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SAVIT - A DYNAMIC MODEL TO
PREDICT VIBRATORY MOTION
WITHIN A SPENT FUEL SHIPPING
CASK - RAIL CAR SYSTEM

MASTER

Hanford Engineering Development Laboratory

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S.R.Fields

March 1978

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CASK-RAIL CAR SYSTEM

S. R. Fields

ABSTRACT

A dynamic model of a spent fuel shipping cask-rail car system has been developed to estimate the vibrational response of the coupled components of the system, especially the spent fuel assemblies, to a time-varying track roughness.

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I would like to acknowledge the assistance of E. C. Strozyk who modified the programming sequence to produce the plots shown in Figures 1 through 3.

S. R. Fields

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I. SUMMARY

A dynamic model of a spent fuel shipping cask-rail car system has been developed to provide estimates of the vibratory motion of LWR spent fuel assemblies during transport and to estimate the effects of this motion on the condition of the assemblies when they arrive at receiving and storage facilities. Results of preliminary test computations are presented to illustrate the capabilities of the model.

II. INTRODUCTION

In late FY-1976, the Hanford Engineering Development Laboratory initiated a program to help define design criteria for spent fuel assembly receipt and handling systems in LWR fuel reprocessing plants. This program had four objectives:

- (1) To develop a spent fuel storage and logistics model,
- (2) to develop models of spent fuel assembly response to loadings experienced during transportation and handling,
- (3) to establish the mechanical and structural properties of zirconium alloy clad LWR fuel assemblies upon discharge from the reactor, and
- (4) to project mechanical property degradation during long term storage.

This report documents the work accomplished in partial realization of the second of these objectives.

A preliminary dynamic model of a spent fuel shipping cask-rail car system, SAVIT, has been developed to determine the vibratory motion of LWR spent fuel assemblies during transport to receiving and storage (or interim storage). This model was developed to provide a tool for estimating the extent of damage to the fuel assemblies, due to this vibratory motion, which may be expected when they arrive at receiving and storage.

III. RESULTS

The primary objective of this report is to document the development of SAVIT rather than to report calculated results, however, the results of preliminary trial computations to test the model are presented to demonstrate the capabilities of the model. These results must not be looked upon as representing the behavior of any actual cask-rail car system because the computations were based on arbitrary and crude assumptions of system properties, system configuration and track roughness. The study was terminated before these assumed properties and conditions could be replaced with more realistic assumptions or actual data.

The results of the trial or test computations are presented in Figures 1, 2 and 3. These figures show the displacement of the fuel elements, cask and rail car following a brief 1-inch displacement of the rail car trucks. The results show that a maximum fuel element displacement of about 0.7 inch may be expected when this severe pulse is experienced by a system with the assumed properties.

FIGURE 1. Displacement of Fuel Element in Spent Fuel Shipping Cask ($\kappa_D = 1000$).

FIGURE 2. Displacement of Rail Car Carrying Loaded Spent Fuel Shipping Cask ($\kappa_D = 1000$).

FIGURE 3. Displacement of Spent Fuel Shipping Cask on Rail Car ($\kappa_D = 1000$).

IV. ANALYTICAL APPROACH

SAVIT is a spring-mass-dashpot model of the one-dimensional cask-rail car system shown in Figure 4. Figure 5 depicts a system capable of motion in both the vertical and horizontal (front-to-back) planes, but, as a first approximation, motion was limited to the vertical, with the intention of expanding the model later to simulate the system with motion in both the vertical and horizontal planes. SAVIT consists of the following set of coupled equations of motion, one equation for each mass of the spring-mass-dashpot model of Figure 4.

Fuel Assemblies

$$\frac{W_F}{g} \frac{d^2 y_F}{dt^2} = k_{FC} (y_C - y_F) \quad (11)$$

Cask, Basket and Coolant

$$\frac{W_C}{g} \frac{d^2 y_C}{dt^2} = k_{FC} (y_F - y_C) + k_{CRC} (y_{RC} - y_C) \quad (12)$$

Rail Car

$$\frac{W_{RC}}{g} \frac{d^2 y_{RC}}{dt^2} = k_{CRC} (y_C - y_{RC}) + k_{RCT} (y_T - y_{RC}) + k_D \left(\frac{dy_T}{dt} - \frac{dy_{RC}}{dt} \right) \quad (13)$$

Rail Car Trucks (Suspension)

$$\frac{d^2 y_T}{dt^2} = \frac{d}{dt} \left[\frac{d}{dt} (y_T) \right] \quad (14)$$

$$y_T = y_T(t) \quad (15)$$

where

g = the acceleration of gravity, inches/sec².

k_{CRC} = the elastic or spring constant of the cask supports,
lbs_F/inch.

k_D = the damping coefficient of a shock absorber on the truck
suspension, lbs_F - sec/inch.

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FIGURE 4. One-Dimensional Dynamic Model of Spent Fuel Shipping Cask - Rail Car System (Vertical Motion Only).

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FIGURE 5. Two-Dimensional Dynamic Model of Spent Fuel Shipping Cask - Rail Car System

k_{FC} = the elastic or spring constant of the fuel assemblies assumed to be a beam with ends supported rigidly by the basket, lbs_F/inch.

k_{RCT} = the elastic or spring constant of the springs on the truck suspension, lbs_F/inch.

t = the time, seconds.

W_C = the combined weight of the cask, basket and coolant, lbs_F.

W_F = the weight of the fuel assemblies, lbs_F.

W_{RC} = the weight of the rail car bed, lbs_F.

W_T = the weight of the trucks, lbs_F.

y_C = the displacement of the combined cask, basket and coolant, inches.

y_F = the displacement of the fuel assemblies assumed to be a beam with the total weight concentrated at the center of the span, inches.

y_{RC} = the displacement of the rail car bed, inches.

y_T = the displacement of the rail car trucks, inches.

This system of equations, along with a few auxiliary equations, has been programmed on the MIMIC continuous system simulation program⁽¹⁾ and the differential equations integrated to obtain the displacements as a function of time.

V. ASSUMPTIONS

As stated earlier, this study was terminated before anything more than preliminary trial computations to test the model could be made; and that these initial computations were based on arbitrary and crude assumptions of track roughness, system properties and system configuration.

The stimulus that sets up vibratory motion within the system of Figure 4 is the displacement, y_T , of the rail car trucks. This displacement is expressed as a function of time in Equation (15) of the preceding section. y_T may be any function of time and would probably be some random function, however, to test the model, y_T was assumed to be a function representing the response of the trucks to a rather severe pulsed discontinuity in the road bed. It was assumed that

$$\begin{aligned} y_T &= 0. && \text{when} && 0 < t < 0.0011 \text{ seconds} \\ y_T &= 1.0 \text{ inch} && \text{when} && 0.0011 < t \leq 0.002 \\ y_T &= 0. && \text{when} && 0.002 < t. \end{aligned}$$

A damping coefficient, k_D , of $1000 \frac{\text{lbs}_F - \text{sec}}{\text{inch}}$ was assumed for the truck suspension for these computations. Also, it was convenient to arbitrarily assume that the spring constant for the truck suspension, k_{RCT} , could be represented by the expression

$$k_{RCT} = \frac{k_{CRC}}{1000} \quad (16)$$

where

$$k_{CRC} = \text{the spring constant of the cask tiedowns, } \frac{F}{L} .$$

A considerable amount of data on rail car suspension systems was obtained from a rail car manufacturer, but these data were not reduced to equivalent damping coefficients and spring constants in time to replace those assumed.

It was assumed that the cask was tied down to the rail car by four 1-inch diameter rods or cables, each 5 feet in length. The spring constant for these four rods acting together, k_{CRC} , was obtained from Equation (17),

$$k_{CRC} = \frac{EA}{L} \quad (17)$$

where

A = the cross-sectional area of the rods, L^2

L = the length of the rods, L

E = the modulus of elasticity of the rods, $\frac{F}{L^2}$.

The fuel assembly was assumed to act as a simply supported beam, with its mass concentrated at the center of the span. A spring constant of 2000 $lb_f/inch$ was arbitrarily assumed for this beam. Later, when compared to some calculated values reported in Reference (2) for a coupled tubular assembly, it was found that this spring constant fell about half way between the value reported for an assembly with infinite coupling and the value reported for the same assembly with finite coupling (in this case, 20% of infinite coupling).

VI. CONCLUSIONS

The dynamic model, SAVIT, will provide estimates of the vibratory motion of LWR spent fuel assemblies in the vertical direction due to the response of the cask-rail car system to the vertical displacement of the rail car trucks.

Simulation of the response of an actual system will require the assembling of proper data on system configuration, system properties and track roughness for input to the model. The results presented do not represent the behavior of any real system. They were obtained from preliminary test computations based on arbitrarily assumed input data. However, these results serve to illustrate the capabilities of the model.

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