Conf-920631--27

ANL/CP--75215

DE92 012653

Seismic Qualification of Existing Safety Class Manipulators*

by

Ting-shu Wu and T. J. Moran

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

ABSTRACT

There are two bridge type electromechanical manipulators within a nuclear fuel handling facility which were constructed over twenty-five years ago. At that time, there were only minimal seismic considerations. These manipulators together with the facility are being reactivated. Detailed analyses have shown that the manipulators will satisfy the requirements of ANSI/AISC N690-1984 when they are subjected to loadings including the site specific design basis earthquake.

---

*Work performed under the auspices of the U. S. Department of Energy under contract No. W-31-109-ENG-38.

I. INTRODUCTION

A nuclear fuel handling facility designed and constructed more than twenty-five years ago is to be reactivated. Within this facility, there are two bridge type electromechanical manipulators (EMMs) for handling materials and equipment not exceeding 750 lbs. The EMMs are of safety class and are being requalified against natural hazards including the site specific design basis earthquake (DBE), in accordance with the DOE document UCRL-15910 [1] to the extent that their safety functions are not impaired.

The EMMs are installed within the closed facility. They will not be subjected to natural hazards such as high wind. Earthquake is the only natural hazard that should be considered for these EMMs.

The facility has been designated as a "moderate hazard" facility. A more conservative goal in qualification is to treat the facility and the EMMs as those will be required for a "high hazard" facility. This is not intended to imply that the facility and the EMMs are more hazardous than its "moderate hazard" designation. Rather, the choice of this more conservative goal reflects the desire to ensure that no interruption will occur to the facility and the EMMs should there be changes in the perception of natural phenomenon threats. Accordingly, the maximum horizontal ground surface acceleration at the site, or DBE, used in the qualification is of 0.21 g [1].

The EMMs are required to meet the criteria of ANSI/AISC N690-1984 [2]. As safety items, the EMMs shall not fail in a manner that compromises the integrity of the facility's confinements, the integrity of the fuel elements, or waste cans within the facility. Thus, the carriages, bridge structures, and suspended loads should remain supported during and after the DBE.

Carriages of the EMMs are heavily lined with lead bricks to protect their internal components from radiation. As a result, a carriage weighs more than twice the remaining weight of an EMM. During the DBE, the heavy carriage exents strong dynamic loads to the bridge.

Analytical models used in this investigation conform with the guidelines of N0G-1-1983 [3]. Results obtained from dead, live, and DBE loads are combined in accordance with the required codes and specifications to produce the maximum responses for the EMM.

II. ELECTROMECHANICAL MANIPULATORS (EMMs)

The nuclear fuel handling facility shown in Fig. 1 is provided with different types of remote handling equipment, including a 5-ton crane, several master/slave manipulators, and two EMMs. The crane and EMMs perform much of the moving and manipulating of equipment and materials within the facility. The EMMs have considerable flexibility but have a load limit of 750 lb. Loads over 750 lb. are handled by the crane.

The EMM bridges operate on parallel tracks along the ledges in the walls of the facility. These bridges travel at a level sufficiently below the crane bridge so that, with the crane hooks fully retracted, the crane can pass over the EMM carriages.

Each bridge has four flanged wheels (two on each side) of which one on each side is a drive wheel. The carriage which moves back and forth on a bridge also has four flanged wheels. Flange depth of the bridge wheels and the carriage wheel is 1/2 in. A vertical telescoping arm with five concentric tubes (Fig. 2) is attached to the carriage for handling materials and equipment. The arm can be raised, lowered, or rotated. The end of the telescoping arm terminates in a removable working tool. Various tools or mechanisms as shown in Fig. 3 can be attached to the end of the telescoping arm.

The bridge has length about 16 ft. It consists of 12 X 5 1/4 X 40.8 I-Beam and 3/4 X 1 3/4 rails. The rails are slightly over 13 ft. above the operating floor. Each carriage is heavily lined with lead blocks to shield its internal components from radiation. Weight of a carriage is of 6,100 lb, which is more than twice the weight of the bridge system. Accordingly, location of the carriage on an EMM bridge is also an important factor for the dynamic characteristics of the EMM.

Other than gravity, there is no positive restraint to hold down the EMMs and their carriages against vertical moments. There is concern, in addition to the stress adequacy of an EMM's overall structural design, on the potential jump-off of the EMM or its carriage from their respective tracks during the DBE.

III ANALYSIS MODELS

The position of the exceedingly heavy EMM carriage on the bridge is expected to be a dominant parameter on the responses, especially the dynamic responses, of an EMM. Finite element models have been constructed to simulate an EMM with its carriage at different locations on the bridge. The lifting weight, limited to 750 lb, is much lower than the total weight of an EMM, and is not expected to contribute significantly to its responses. Different amount of lifting nevertheless has been considered in this investigation.

Three dimensional beam and mass elements of the ANSYS computer program have been used to simulate an EMM. Fig. 4 shows a typical model used in this investigation. For each model with the carriage at a specific location on the bridge, two lifting cases, 0 and 100% of the capacity, have been considered. Linear behavior of the system is generally assumed in the analyses. Influences which would introduce non linear behavior of the system is generally assumed in the analyses. Influences which would introduce non linear behavior such as gaps at the supports, wheel uplift, friction, and the shifting of carriage location during an earthquake have not been included in this study.

Boundary and restraint conditions used in this investigation follow the guidelines provided in NOG-1 [3]. Load combinations, allowable stresses, and applicable stress coefficient limits are all evaluated and assessed based on N690 [2]. Both the response spectrum analysis and the direct solution method of linear transient analysis of ANSYS have been used to obtained the dynamic responses of the EMM. Damping considered in these analyses is 5% of the critical damping.

IV LOADING CONDITIONS

The EMMs are installed within the closed nuclear fuel handling facility which has very limited fluctuations on temperature and pressure. The only loads other than dead and live loads are those from earthquakes. In accordance with the guidelines for qualifying components and equipment within this fuel handling facility, the site specific DBE is equivalent to a safe shutdown earthquake (SSE), and the operating basis earthquakes (OBE) are taken to be zero. Impact loads in vertical, transverse horizontal, and longitudinal horizontal directions have been included and are applied at the top of the rails.

The design response spectra at the EMM elevation as shown in Figs. 5-7 have been used as inputs in the response spectrum analysis. Peak spectral accelerations from these figures with 5% damping are 2.4, 2.05, and 0.79g, respectively, in NS, EW, and vertical directions. In the time-history analysis, three sets of displacement time-histories at the EMM elevation are used as inputs. They are based on the DBE, and are designated as AA, A2, and A4. Each set of the displacement transients consists of three orthogonal components, i.e. components in NS, EW, and vertical directions. Damping incorporated in the time-history analysis is also 5% of critical damping.

V ALLOWABLE STRESSES AND DESIGN LIMITS

Allowable stresses in shear, tension, compression, and bending are established following the guidelines provided in N690 [2]. In evaluating these allowable stresses, the yield stress used is of 33 ksi, and the over all bridge length has been taken as the length of column or beam. It has been observed that the allowable compression and bending stresses of the EMM are controlled by stability considerations.

The only loadings that an EMM will be subjected to are dead loads D, live loads L (including impact), and DBE which is equivalent to SSE. Only two of the load combination cases of N690 {2} therefore have to be considered. Load combinations of these two cases are, together with their respective stress coefficient limits,

Normal: $D+L \leq 1.0$

Extreme: $D+L + DBE \leq 1.6$ (1.4 for shear)

VI STRUCTURAL ANALYSIS RESULTS

When the EMM is subjected to dead loads and live (including impact) loads, its bridge has both axial and bending stresses. These stresses are proportioned to yield the stress coefficient as required by N690 [2]. These normal condition stress coefficients are included in Table 1, and they are all within the allowable of 1.0. Configuration 1 in Table 1 refers to the case when the carriage is near the end of the bridge, and configuration 2 is when the carriage is close to the middle of the bridge.

To qualify the EMM for the extreme loading condition, responses of an EMM to DBE are investigated. Both the response spectrum method and the time-history method have been used to study the EMM's responses to the DBE.

The response spectrum method, which is simple yet conservative, has been applied to all cases considered. The fundamental frequencies shown in Table 1 reveals that the location of the carriage affects more significantly on the EMM's dynamic characteristics than the amount of lifting. This is not unexpected in view of the fact that the EMM's capacity of 750 lb is less than ten percent of an EMM's total weight.

Spectral responses are combined following the NRC regulatory guide 1.92 [4]. That is, for each floor design response spectrum input from the DBE, values of the response of individual significant modes are combined using the square root of the sum of square (SRSS) method, or the ten percent method for closely spaced modes. Responses caused by the three orthogonal floor design response spectra are combined using the SRSS method.

Responses of an EMM to the DBE obtained from the response spectrum analysis are combined with responses from dead and live loads to evaluate the extreme condition stress coefficients. As shown in Table 1, the extreme condition stress coefficients for Configuration 2 exceed the allowable of 1.6. Shear responses are very low, and are within the allowable.

Responses obtained from the response spectrum analysis generally are conservative. To assess the seismic responses, and therefore the extreme condition stress coefficients of an EMM more accurately, the linear time-history method is next applied to the EMM for the case when the carriage is at Configuration 2 position and has full capacity lifting, that is, the case with the highest stress coefficient in Table 1.

Three sets of displacement time-histories, designated as AA, A2, and A4 have been used as inputs in the time-history analysis. Maximum values of the displacement components in the NS, EW, and vertical directions, from these three sets time-histories, are 5.52, 2.30, and 0.93 in, respectively. Each set of the displacement time-histories is applied to the finite element model simulating an EMM with its carriage at Configuration 2 position and lifting at full capacity, the case which yields the highest stress coefficient in Table 1.

Responses of an EMM to each of these three sets of time-histories are combined with its dead and live load responses, and the corresponding extreme stress coefficients are evaluated following the same procedure used in the previous response spectrum analysis. Extreme stress coefficients from time-histories AA and A2 are 1.52 and 1.53 respectively. Both of these coefficients are within the allowable of 1.6. Extreme stress coefficient for time-history A4 is of 1.70, which is slightly above the allowable. This coefficient is reduced to 1.52 when the 20% additional seismic capacity allowed by UCRL-15910 [1] for existing facility and equipment is used in evaluating the extreme stress coefficient.

Energy method and equivalent static method have been used to assess the uplifts of the carriage and the bridge, maximum horizontal displacement of a properly lifted weight, and integrity of the telescoping arm. Results show that maximum potential uplift is less than the wheel flange depth, or no jump-off is expected to occur. Safety margin for the telescoping arm exceeds 8. Maximum horizontal displacement of a lifted weight is less than 7 in. It is therefore suggested that, in order to avoid impact, no other equipment should be within the 1 ft range from a vertical telescoping arm.

VII CONCLUSIONS

A safety class electromechanical manipulator, which was designed and constructed over twenty-five years ago, has been re-evaluated based on current design codes. Loadings considered in this investigation are dead loads, live loads and loads from the site specific design basis earthquake. Detailed analyses, including time-history analysis, show that the manipulator will satisfy the design code ANSI/AISC N690-1984. In this re-qualification, the entire manipulator is simulated as an elastic system, or the inelastic demand-capacity ratio $F\mu$ defined in the DOE document UCRL-15910 has been taken to be unity. For moderate or high hazard equipment, UCRL-15910 allows some inelastic behavior, or $F\mu > 1.0$. This means that the manipulator will have higher design margins than those presented here.

REFERENCES

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

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

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

4. "Combining Modal Responses and Spatial Components in Seismic Response analysis", US Regulatory Guide 1.92, February 1976.

TABLE 1, Stress Coefficients for Electromechanical Manipulator, Response Spectrum Analysis

		Configuration 1	Configuration 2
Normal Condition (allowable = 1.0)		0.42	0.60
Extreme Condition (Allowable = 1.6)	0 Lifting	8.53 (21.9*)	2.61 (7.6)
	100% Lifting	0.54 (21.2)	2.79 (7.3)

* Numerals within the parentheses are fundamental frequencies in Hz.

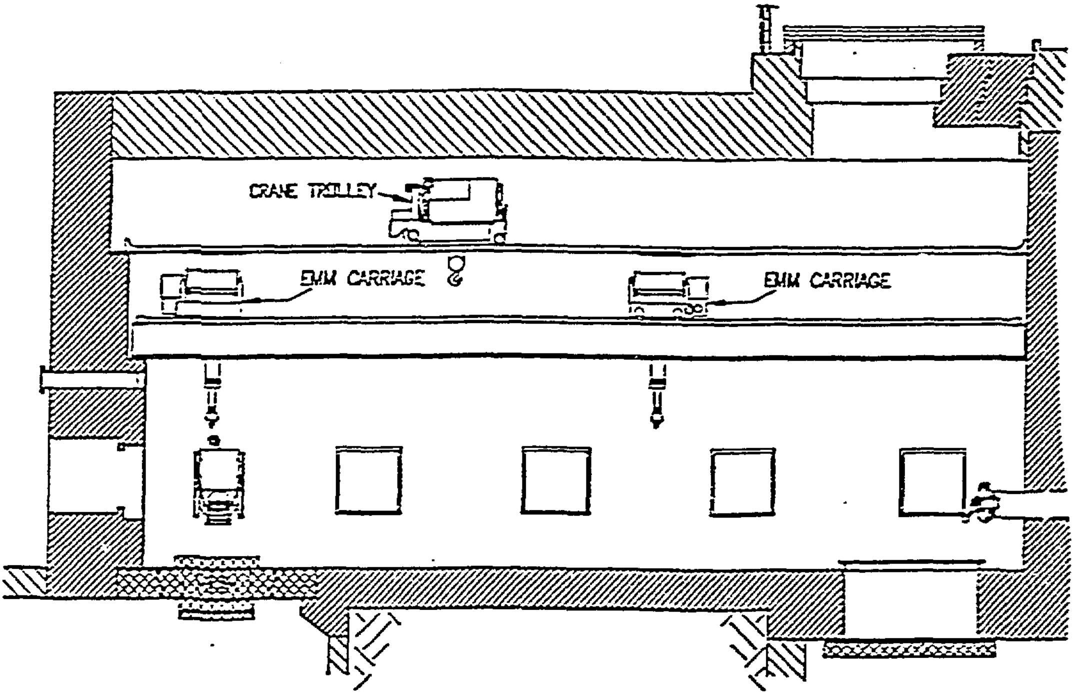

Fig. 1 Lifting Devices in a Fuel Handling Facility

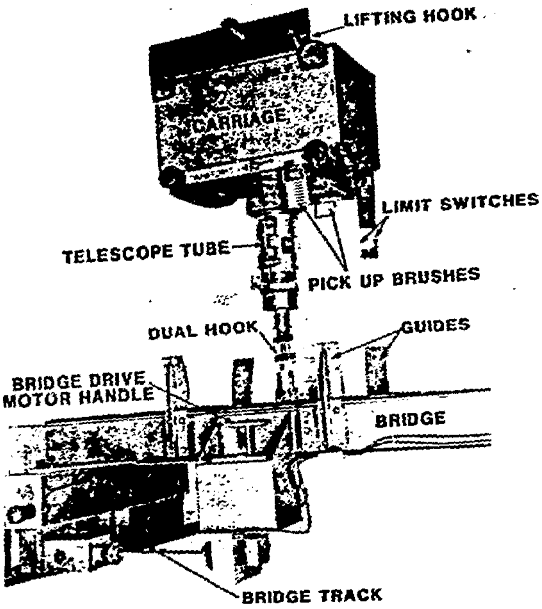

Fig. 2 An Electromechanical Manipulator

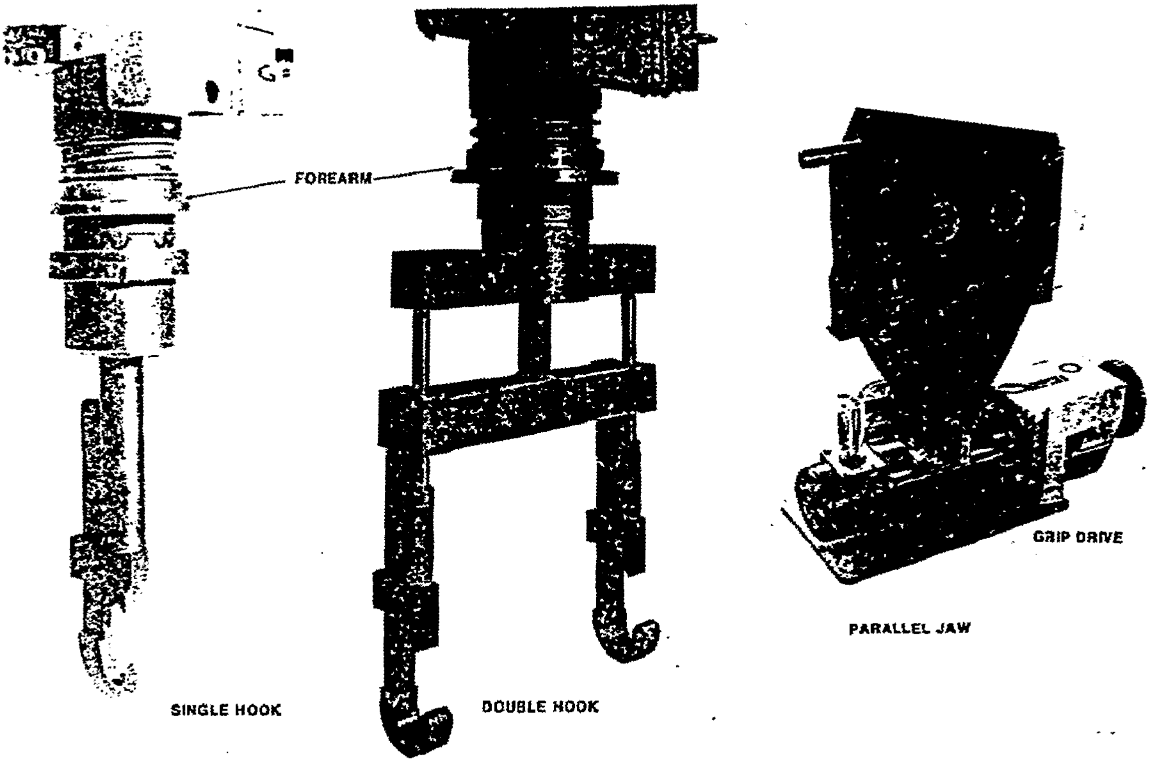

Fig. 3 Gripping Tools Attached to Manipulator Forearms

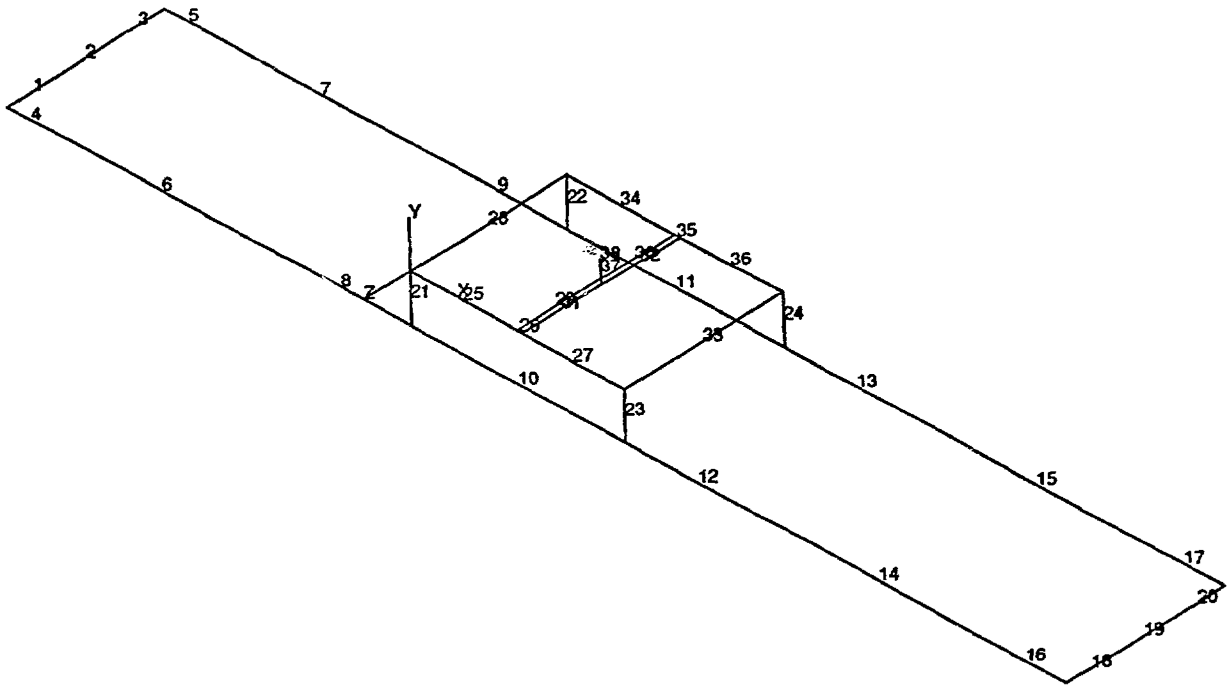

Fig. 4 A Typical Finite Element Model for an Electromechanical Manipulator

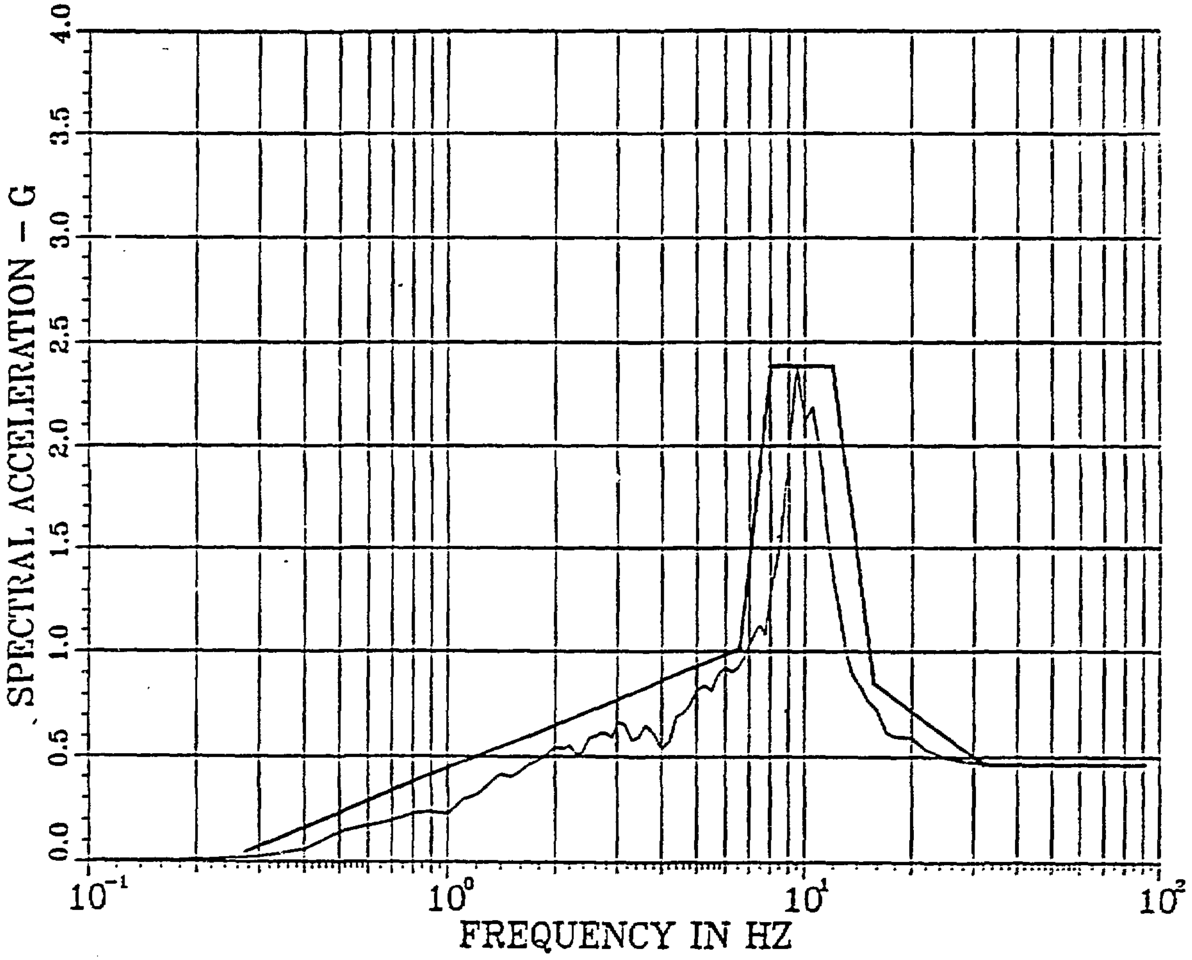

Fig. 5 N-S Spectrum

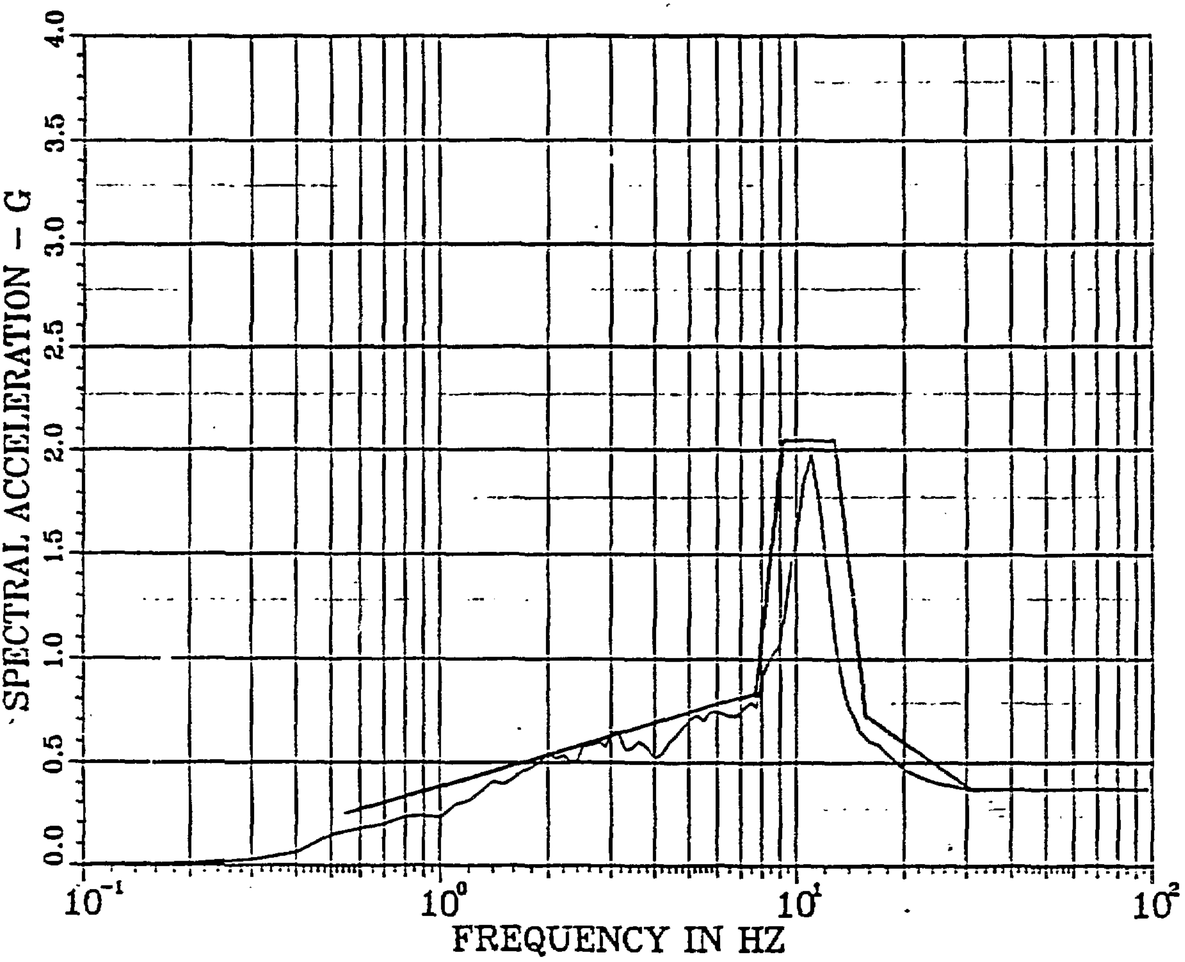

Fig. 6 E-W Spectrum

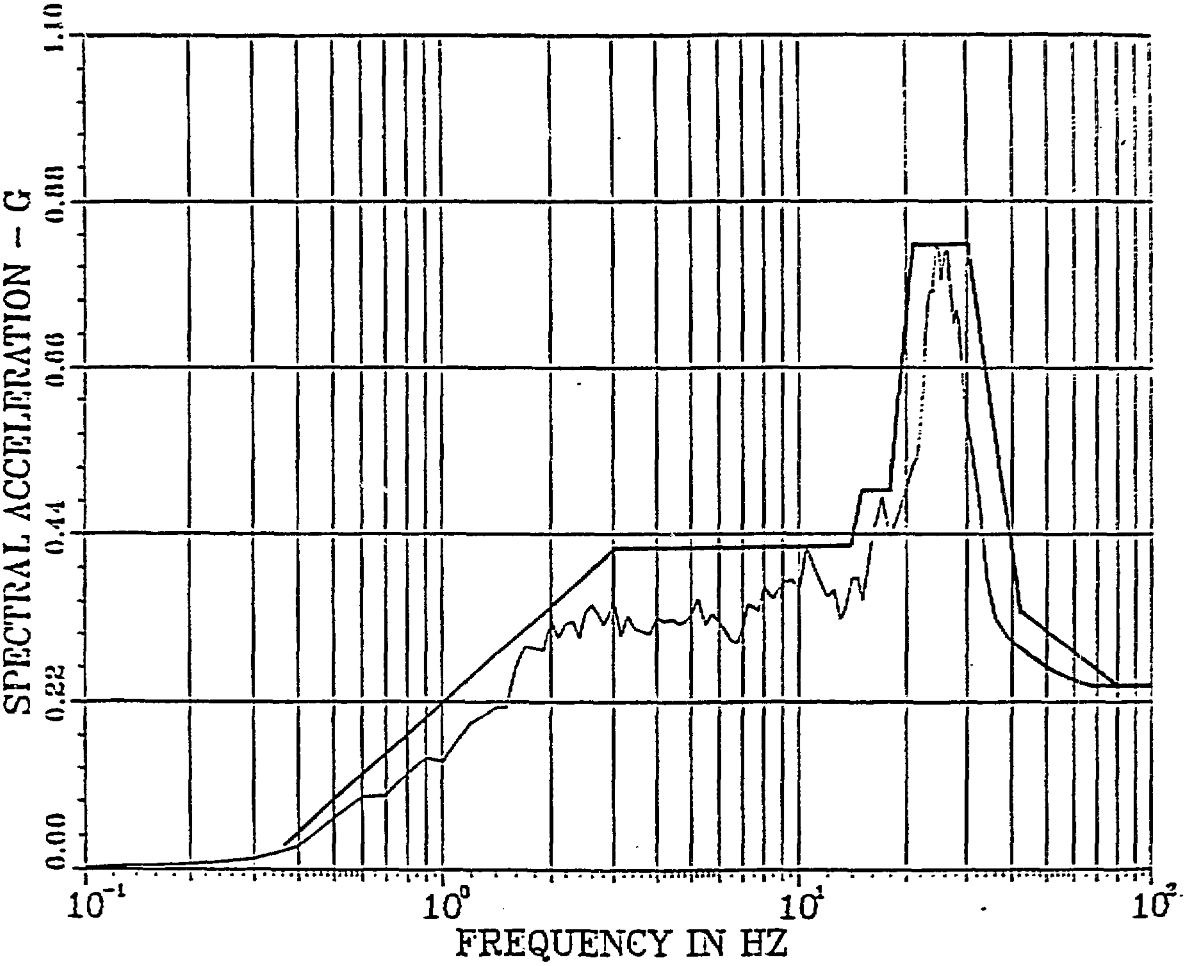

Fig. 7 Vertical Spectrum