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DYNAMIC ANALYSIS TO ESTABLISH NORMAL SHOCK AND VIBRATION ENVIRONMENTS EXPERIENCED BY RADIOACTIVE MATERIAL SHIPPING PACKAGES

**QUARTERLY PROGRESS REPORT
JANUARY 1, 1978 - MARCH 31, 1978**

Hanford Engineering Development Laboratory

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July 1978

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DYNAMIC ANALYSIS TO ESTABLISH NORMAL SHOCK AND VIBRATION ENVIRONMENTS EXPERIENCED BY RADIOACTIVE MATERIAL SHIPPING PACKAGES

**Quarterly Progress Report
January 1, 1978 - March 31, 1978**

S. R. Fields and S. J. Mech

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**Division of Safeguards, Fuel Cycle and Environmental Research
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Dynamic Analysis to Establish Normal
Shock and Vibration Environments Experienced
by Radioactive Material Shipping Packages
Quarterly Progress Report
January 1 - March 31, 1978

S. R. Fields
S. J. Mech

ABSTRACT

This report presents work performed at the Hanford Engineering Development Laboratory operated by Westinghouse Hanford Company, a subsidiary of Westinghouse Electric Corporation, for the Nuclear Regulatory Commission, under Contract No. EY-76-C-14-2170. It describes technical progress made during the reporting period by Westinghouse Hanford Company and supporting contractors.

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INTRODUCTION

The objective of this study, initiated in October 1977, is to determine the extent to which the shocks and vibrations experienced by radioactive material shipping packages during normal transport conditions are influenced by, or are sensitive to, various structural parameters of the transport system (i.e. package, package supports, and vehicle). This will enable us to identify those parameters which significantly affect the normal shock and vibration environments in order to provide the basis for determining the forces transmitted to radioactive material packages. Determination of these forces will provide the input data necessary for a broad range of package-tiedown structural assessments.

This is the second quarterly report on this work. The first quarterly report, issued as NUREG/CR-0071, and HEDL-TME 78-19 presented a work plan consisting of seven tasks. Progress on these tasks during this reporting period will now be discussed.

PROGRESS TO DATE

The work plan for this study, presented as Figure 1, shows the various tasks and their relationships to one another. The following paragraphs contain a report of progress on each of these tasks during this reporting period.

1. Develop Dynamic Model

The rail car coupler and draft gear subsystem affects the response of the cask-rail car system more than any other component because the shock of impact is attenuated and transmitted to the cask-rail car system through this device. The rail car suspension subsystem is also important since it controls the vertical and rotational movement of the car during and after impact. Expanded simulations of these subsystems are now in progress.

The Burlington-Northern rail yards in Pasco, Washington, one of the largest computerized classification yards in the nation, was visited to obtain detailed information on rail car construction. A tour of the repair facilities where rail cars are dismantled, repaired, and maintained provided needed information on the construction of couplers, draft gear, and suspension subsystems. Based on this information, these subsystems have been modeled as the spring and damper arrangements shown in Figure 2.

The damper on the coupler and draft gear subsystem is a viscous damper while that on the suspension subsystem is a dry, sliding or friction damper. In both subsystems, the springs and dampers are in series. An energy balance was written for each subsystem to arrive at the proper mathematical formulations to be used in the cask-rail car model. These formulations have been verified by an alternate method. The coupler and suspension submodels will become part of the cask-rail car model as soon as logic is completed to handle the cyclic energy dissipation and displacements, and bottoming out of both springs and dampers when full travel is reached.

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FIGURE 1: Work Plan -- Dynamic Analysis of Radioactive Material Shipping Packages.

HEDL 7804-174.2

FIGURE 2: Arrangement of Springs and Dampers Simulating Rail Car Coupler and Suspension Subsystems.

During the visit to the Burlington-Northern classification yard, several different types of rail cars damaged during coupling operations were examined. These cars suffered extensive structural damage, and some appeared to be beyond repair. The cars examined were box cars and dry cargo tank hopper cars. No flat bulkhead cars were observed among the damaged cars.

The simulated model of the cask-rail car system has been expanded to include bending of the rail car. However, although the spring arrangement to represent bending has been developed and incorporated into the model, further work is required before it can become a functioning part of the model. At present, the bending submodel is isolated from the rest of the model by the use of switching functions. The bending submodel will remain isolated until the submodels of the coupler and suspension subsystems are completed and included in the model.

The system of equations which define the present rail car model is based on the rotation (front to back pitching) of a rigid, non-bending rail car. The displacement at all support points on the rail car (cask to rail car and rail car to trucks) are functions of the vertical displacement of the center of mass of the rail car, angle of rotation, and a constant (non-bending) distance from the center of mass to the support points. When bending of the rail car occurs, the center of mass and, therefore, the vertical displacement, is no longer located on a straight line and can no longer be related to the support points simply as a function of the distance and angle of rotation. If the increment of displacement due to bending is small, the present bending submodel may be used with little error. If the effect of bending is large, modifications will be made to assure that the displacements of the support points are correctly represented.

The proper spring arrangement to represent bending of the rail car was established by considering the rail car as a beam, and defining a stiffness coefficient k_{ij} to be a force applied at point j to produce a deflection

equal to unity in the direction of the force, while point i is restrained against translation (zero deflection at i). The coefficients k_{ij} represent a force system that is capable of translating point j a unit amount while preventing the translation of point i . For example, in Figure 3, application of the force k_{11} at position 1 to give a deflection $y_1=1$, while preventing translation or deflections at the other load positions, causes the reactions k_{R1} , k_{31} , k_{21} , and k_{F1} at the rear support R , positions 3 and 2, and the front support F , respectively. Similar application of the forces k_{33} and k_{22} yields the reactions shown. Because of Maxwell's reciprocal law

$$\begin{aligned} & k_{12} = k_{21} \\ \text{and} \quad & k_{23} = k_{32}. \end{aligned}$$

Relating the mass or load positions to the reactions, the bending submodel of the beam (rail car) may be represented as shown in Figure 4(a). If the front and rear supports are mounted on springs (suspension system), the bending submodel is represented by the spring-mass arrangement of Figure 4(b).

The stiffness coefficients or spring constants, k_{ij} , for the bending submodel are obtained from a determination of flexibility influence coefficients. The influence coefficients are determined, as shown in Figure 5, by placing a unit load at one load position at a time (positions 1, 2 and 3 in Figure 5), and making use of the area-moment method to determine the deflections D_{ij} . These deflections are superimposed and then combined with the actual loads (F_i) at the positions to obtain the total deflections

$$y_1 = F_1 D_{11} + F_2 D_{12} + F_3 D_{13}$$

$$y_2 = F_1 D_{21} + F_2 D_{22} + F_3 D_{23}$$

$$\text{and} \quad y_3 = F_1 D_{31} + F_2 D_{32} + F_3 D_{33}.$$

FIGURE 3: Deflection Diagrams for Rail Car Beam with Restraints to Define Force-Reaction System.

(a) Rail Car as Beam on Rigid Supports

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(b) Rail Car as Beam Supported by Springs

FIGURE 4: Spring-Mass Submodel Representing Bending of Rail Car.

FIGURE 5: Deflection Diagrams for Rail Car Beam to Determine Deflections and Influence Coefficients

HEDL 7804-174.3

When this system of equations is solved for the loads, three equations of motion are obtained. The coefficients of y_1 , y_2 and y_3 in these equations of motion are combinations of the D_{ij} , and can be shown to be equal to the appropriate k_{ij} . Equations for the D_{ij} and the k_{ij} , in terms of the locations of the support points and other rail car parameters, have been programmed into the model.

The springs representing bending have been incorporated into the cask-rail car model, as shown in Figure 6. However, as stated earlier, this bending submodel will not be activated until the rail car coupler and suspension submodels have been completed and become part of the model.

2. Data Collection and Reduction

Shock and vibration data gathered from the proposed rail tiedown tests will be reduced and analyzed to validate the dynamic model of the cask-rail car system. To accomplish this objective, transducers sensitive to force, displacement, and acceleration will be mounted on the shipping container, tiedowns, and rail car in positions which correspond to those in the analytical model. Following data reduction, the empirical data, together with the corresponding analytical data, will be analyzed such that the model can be modified and verified. A simplified flow diagram of the procedure from data collection through model verification is shown in Figure 7.

The tentative locations, types, and ranges of selected transducers have been based on preliminary analytical results. Since the dynamic model described in the previous section simulates the longitudinal, vertical and rotational motion of the cask-rail car system, four additional data locations will be required. These locations, on each set of trucks and on the car bed immediately above those trucks, are expected to produce accelerations in the ranges of $\pm 120g$ and $\pm 150g$, respectively, within a frequency band of 3 to 1100 hertz. These requirements fit within the scope of previously planned instrumentation support.

FIGURE 6: Dynamic Model of Cask-Rail Car System with Bending Submodel.

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FIGURE 7: Shock/Vibration Data Flow for Data Reduction Model Verification.

The current test plan states that 26 data channels plus a voice channel and timing channel with a FM-multiplexed into 2 channels of information on the test vehicle. The 2 channels will be transmitted via a radio frequency link to a Sandia-supplied ground station, where it will be recorded on both magnetic tape and oscillograph.

Oscillographic data will give on-line quick-look data for test data verification. The magnetic tape recordings, because they represent the only reproducible form of all the test data, will be reproduced under laboratory conditions at Sandia following the tests. Once copies of the original data tapes are made, they will be demodulated to their original analog form and remodulated and recorded in a wide band FM format compatible with equipment at the Hanford Engineering Development Laboratory (HEDL). Following this re-recording, the tapes containing all of the experimental data and timing information will be sent to HEDL for data reduction and analysis.

Data reduction will consist of reducing all data channels, with the aid of the appropriate calibration information and timing tracks, to a set of time-amplitude digital records of the experimental data. This step will be performed on an existing Time-Data system, producing digital records compatible with Digital Equipment Corporation PDP-11 series computers.

Digital data may now flow between the Time-Data system and the existing PDP-11/34 for various forms of data analysis; and between the PDP-11/34 and Boeing Computer Service's (BCS) Cyber 74 and Univac 1140/44 for model verification.

Initial data reduction will consist of conventional normalization of data amplitude with respect to calibration information. Digital and analog recordings of the time domain record will be prepared for comparison with the original on-line oscillographic recordings. Simultaneously, the power spectra of each information channel will be generated.

Data analysis and model verification will, where practical, employ existing software. Software systems available include:

Time-Data: TSL (Time Series Language) - Time-Data proprietary analysis software system.

PDP-11/34: SPS-Basic (Scientific Programming System) - A Tektronix operating system with graphical, as well as analysis, capabilities.

SPARTA: A DEC RT-11 buffer oriented interactive system.

SSP: (Scientific Subroutine Package) DEC RT-11 Fortran subroutines.

RT-11: DEC operating system; digital information transfer to BCS.

RSX-11M: DEC operating system; multi-user operating system for special verification and analysis software.

These software systems, together with the communications link to the analytical model at BCS, will enable model validation.

3. Validate Model

Model validation is not a trivial problem, hence only an outline of possible approaches can be hypothesized at this point.

Assuming that the frequency components of the analytical data and the test data are not identical, the time-domain pictures will not appear similar. An initial analysis step would be to convert both data sets to their frequency domain representation by Fast Fourier Transform (FFT)⁽¹⁾. The results of an FFT operation is a complex number representing magnitude and phase as a function of frequency. (The vector length squared as a function of frequency is more commonly known as the power spectrum obtained from a wave analyzer.)

At this point, it may be possible to determine the similarity and differences of data by simple transfer function calculation. For a linear, time-invariant system:

$$\bar{H}(f) = \frac{\bar{Y}(f)}{\bar{X}(f)} = \text{transfer function}$$

where: $X(f)$ = complex frequency domain input function

$Y(f)$ = complex frequency domain output function

The transfer function obviously is dependent on the input and output spectra being over the same range; hence, windowing or filtering may be necessary. It is conceivable that a matrix of transfer function, appropriately windowed, will permit the data to verify the model in a piece-wise linear fashion. At the minimum, it should give insight into the nature of the required model modification.

Other analysis techniques presently available in software which may assist in this verification effort are:

G_{AB} = cross spectra
Indicates the frequencies where both A and B have content and the difference between their phase angles.

$R_{AB}(\tau)$ = cross correlation
Indicates the magnitude of similarity between two time domain signals as a function of τ , time delay.

It is important to realize that many tools of analysis exist, but the data itself will direct what tools are employed and in what manner.

4. Collect Parameter Data

Sources of parameter data in the literature, in turn, usually refer to publications of the Association of American Railroads (AAR) as the source of their information. Several individuals in the AAR have been contacted to obtain information on rail car suspension subsystem and coupler subsystem components. At present, information is being sought on friction dampers

in the suspension subsystem and viscous dampers in the coupler subsystem; however, additional information on side springs in the suspension subsystem spring group has been requested. To obtain the large amount of parameter data needed as soon as possible, AAR specifications will be requested or purchased which contain a broad spectrum of pertinent information on flat bulkhead cars or other types of cars for hauling heavy radioactive material packages.

5. Parametric and Sensitivity Analysis

This task is not scheduled to begin until December 1, 1978 (see Figure 1).

6. Interim Report

This report is not scheduled for preparation until August 1, 1978 (see Figure 1).

7. Final Report

This report is not schedule for preparation until August 1, 1979 (see Figure 1).

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- (1) R. W. Ramirez, "The FFT: Fundamentals and Concepts," Tektronix, Inc., P. O. Box 500, Beaverton, Oregon, 1975.

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