having estimated the restoring force characteristics of all constituent members by experimental means (represented, for example, by a group of empirical equations), it is possible to estimate the non-linear characteristics of the complete structure and to trace the damaging process for each constituent member under a given ground motion disturbance. However, this technique, which is directly based on member-level properties, generally requires rather laborious computational procedures; for practical reasons it is necessary to develop a simplified model, reducing the required calculation without losing the substance of the mechanical phenomena. Thus the reliability of simplification by conventional shear modeling is examined in direct comparison with the response results from rigorous modeling.

76-1837

A Generalized Continuum Method for Dynamic Analysis of Asymmetric Tall Buildings

A. Danay, J. Gluck and M. Geller

Ove Arup and Partners, London, England, Intl. J. Earthquake Engr. Struc. Dynam., 4 (2), pp 179-203 (Oct-Dec 1975) 13 figs, 15 refs

Key Words: Multistory buildings, Seismic response, Blast response, Earthquake response

The paper presents a continuum method for dynamic analysis of asymmetric tall buildings with uniform cross-section in which the horizontal stiffness is provided by shear walls and columns of arbitrary shape and layout, coupled by horizontal beams.

76-1838

Response of Multi-Story Buildings Under Earthquake Excitation

T. Hsu

Ph.D. Thesis, Georgia Inst. of Technology, 1976, 181 pp

UM 76-16, 284

Key Words: Multi-story buildings, Seismic response, Earthquake response, Mathematical models

This report contains a method for the simulation of earthquake ground motion as well as a procedure for obtaining the dynamic response of multi-story shear buildings subjected to simulation earthquake excitation. The earthquake disturbance is simulated as a modulated nonstationary random process in which the stationary random process is expressed directly in terms of random functions. Then, a mathematical model is used to represent a tall building structure which includes not only viscous damping but also structural damping. The governing equations of motion of the building model are derived subsequently and then analyzed by the normal mode method. Finally, random vibration theory is employed in obtaining the dynamic response of buildings to the simulated earthquake excitation.

76-1839

Seismic Behavior of Framed Tubes

J. C. Anderson and G. Gurfinkel

Dept. of Civil Engrg., Univ. of Southern California, Los Angeles, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4 (2), pp 145-162 (Oct-Dec 1975) 23 figs, 12 refs

Key Words: Seismic design, Earthquake-resistant structures, Framed tube technique

A framed tube, consisting of closely spaced columns connected by deep spandrel beams, is designed in reinforced concrete for building code loads. The members of the frame are proportioned using strength concepts. A planar model of the tube is developed and its behavior is compared to that of the three-dimensional structure. The planar model is then used to evaluate the inelastic behavior of the framed tube when subjected to strong ground motion. The effects of the finite element discretization and the ground motion characteristics are investigated.

76-1840

Vibrations of a Nuclear Power Station Charge Hall

A. P. Jeary and A. W. Irwin

Building Research Station, England, Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 221-229 (Jan-Mar 1976) 8 figs, 11 refs

Key Words: Nuclear power plants, Buildings, Wind-induced excitation

In an effort to determine the nature and size of the response of unusually shaped power station buildings, an investigation of one power station building has been made, both theoretically and experimentally. The dynamic response of the structure to wind excitation has been monitored, analyzed and compared with theoretical values obtained from an analysis of a simplified structure. The shapes of pure modes of vibration are consistent with the predicted shapes, and correlation between measured and predicted *frequency is better than 10 per cent. Damping measure*ments from the experimental study are included where the signal/noise ratio permitted, and these were found to be in a range that is consistent with values found in other types of steel construction.

76-1841

Stochastic Considerations in Seismic Analysis of Structures

M. P. Singh and S. L. Chu

Sargent and Lundy, Chicago, IL., Intl. J. Earthquake Engr. Struc. Dynam., 4 (3), pp 295-307 (Jan-Mar 1976) 7 figs, 7 refs

Key Words: Buuldings, Spectral energy distribution, Seismic response, Stochastic processes

A method is presented for stochastic modeling of a design earthquake by a power spectral density function for seismic analysis of structures. The method can be adopted with information currently available in the form of design response spectra for earthquake motion. Accurate seismic responses of structures can be easily obtained using such stochastic models. The methods for accurate response analysis of structures with closely spaced modes and for generation of floor response spectra of a building using a prescribed ground response spectrum directly are also presented. The hypothesis that a design earthquake can be modeled by a power spectral density function is used only implicitly in developing these methods.

EARTH

76-1842
Vibration Tests and Analysis of a Model Arch Dam

J. P. Balsara and C. D. Norman
U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., Intl. J. Earthquake Engr. Struc. Dynam., 4 (2), pp 163-177 (Oct-Dec 1975) 12 figs, 8 refs
Sponsored by the Office of Chief of Engineers

Key Words: Dams, Natural frequencies, Mode shapes, Vibration tests, Finite element technique

Vibration tests were conducted on a 1/24-scale model of the North Fork Dam, a double-curvature arch dam, to determine natural frequencies, mode shapes and hydrodynamic pressures. The mode shapes and natural frequencies were determined from tests using two vibrators mounted on the crest of the dam. Hydrodynamic pressures at the dam/reservoir interface were determined from tests in which the vibrator was attached to the downstream foundation of the dam. The hydrodynamic pressures calculated using Westergaard's theory and a theory for arch dams developed by Perumalswami and Kar accurately predicted the measured pressure at frequencies below the first mode frequency of the dam. The differences in the two theories were insignificant. The Structural Analysis Program (SAP), a linear three-dimensional (3-D) finite element code, was used to compute mode shapes and frequencies for the dam with its base fixed and with a foundation. Numerical solution schemes used in the finite element analysis consisted of a Ritz analysis and a subspace iteration method. Calculations were conducted for both full and empty reservoir conditions.

76-1843
Analysis of Response of Large Embankments to Traveling Base Motions

T. Udaka
Ph.D. Thesis, Univ. of California, Berkeley, 1975, 351 pp
UM 76-15,400

Key Words: Computer programs, Dams, Finite element technique, Earthquakes, Seismic response

Most currently available procedures for seismic response analysis of earth dams assume that the motions of all points at, or at some depth below, the base of the dam are identical and in phase at all times. This is a good approximation for small dams but may not suffice for large, and thus very wide, dams. Hence, a special finite element procedure has been developed which can consider the effect of base motions which travel horizontally across the base at some specified phase velocity, thus introducing a difference in phase between motions at different points of the base. The procedure uses the complex response approach, according to which the input earthquake motions are decomposed into a finite sum of harmonic motions by the Fast Fourier Transformation. Each harmonic component is analyzed separately and the resulting harmonic responses are superimposed by the Inverse Fast Fourier Transformation.

ELECTRICAL

(See No. 1805)

HELICOPTERS

76-1844
Environmental Noise Impact of Army Helicopters

A. B. Broderson and R. G. Edwards
Environmental Div., Watkins and Assoc., Inc.
J. Environ. Sci., 19 (3), pp 9-18 (May-June 1976)

Key Words: Helicopter noise, Surveys

The environmental noise impact of off-post flights of the Army's Kiowa, Cobra, Huey, and Chinook helicopters was evaluated as part of an Environmental Impact Statement study. The study featured a community questionnaire, contact with affected agencies, and measurement of ambient sound levels throughout a 2,500 square mile area surrounding Fort Campbell, Kentucky-Tennessee. Extensive helicopter noise measurements included octave band analyses during hovering and sound level-time histories during flyovers in groups of one, two, and four helicopters at distances of 50, 500, and 2,000 feet (15, 152, and 610 m).

ISOLATION

76-1845

Feasibility Analysis and Evaluation of an Adaptive Tracked Vehicle Suspension and Control System

R.M. Salemka and R.R. Beck

National Water Lift Co., Kalamazoo, MI., Rept. No. TACOM-TR-11893, LL-146, 18 pp, (June 1975) AD-A023 984/8GA

Key Words: Tracked vehicles, Suspension systems (vehicles), Vibration isolators, Mathematical models

This study shows that adaptive control of the jounce damping characteristics of the first and last wheel of a tracked vehicle can cause a significant improvement in performance. This improvement resulted in an overall 30 percent reduction in average pitching rate of the hull, as measured on the simulation of the MICV vehicle traversing the JEA bump course. Verification testing of the computer model with actual performance data of the MICV vehicle showed good correlation of peak amplitude and hull resonance. This data also confirmed that the actual dampers are working well below recommended levels.

76-1846

Vibration Isolating Mountings for Sensitive Equipment -- New Design Criteria

J.A. Macinante

National Measurement Lab., CSIRO, Sydney, Australia, 2008, Shock and Vibration Digest, 8 (7), pp 3-24 (July 1976) 14 figs, 2 refs

Key Words: Equipment mounts, Vibration isolation

This article shows how the characteristics of the critical element influence the quality of the vibration isolation and presents a practical method of deciding suitable values for the natural frequencies of a mounting for equipment having a critical element of given characteristics and subjected to damped harmonic or steady-state vibration of a given frequency.

76-1847

Preventing Vibration Damage in Electronic Assemblies

D.S. Steinberg

Singer Kearfott Div., Wayne, NJ., Mach. Des., 31 (1), pp 74-77 (July 8, 1976)

Key Words: Electronic instrumentation, Coupled response, Vibration reduction, Equipment mounts

An electronic module and its support structure form a complex vibratory system that usually must be analyzed by time-consuming computer techniques. Two non-computer methods that give approximate but fast answers are given.

76-1848

Dynamic Vibration Absorbers of Conventional and Novel Design

M.A. Nobile

Appl. Res. Lab., Pennsylvania State Univ., University Park, PA., Rept. No. TM-75-293, 164 pp (Oct 1975) AD-A023 816/2GA

Key Words: Dynamic vibration absorption (equipment), Viscoelastic damping, Laminates, Viscous damping

The behavior of dynamic vibration absorbers of conventional and novel design has been investigated experimentally. Transmissibility and relative displacement measurements have been obtained for absorbers attached to a one-degree-of-freedom primary system, and the resultant data have been compared with the predictions of existing theories. The absorbers tested ranged from those possessing a conventional mass-spring-dashpot configuration, to those possessing novel configurations. In all cases, the experimental results were in close agreement with theoretical predictions. The novel configurations included (1) an absorber employing a viscoelastic (Butyl rubber) material as a combined spring-and-damper element, (2) absorbers employing damped *laminated beams as spring-and-damper elements*, (3) so-called "dual dynamic absorbers"--a conventional, viscously damped absorber in parallel with a less massive undamped absorber, and (4) a single nominally undamped absorber or a pair of nominally undamped absorbers attached to a heavily damped primary system.

MECHANICAL

(Also see No. 1773)

76-1849

Dunkerley-Mikhlin Estimates of Gravest Frequency of a Vibrating System

J.E. Brock

Dept. of Mech. Engrg., Naval Postgraduate School, Monterey, CA., J. Appl. Mech., Trans. ASME, 43 (2), pp 345-348 (June 1976) 6 refs

Sponsored by ONR

Key Words: Mechanical systems, Linear systems, Vibration response

Estimates are made of the smallest nonzero frequency of vibration of undamped linear mechanical systems having lumped and/or distributed mass and permitting rigid body motions. The approximations are smaller than the correct values but remarkable accuracy may be achieved. The procedures are based upon methods of S. Dunkerley and S.G. Mikhlin.

76-1850
The Nonsteady Behaviour of the Linear Oscillator with One Degree of Freedom. Part 2

G. Dittrich and J. Sommer
VDI-Z, 118 (10), pp 477-482 (May 1976) 20 figs, 7 refs
(In German)

Key Words: Oscillators, Linear systems, One-degree-of-freedom systems, Machinery

Engineers make efforts to increase the performance of machines through increases in working velocity. The solving of the tasks connected with this fact requires a mathematical treatment of nonsteady occurrences. A method is presented for the calculation of the steady and the nonsteady behavior of linear oscillators with one degree of freedom.

OFF-ROAD VEHICLES

(See No. 1845)

PUMPS, TURBINES, FANS, COMPRESSORS

(Also see Nos. 1800, 1801, 1802)

76-1851
An Investigation into the Dynamic Performance of a Variable Pitch Turbofan Using a Hybrid Computer

B.D. MacIsaac and H.I.H. Saravanamutto
National Research Council, Ottawa, Canada, ASME Paper No. 76-GT-31

Key Words: Fans, Rotor blades (turbomachinery), Computer simulation

This paper discusses the results of a study of the dynamic performance of a hypothetical variable pitch turbofan; the study was conducted via a hybrid computer simulation of the engine dynamics.

76-1852
Noise Technology Requirements for Future Aircraft Powerplants

J.D. Kester and A.A. Peracchio
Pratt & Whitney Aircraft, East Hartford, CT., ASME Paper No. 76-GT-69

Key Words: Fans, Aircraft noise, Noise reduction, Jet noise, Ducts, Noise generation

Noise technology requirements are surveyed for several future aircraft powerplants. The applications considered range from growth versions of current production engines to future advanced supersonic transport applications. Although a variety of complex and challenging noise-suppression problems are identified, a sampling of several basic problems common to a variety of engine designs are discussed in more detail. Among these are: the prediction of fan noise generation and propagation in treated ducts, the use of mixer nozzles to reduce jet exhaust noise, and the prediction and absorption of combustion noise. Discussed in the paper are analytical and experimental approaches applicable to solving these problems.

76-1853
The Determination of Sound Power Level of Fans

K. Bien and P. Kölzsch
Zentralinstitut f. Arbeitsschutz Dresden, Leitstelle f. Lärm- u. Schwingungsabwehr, Dresden, Germany, Maschinenbautechnik, 25 (1), pp 15-18, 39 (Jan 1976) 3 figs, 26 refs
(In German)

Key Words: Ducts, Fans, Sound level meters, Standards

A "Guideline for the Determination of Acoustic Power of Fans," known as the KDT-Guideline, has been developed and is explained in the article. The problems of fan noise determination are discussed. The characteristics of fan noise, as well as methods and instrumentation for its determination are discussed. Several unsolved problems are described.

76-1854
The Dynamic Transfer Function for a Cavitating Inducer

C. Brennen and A.J. Acosta
California Inst. of Technology, Pasadena, CA., J. Fluids Engr., Trans. ASME, 98 (2), pp 182-191 (June 1976) 11 figs, 32 refs

Key Words: Pumps, Cavitation

Knowledge of the dynamic performance of pumps is essential for the prediction of transient behavior and instabilities in hydraulic systems; the necessary information is in the form of a transfer function which relates the instantaneous or fluctuating pressure and mass flow rate at inlet to the same quantities in the discharge from the pump. The presence of cavitation within the pump can have a major effect on this transfer function since dynamical changes in the volume of cavitation contribute to the difference in the instantaneous inlet and discharge mass flow rates. The present paper utilizes results from free streamline cascade theory to evaluate the elements in the transfer function for a cavitating inducer and shows that the numerical results are consistent with the characteristics observed in some dynamic tests on rocket engine turbopumps.

76-1855
Calculation of Basic Resonance for Acoustic Vibration in Fast Reactors

P.G. Bentley and D. Firth
Risley Engrg. and Materials Lab., Risley, Warrington WA3 6AT, England, Computers and Struc., 6 (3), pp 187-192 (June 1976) 2 figs 10 refs

Key Words: Pumps, Nuclear reactor components, Resonant frequency, Computer programs

In liquid-metal cooled fast breeder reactors, large pumps are used to circulate the coolant. These pumps radiate acoustic energy at specific frequencies, for example, multiples of blade passing frequency. (For the Prototype Fast Reactor of the United Kingdom Atomic Energy Authority blade passing frequency is 112 Hz at full speed.) This acoustic energy can excite various structures at their resonant frequencies and may give undesirable vibrations. An understanding of resonances of simple structures in liquid systems has come from both theoretical and practical background studies in REML and in particular it has been found possible to calculate the frequencies quite accurately in cases of cylindrical symmetry.

76-1856
An Investigation of the Noise from a Scale Model of an Engine Exhaust System

W.D. Bryce and R.C.K. Stevens
National Gas Turbine Establishment, Pyestock, Farnborough, GU14 OLS, England, J. Sound Vib., 47 (1), pp 15-37 (July 8, 1976) 17 figs, 34 refs

Key Words: Aircraft noise, Engine noise, Turbines, Noise source identification

To assist in the identification and understanding of the noise sources that contribute to the exhaust noise of aircraft gas turbine engines, controlled experiments have been carried out to study the noise characteristics of a model turbo-jet exhaust system. The noise data have been related to measurements of the aerodynamic conditions in the model and, with the aid of specific diagnostic tests, the predominant noise mechanisms are considered to have been recognized. The noise radiation, above that of the jet, is attributed primarily to dipole sources generated by the turbine outlet struts, the transmission of this noise being modified by duct propagation and nozzle impedance effects.

RAIL

76-1857
The Effect of Gusts on High-Speed Trains

H. Neppert and R. Sanderson
Messerschmitt-Bolkow-Blohm GmbH Unternehmensbereich Hamburger Flugzeugbau Kreetslag 10, Postfach 95 01 09, 2103 Hamburg 95, Z. Flugwiss., 24 (3), pp 151-161 (May/June 1976) 18 figs, 12 refs (In German)

Key Words: Railroad trains, Wind-induced excitation

Peak gust speeds and gust factors have been obtained from meteorological statistics for a typical high-speed train route in the Federal Republic of Germany. Hence relationships have been determined of train speed, gust speed and yaw angle for use in conjunction with model tests in a water towing tank. The short period gust was simulated by a water jet situated at right angles to the path of the model. A model of a test vehicle having different nose sections, a middle section, and a tail section has been tested. The effects of gusts on the lift force, side force and pressures were measured in the open, during the exit from a tunnel and when two trains meet. A conversion factor is given which allows the effect of different gust speeds to be estimated.

76-1858
Criteria and Limits for Wayside Noise from Trains

D.N. May
Res. and Dev. Div., Ministry of Transportation and Communications, 1201 Wilson Ave., Downsview, Ontario, M3M 1J8, Canada, J. Sound Vib., 46 (4), pp 537-550 (June 22, 1976) 3 figs, 36 refs

Key Words: Railroad trains, Noise generation, Surveys

Existing knowledge on speech interference, community annoyance, hearing hazard and sleep disturbance is reviewed in order to suggest criteria for the wayside noise from trains, it being borne in mind that the sound is intermittent and its points of reception may be indoors or outdoors. Criteria in terms of energy equivalent sound level are suggested for speech interference, community annoyance and hearing hazard. No authoritative criterion for sleep disturbance was found. Limits recommended by other authorities are summarized, and there is a worked example assessing the impact of a new urban rail system.

76-1859
Prediction of Environmental Noise from Fast Electric Trains

D.H. Cato
Bldg. Res. Station, Garston, Watford WD2 7JR, England, J. Sound Vib., 46 (4), pp 483-500 (June 22, 1976) 15 figs, 14 refs

Key Words: Railroad trains, Noise prediction, Mathematical models

A model is presented for the environmental noise of fast electric trains on continuous welded rails, based on a consideration of the possible modes of vibration of the wheels. Evidence is presented to support the idea that the wheels are the dominant sources of noise and radiate as resonant dipoles. The model is calibrated by the results of measurements and methods of predicting train noise level and noise energy (per unit area) are developed. The noise intensity is found to increase as the fourth power of the speed. Energy (per unit area) at an observer increases as the third power of the speed and is proportional to train length divided by the distance of the observer from the track. The relevance of the model as a basis for the calculation of train noise in terms of some noise indices is then discussed and it is shown that it can be used to predict the parameters required by some indices which may be relevant to the subjective effects of environmental train noise.

REACTORS

(Also see Nos. 1732, 1855)

76-1860
Seismic SSI of Nuclear Power Plant Structures

I.M. Idriss and K. Sadigh
Woodward-Clyde Consultants, San Francisco, CA., ASCE J. Geotech. Engr. Div., 102 (GT7), paper 12246, pp 663-682 (July 1976)

Key Words: Nuclear power plants, Seismic design, Interaction: soil-structure, Finite element technique

Nuclear power plant structures are massive structures typically embedded at a considerable depth in a soil deposit. An important aspect in the seismic design of these structures is the evaluation of the dynamic interaction between the structure and the soil. This paper presents results of a study conducted to evaluate seismic SSI effects for a partially embedded massive nuclear plant structure using the finite element method of analysis. The analyses were carried out using the finite element program LUSH which incorporates the use of variable modulus and variable damping in the soil. The high frequency ranges, which must be considered in the study of SSI for nuclear power plants, are also adequately accounted for in the computer program used. Several significant parameters that could affect seismic SSI are examined. Consideration was given to parameters affecting: (1) Accuracy; (2) core storage requirements; and (3) execution time.

76-1861
Geotechnical Investigations at Nuclear Power Plant Sites

H.H. Waldron, R.P. Miller and S.D. Werner
Shannon and Wilson, Inc., Seattle, WA., Nucl. Engr. Des., 36 (3), pp 397-409 (Mar 1976) 2 figs, 14 refs
Sponsored by the U.S. Nuclear Regulatory Commission

Key Words: Nuclear power plants, Seismic design

The vibratory ground motion criteria for nuclear plant sites in the United States are based on comprehensive geologic, seismologic and site soils investigations. This paper summarizes the field, laboratory and office studies necessary to evaluate the regional geology and seismology of the region surrounding the site; results from these studies are used to define the most significant earthquakes for the site. In addition, field and laboratory investigations of site soil properties at nuclear plant sites are outlined; these investigations lead to the dynamic soil properties required for site-response analyses, and to the generalized subsurface profile for the site.

76-1862
Engineering Characteristics of Earthquake Ground Motions

S.D. Werner
Agbabian Associates, El Segundo, CA., Nucl. Engr. Des., 36 (3), pp 367-395 (Mar 1976) 22 figs, 67 refs
Sponsored by the U.S. Nuclear Regulatory Commission

Key Words: Nuclear power plants, Earthquake resistant structures, Ground motion, Seismic design

This paper describes those engineering characteristics of earthquake ground motions pertinent to the development of vibratory motion criteria at nuclear plant sites. It includes a discussion and evaluation of current techniques used to characterize earthquake events and strong motion records, and the geologic factors that influence the ground shaking at a site. In addition, the paper provides an assessment of the data base on which the engineer must draw when formulating criteria; this data base includes the current library of strong motion measurements, artificial earthquake records, empirical scaling curves derived from strong motion records, and soils and geologic data presently available at accelerograph stations.

76-1863
Seismic Test on a One-Fifth Scale HTGR Core Model

B.E. Olsen, A.J. Neylan and W. Gorholt
General Atomic Co., San Diego, CA, 92138, Nucl Engr. Des., 36 (3), pp 355-365 (Mar 1976) 15 figs, 3 refs

Key Words: Nuclear reactors, Seismic response

This paper describes a seismic test on a one-fifth scale HTGR graphite core model. The test program included: a horizontal uniaxial excitation in two orthogonal directions at accelerations up to approximately 1.5 g; sinusoidal, time history (El Centro, Taft, synthesized), excitations imposed on the model; damping and resonance tests; and variation in lateral restraint structure, soft and hard springs. The test program also included pendulum collision test of one-fifth scale and full-scale blocks, two-dimensional array tests, and instrumentation development in support of the final test. The purpose of the test was to: study collision dynamics between graphite blocks; employ data to aid in verifying model scaling laws; investigate model dynamic behavior and response characteristics; provide specific data on block relative displacement, acceleration and strain; and measure boundary support forces; provide data for correlation with analytical models; and provide preliminary design data.

76-1864
Flow-Induced Vibration of Nuclear Reactor System Components

T.M. Mulcahy and M.W. Wambsganss
Components Technology Div., Argonne National Lab., Argonne, IL., Shock and Vibration Digest, 8 (7), pp 33-40 (July 1976) 5 figs, 108 refs

Key Words: Nuclear reactor components, Flow-induced excitation, Reviews

The flow-induced vibration (FIV) potential of structures has been long-recognized. FIV problems that have been experienced in many industries include airplane and hydrofoil flutter, power line galloping, smoke stack motion produced by vortex shedding, building buffeting by turbulent wind, and heat exchanger tube resonances induced by acoustic excitation. Such problems led to the development of extensive testing and analytical methods. Most have progressed no further than the developmental stage because of the complexities of the phenomena and the difficulties inherent in new designs. In this review, emphasis is placed on illustrating the FIV potential of typical reactor configurations and on reviewing and assessing the state-of-the-art methods employed in design evaluation.

RECIPROCATING MACHINE

76-1865
Changing the Effect of a Supercharged 8-Cylinder-V-Engine on Its Foundation

W. Pietrzyk
Maschinenbautechnik, 25 (1), pp 40-43 (Jan 1976) 8 figs
(In German)

Key Words: Locomotives, Engine vibration, Vibration resonance

An unnoticed property of a supercharger 8-cylinder-V-engine, with cylinders connected by joint turbo-super-charger supply lines, is described. It was found that without any design change of the engine--only by adapting the camshaft to the proper ignition timing--the inertia forces of the second order may be substituted by moments, thus (e.g. in locomotive engines) preventing resonances in locomotive components.

ROAD

(Also see Nos. 1733, 1735, 1736, 1738, 1753, 1779)

76-1866

Extensions and Refinements of the Crash Computer Program. Part 1. Analytical Reconstruction of Highway Accidents

R.R. McHenry

Calspan Corp., Buffalo, NY., Rept. No. CALSPAN-ZQ-5708-V-2, DOT-HS-801 837, 29 pp (Feb 1976) (also see Part 2 - PB-252 115)

PB-252 114/4GA

Key Words: Collision research (automotive), Computer programs

The Calspan Reconstruction of Accident Speeds on the Highway (CRASH) computer program was modified to improve its accuracy and user convenience in the prediction of trajectories involving spins; permit the optional entry of two, four or six measurements of damage extent in the calculation of absorbed energy; improve the interpretation of damage in oblique collisions and adapt the program as a preprocessor for the Simulation Model of Automobile *Collisions (SMAC) computer program.*

76-1867

Development of Mathematical Model for Pneumatic Tire-Soil Interaction in Layered Soils

L.L. Karafiath

Res. Dept., Grumman Aerospace Corp., Bethpage, NY., Rept. No. RE-516, TACOM-TR-12109, LL-152, 122 pp (Nov 1975)

AD-A024 162/0GA

Key Words: Pneumatic tires, Interaction: wheel-tire, Mathematical models, Soils

Mathematical models of tire-soil interaction have been developed for nonhomogeneous soil conditions where the soil strength varies either continuously or discretely with depth. New methods of solving the differential equations of plasticity for soils have been developed for the bearing capacity problem in two-layer soils. Composite slip line fields obtained by these methods and the associated bearing stresses are shown for two cases: upper layer stronger than the lower layer and upper layer weaker than the lower layer. An approximate procedure, based on these composite slip line fields, is given for the estimation of bearing stresses in two-layer soils. This approximate procedure is applied in a tire-soil model expanded for the consideration of two-layer soils.

76-1868

Vehicle Noise Abatement During Development Work and in Series Production. Part 1.

K. Kurz, K. Tötös and M. Horvath

Automobiltech. Z., 78 (5), pp 221-223 (May 1976) 6 figs

(In German)

Key Words: Ground vehicles, Noise reduction

Most of the work on vehicle noise abatement is based on prototypes or on individual vehicles. The authors of this article have conducted vehicle noise abatement tests during vehicle development as well as in series production, and have been able to attain a sound level reduction of about 7 dB.

76-1869

New Experimental Methods in Body Acoustics. Measurements of Transfer Functions by Means of the Impulse Technique

H. Bathelt and D. Bosenberg

Ingolstadt, Germany, Automobiltech. Z., 78 (5), pp 211-214, 217-218 (May 1976) 12 figs, 15 refs

(In German)

Key Words: Automobiles, Noise reduction

The most effective means for investigating the acoustical characteristics of passenger car bodies is the transfer function measurement. With the advent of digital time series analysis, based on Fast Fourier Transform, an impulse method of testing linear vibration systems became available. An application of this method to the generation of low frequency noise by body shell vibrations is described.

ROTORS

76-1870

Vibration of Large Turbo-Rotors in Fluid-Film Bearings on an Elastic Foundation

R. Gasch

Institut fur Luft-und Raumfahrt, Technische Universität Berlin, 1 Berlin 10, Germany, J. Sound Vib., 47 (1), pp 53-73 (July 8, 1976) 17 figs, 34 refs

Key Words: Rotors, Turbomachinery, Finite element technique, Fluid-film bearings, Elastic foundations

In the first sections of this paper the flexible rotating shaft of a turbo-rotor is treated by finite element analysis. Internal and external damping, gyroscopic forces, fluid-film forces, aerodynamic cross-coupling from steam flow and magnetic pull are taken into account. Although some hundred degrees of freedom have to be introduced to describe a realistic turbo-rotor, computational effort can be enormously reduced by making use of the banded structure of the system matrices. In the second part foundation dynamics are introduced into the rotor equations via a receptance formulation. The receptance matrices of the foundation or supporting systems can be obtained either from shaker tests or from the mode analysis of the foundation without shaft. Numerical examples are given.

SHIP

76-1871

Hydrodynamic Pressure Field on a Slender Ship Moving Over a High-Frequency Wavy Shallow Bottom

A. Plotkin
Dept. of Aerospace Engrg., Univ. of Maryland, College Park, MD., J. Appl Mech., Trans. ASME, 43 (2), pp 232-236 (June 1976) 3 figs, 11 refs

Key Words: Ships, Hydrodynamic excitation, Water waves, Perturbation techniques

The hydrodynamic pressure field for the unsteady subcritical potential flow of a slender ship moving over a wavy wall in shallow water is analyzed using perturbation techniques. For the case of wall wavelength much smaller than the ship length but larger than the transverse ship dimensions, a combination of the methods of matched asymptotic expansions and multiple scales is used to obtain the lowest-order effect of the bottom variation.

SPACECRAFT

(See No. 1799)

STRUCTURAL

(See No. 1781)

TURBOMACHINERY

(See No. 1870)

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CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1976 DEC		
Winter Annual Meeting, ASME	5-10	New York, NY	ASME Hq.
	1977 FEB		
Automotive Engineering Congress and Exposition (SAE Annual Meeting), SAE	28-4	Detroit, MI	SAE Hq.
Symposium on Biodynamic Models and Their Applications, CHABA of NAS-NRC	15-17	Dayton, OH	G. Thomas Collins, Univ. of Dayton Dayton, OH 45469
	MAR		
Gas Turbine Conference and Products Show, ASME	27-31	Philadelphia, PA	ASME Hq.
Joint Railroad Conference, IEEE/ASME	30-2	Washington, D.C.	IEEE Hq.
	APR		
American Power Conference, Ill. Inst. Tech.	18-20	Chicago, IL	R.A. Budenholzer, Dir. APC c/o IIT, 10 W 35th St. Chicago, IL 60616
Design Engineering Conference and Show, ASME	18-21	New York, NY	ASME Hq.
Mini-Conference on Transportation	19-21	Ann Arbor, MI	Highway Safety Research Institute *The University of Michigan* Ann Arbor, MI 48109 Tele. (313) 764-2168
Diesel and Gas Engine Power Conference and Exhibit, ASME	24-28	Dallas, TX	ASME Hq.
IES Annual Meeting	24-27	Los Angeles, CA	IES Hq.
International Conference - Tribology	April	Cambridge, MA	Lt. R.S. Miller, Code 211 Office of Naval Research Ballston Tower No. 1 Arlington, VA 22117 Tele. 692-4421
	MAY		
31st Annual Technical Conference, ASQC	16-18	Philadelphia, PA	R.W. Shearman, ASQC Hq.
93rd Meeting of the Acoustical Society of America	17-20	State College, PA	J. C. Johnson, Chairman, ASA
Structures, Structural Dynamics and Materials Conference, AIAA	May		AIAA Hq.

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1977 JUNE		
Fuels and Lubricants Meeting, SAE	7-9	Tulsa, OK	SAE Hq.
Applied Mechanics Conference, ASME	14-16	New Haven, CT	ASME Hq.
Lubrication Symposium, ASME	June	St. Louis, MO	ASME Hq.
	SEPT		
Vibrations Conference, ASME	26-28	Chicago, IL	ASME Hq.

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, N.J. 07645

AGMA: American Gear Manufacturers Association
1330 Mass. Ave., N.W.
Washington, D.C.

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, N.Y. 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, N.Y. 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, Ill. 60605

AHS: American Helicopter Society
30 E. 42nd St.
New York, N.Y. 10017

ARPA: Advanced Research Projects Agency

ASA: Acoustical Society of America
335 E. 45th St.
New York, N.Y. 10017

ASCE: American Society of Civil Engineers
345 E. 45th St.
New York, N.Y. 10017

ASME: American Society of Mechanical Engineers
345 E. 47th St.
New York, N.Y. 10017

ASNT: American Society for Nondestructive Testing
914 Chicago, Ave.
Evanston, Ill. 60202

ASQC: American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, Wis. 53203

ASTM: American Society for Testing and Materials
1916 Race St.
Philadelphia, Pa. 19103

CCCCAM: Chairman, c/o Dept. ME, Univ. Toronto, Toronto 5, Ontario, Canada

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, N.Y. 10017

IES: Institute Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, Ill. 60056

IFToMM: International Federation for Theory of Machines and Mechanisms, US Council for TMM, c/o Univ. Mass., Dept. ME, Amherst, Mass. 01002

INCE: Institute of Noise Control Engineering
P. O. Box 3206, Arlington Branch,
Poughkeepsie, N.Y. 12603

ISA: Instrument Society of America
400 Stanwix St., Pittsburgh, Pa. 15222

ONR: Office of Naval Research
Code 40084, Dept. Navy, Arlington, Va.22217

SAE: Society of Automotive Engineers
400 Commonwealth Drive,
Warrendale, Pa. 15096

SEE: Society of Environmental Engineers
6 Conduit St.
London W1R 9TG, England

SESA: Society for Experimental Stress Analysis
21 Bridge Sq.
Westport, Conn. 06880

SNAME: Society of Naval Architects and Marine Engineers, 74 Trinity Pl.
New York, N.Y. 10006

SVIC: Shock and Vibration Information Center
Naval Research Lab., Code 8404
Washington, D.C. 20375

URSI-USNC: International Union of Radio Science-US National Committee c/o MIT Lincoln Lab., Lexington, Mass. 02173

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