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Seismic Requalification of a Safety Class Crane*

by

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ABSTRACT

A remotely operated 5-ton crane within a nuclear fuel handling facility was designed and constructed over 25 years ago. At that time, less severe design criteria, particularly on seismic loadings, were in use. This crane is being reactivated and requalified under new design criteria with loads including a site specific design basis earthquake. Detailed analyses of the crane show that the maximum stress coefficient is less than 90% of the code allowable, indicating that this existing crane is able to withstand loadings including those from the design basis earthquake.

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I. INTRODUCTION

A nuclear fuel handling facility show in Fig. 1 has two types of remotely operated material handling equipment: a linear bridge crane and two electro-mechanical manipulators (EMMs). In this paper, analytical investigation on requalifying the crane including loadings from site specific design basis earthquake (DBE) is presented.

The linear bridge crane has capacity of 5-ton. It was designed and constructed over 25 years ago. The crane bridge, which is oriented in NS direction, consists of two 12-WF-50 beams of length approximately 18 ft. and two 30 lb. ASCE rails. The bridge has four flanged wheels. Depth of the flange is 1/2 in.

The trolley carries a cable-operated block hoist. It travels on the bridge with four flanged wheels. Flange depth of these wheels is 3/8 in. At the bottom of the trolley, there is a cross bar of depth 4.5 in. This cross bar is used to guide the trolley on to the bridge. Clearance between the cross bar and the bridge is 1/4 in.

The crane being investigated differs from others that it has a very heavy trolley. To protect components within the trolley from radiation, the trolley is heavily lined with cast lead. Total weight of the trolley is over 9,000 lbs., which is more than three times heavier than the bridge. During earthquakes, this heavy trolley will introduce significant loadings in the minor or weak direction of the bridge beams, resulting high bending stresses.

At the time the crane was designed and constructed, the design criteria were not as severe as they are today. Other than gravity, there is no positive restraint to hold the crane and its trolley against their vertical movements. When this safety class crane is subjecting to loadings, including those from DBE, there are concerns on (1) stress adequacy of overall structural design, (2) potential jump-off of the crane or its trolley from their respective tracks, and (3) load reliability of the hoist cable. Results presented in this paper are mostly related to item (1).

In this requalification by analytical investigation, it has been specified that the DBE is equivalent to a safe shutdown earthquake, and the operating basis earthquake loads could be taken to be zero. The code to be satisfied is ANSI/AISC N690 {1}. With the crane installed within the enclosed facility, which has very small temperature fluctuations, the load combinations to be investigated are the normal and the extreme conditions of {1}.

Various finite element models have been constructed to simulate the crane with its trolley at different locations on the bridge, lifting a different amount of loads. Both response spectrum method and time-history analysis have been used in investigating seismic responses of the crane. Forces and moments obtained from the seismic responses are combined with those from dead and live loads, and the stress coefficients are evaluated following the guideline of {1}. Results show that stress coefficients of this safety class crane are within the allowables of [1], even without using higher seismic capacity permitted by [2] for existing equipment.

II. ANALYSIS MODELS AND SEISMIC LOADS

Seismic analysis of this safety class crane has been performed using finite element models consisting of three-dimensional beam and mass elements. Since the weight of the trolley and the lifting capacity are both significantly higher than the weight of the bridge, dynamic behavior of the crane depends not only on the location of the trolley but also on the amount the crane is lifting. Finite element models have been constructed with the trolley near an extreme end position on the bridge span (configuration 1); close to the 1/4 point of the span positions (configuration 2); and at midspan (configuration 3). For each configuration or trolley location, three lifting conditions were considered: zero, 50%, and 100% of the capacity of 10,000 lbs. Fig. 2 shows a typical model used in this investigation. Boundary and restraint conditions of the models follow the guidance provided in {3}.

Linear behavior of the system is generally assumed in the analysis. Influences which would introduce nonlinear behavior, such as gaps at supports, wheel uplifts, friction, and the shifting of trolley location during earthquake have not been included in this investigation.

Both response spectrum analysis and the direct solution method of linear transient analysis of the ANSYS computer program have been used in this investigation. In the response spectrum method, two horizontal and one vertical floor design response spectra at the crane level shown in Figs. 3-5 are the inputs. Both the NS and EW spectra have high amplification within the frequency range of 8 to 14 Hz, and 20 to 30 Hz for the vertical spectrum. Maximum spectral accelerations are 2.5, 2.1, and .84g, respectively. Damping for these spectra is 5% of the critical damping.

Input motions for the time-history analysis are the three orthogonal displacement time-histories shown in Figs. 6-8. The finite element model used in the time-history analysis is obtained by modifying the corresponding finite element model used in response spectrum analysis. A damping of 5% has been incorporated in the model for time-history analysis.

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III. ANALYTICAL RESULTS

The response spectrum method, which is simple yet generally conservative, is applied to all nine cases; three configurations simulating the trolley at different locations on the bridge, and three different liftings for each configuration. Natural frequencies of these cases are found to vary from case to case. Listed in Table 1 are the fundamental frequency for each case. These fundamental frequencies, which are between 6.9 Hz and 18.5 Hz, are within the high amplification range of the floor design response spectra in Figs. 3-5.

For each floor design response spectrum input of the DBE, forces and moments of individual significant modes are combined using the square root of the sum of the squares (SRSS) method, or the ten percent method for closely spaced modes. Responses caused by each of the three orthogonal floor design response spectra are combined using the SRSS method.

Other major loadings for this safety class crane, which is within the enclosed fuel handling facility with small temperature fluctuations, are the dead and live loads. The combined load conditions that have to be considered are the normal and the extreme conditions {1}. Stress coefficients for these two conditions are evaluated following the guidelines in {1}, and are summarized in Table 2. Among these coefficients, only two of them exceeding the allowable. Both of these two coefficients occur when the crane is subjecting to seismic loadings from DBE and the trolley is at configuration 3 position or at midspan of the bridge, with lifting either 50% or 100% of the capacity.

Stress coefficients for the extreme condition in Table 2 include contributions from seismic responses. These responses are obtained using the conservative response spectrum method. To assess the seismic responses of the crane more accurately, the linear time-history method is next applied to the 5-ton crane for the case when its trolley is at configuration 3 position and has full capacity lifting. That is, the case that response spectrum analysis results yield the highest stress coefficient in Table 2.

When the responses from the linear time-history analysis are combined with the dead and live load responses, the stress coefficient of 2.31 in Table 2 reduces to 1.41, which is within the allowable of {1}. In fact, this new stress coefficient is less than 90% of the allowable. This stress coefficient could further be reduced should the higher seismic capacity allowed by {3} for existing equipment is use in the evaluation.

The potential of either the crane or its trolley jumping off from their respective rails has been investigated using the energy approach. Maximum uplifts of the crane and the trolley are .05 and .74 in , respectively. The crane's maximum uplift of .05 in is much less than the depth of the wheel flange, no jump-off of the crane is expected to occur during DBE. The 0.74 in maximum uplift of the trolley during DBE exceeds the wheel flange depth, yet it is less than the 4.5 in depth of the cross bar. No jump-off is, therefore, expected for the trolley.

IV. CONCLUSIONS

In this requalification study, a safety class linear bridge crane, which was designed and constructed over 25 years ago, has been investigated under various loadings including loads from design basis earthquake. Since the dynamic behavior of the crane will depend on the location of the trolley and the amount of lifting, a number of cases have been studied in this investigation. For most of these cases, the extreme condition stress coefficients including seismic responses from the response spectrum method are within the allowable of ANSI/AISC N690-1984. The case which yields the highest stress coefficient from response spectrum analysis results is further investigated using the time-history method. The new stress coefficient based on time-history method is less than 90% of the allowable. In this study, the higher seismic capacity allowed by UCRL-15910 for existing equipment has not been included in the investigation. Using higher seismic capacity will further reduce the stress coefficient and increase the safety margin of this 5-ton safety class crane.

REFERENCES

1. "Nuclear Facilities------Steel Safety-Related Structures for Design Fabrication and Erection", ANSI/AISC N690-1984.

2. "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards", UCRL-15910, June, 1990.

3. "Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)", ANSI/ASME NOG-1-1983.

Table 1: Fundamental Frequencies (Hz) of a Safety Class Linear Bridge Crane

	Config. 1	Config. 2	Config. 3
No Lifting	18.5	14.8	9.6
50% Lifting	16.4	12.5	7.9
100% Lifting	14.7	11.0	6.9

TABLE 2: Stress Coefficients Based on Response Spectrum Method

		Config. 1	Config. 2	Config. 3
Normal (Allowable = 1.0)		.44	.70	.78
Extreme (Allowable = 1.6)	No Lifting	.49	.94	1.26
	50% Lifting	.55	1.14	1.94
	100% Lifting	.54	1.37	2.31

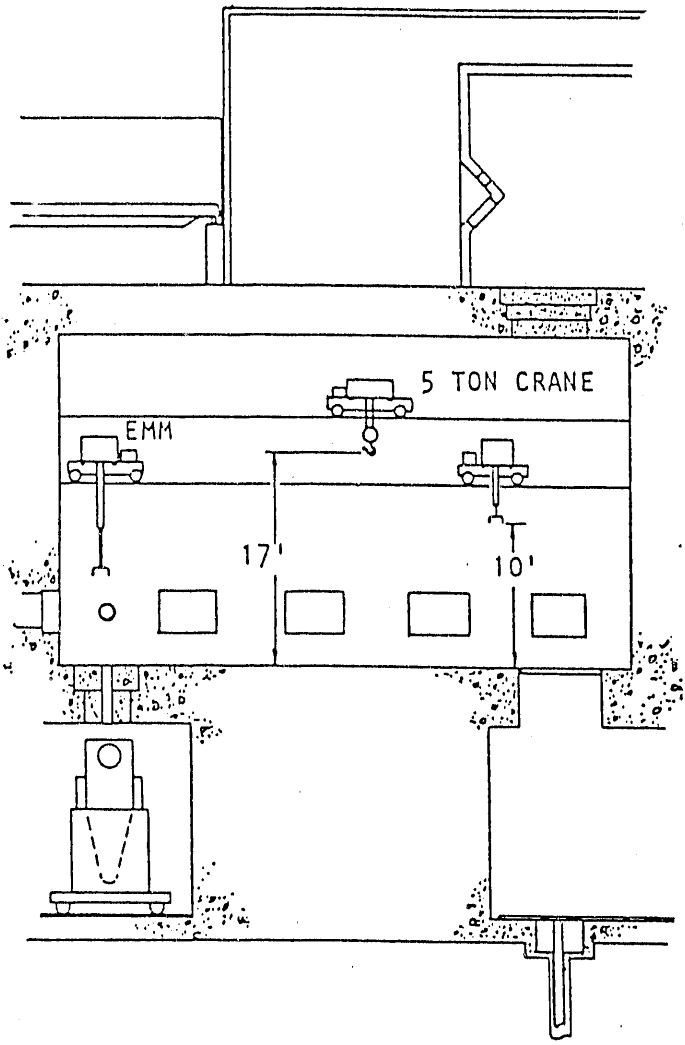

FIGURE 1 Lifting Devices in a Fuel Handling Facility

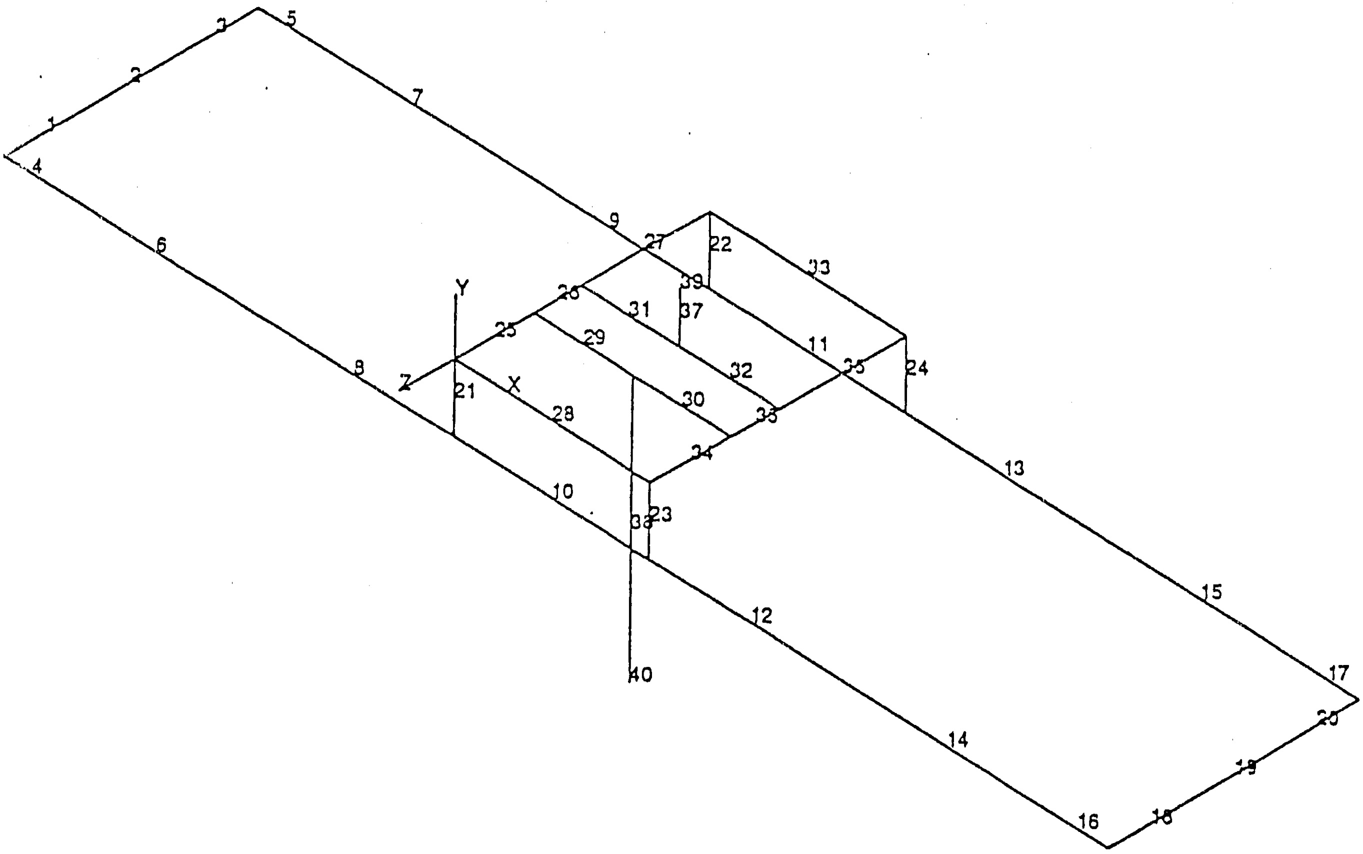

FIGURE 2 A Typical Finite Element Model for a Linear Bridge Crane

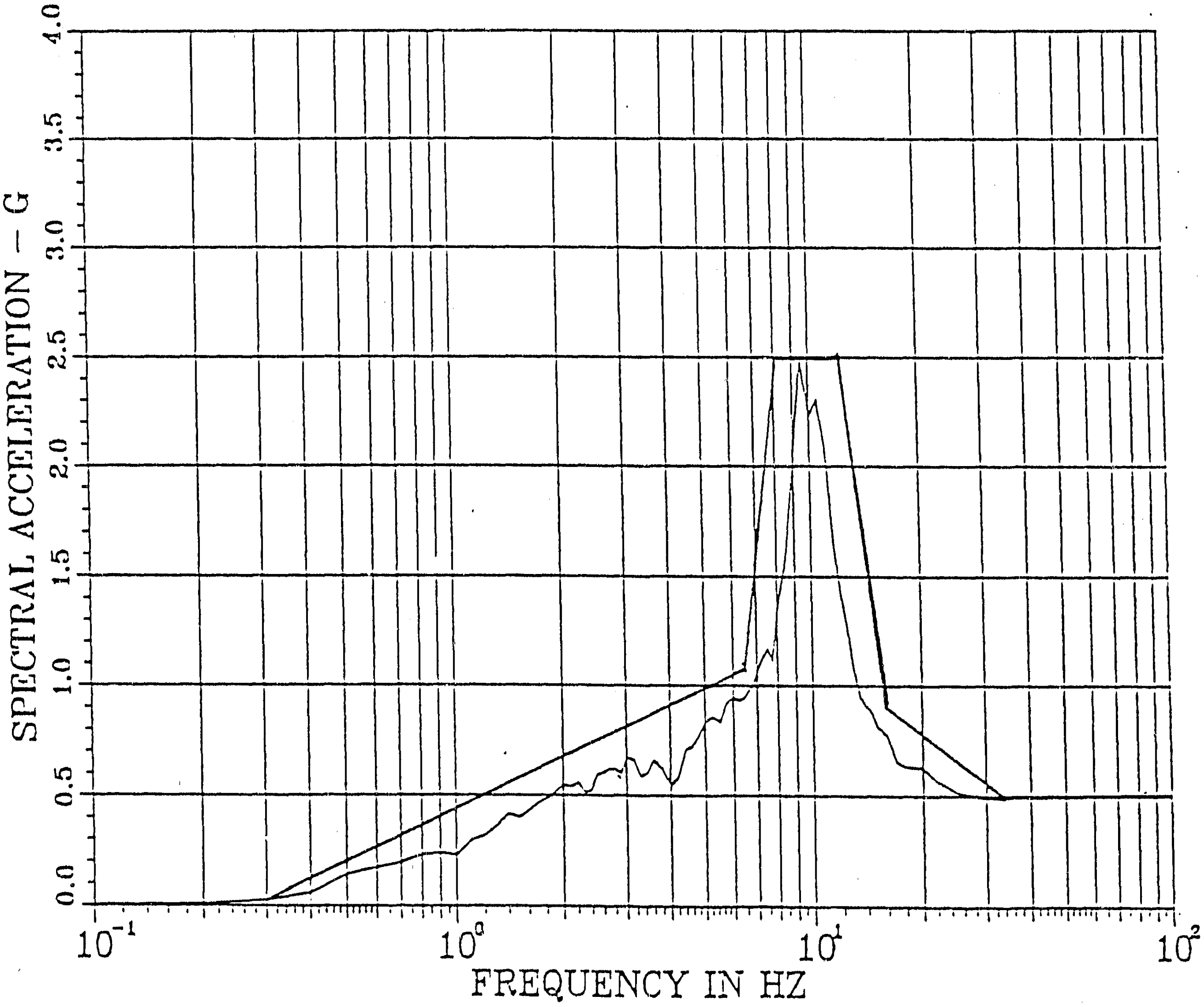

FIGURE 3 N - S Spectrum

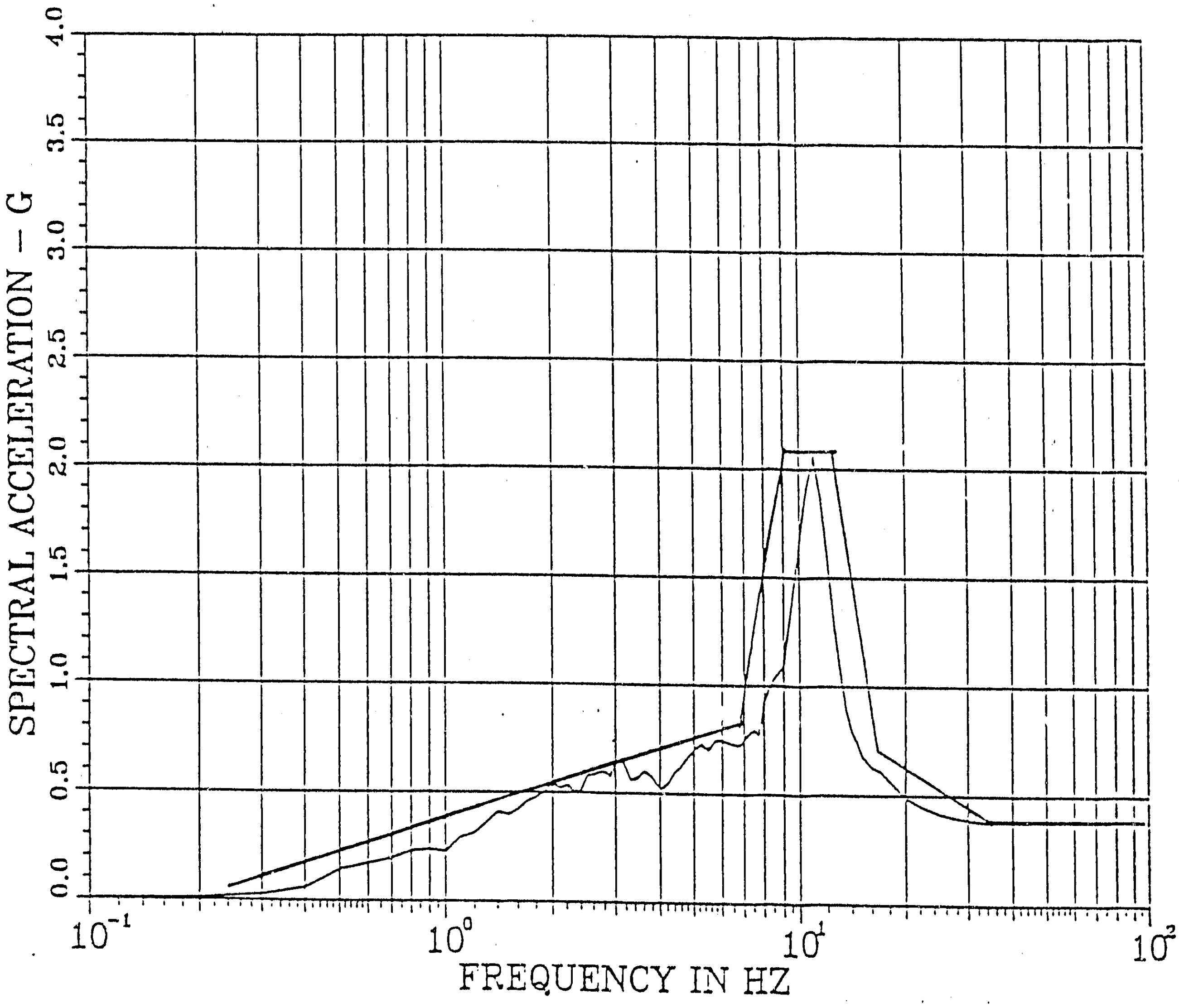

FIGURE 4 E - W Spectrum

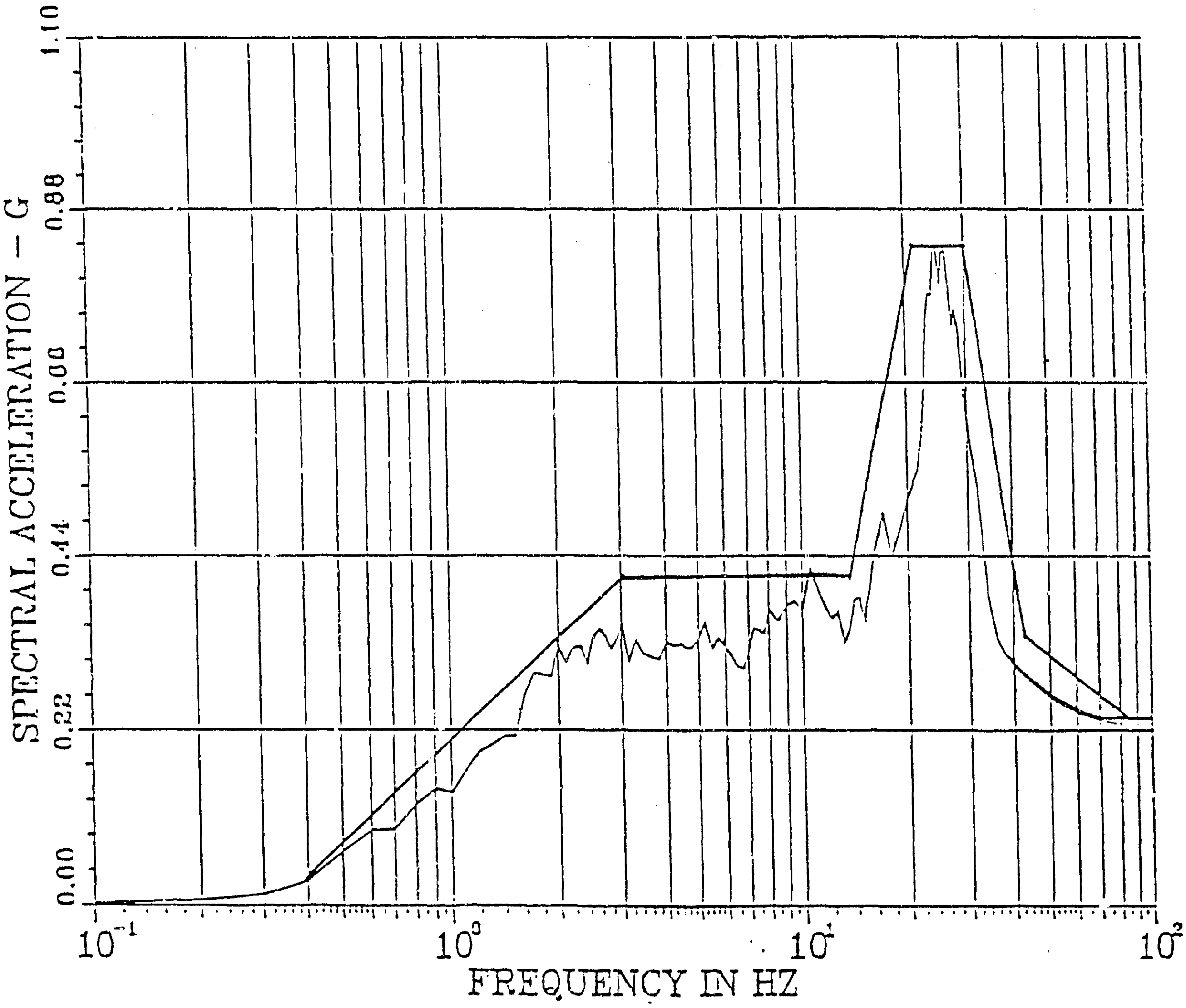

FIGURE 5 Vertical Spectrum

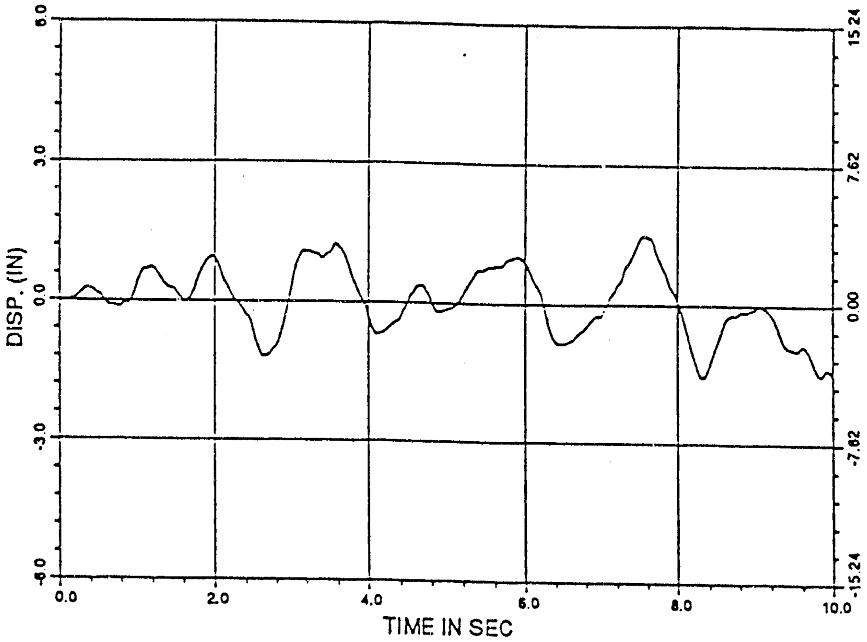

FIGURE 6 N - S Displacement Time History

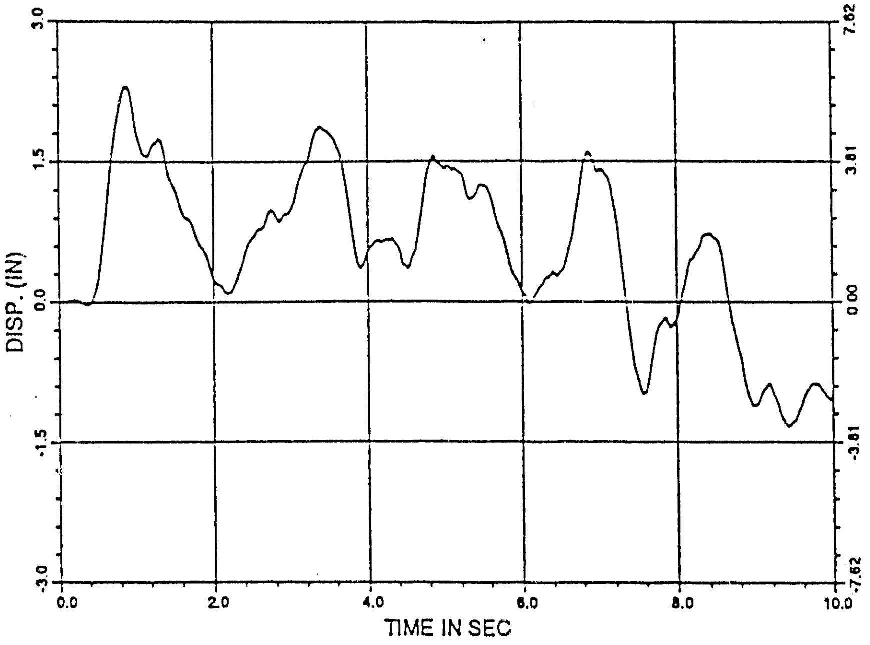

FIGURE 7 E - W Displacement Time History

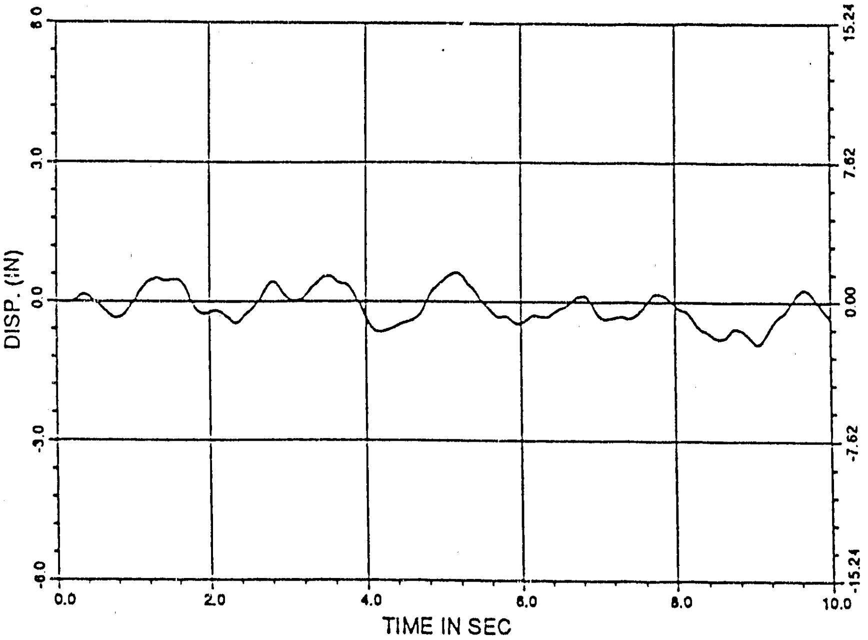

FIGURE 8 Vertical Displacement Time History

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