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SEISMIC RESPONSES OF AN UNANCHORED GENERIC FIXTURE WITH DIFFERENT SIMULATED BOUNDARY CONDITIONS

by

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ABSTRACT

In the design of equipment for seismic loadings, it is common to anchor the equipment to prevent tipping or sliding. However, there are situations where the equipment should not be anchored. An unanchored piece of equipment is held to the floor only by the gravitational effect and, in the absence of friction, it could move freely. In the analytical investigation of an unanchored item during a seismic event, there is uncertainty on the proper simulation of the boundary conditions so that the analysis model will have no rigid-body motion. Seismic responses of a simple analytical model that is representative of a group of unanchored equipment have been investigated with different sets of simulated boundary conditions. The results show that, when the main interest of investigation is to assess the potential for tipping during an earthquake, the case with one of the four supporting pads simply supported, its two neighboring pads constrained against twisting motion, and all pads without vertical displacements yields the most conservative prediction.

I. INTRODUCTION

Most structures and equipment designed to resist seismic loads are anchored either directly or indirectly, for example through isolators, to the foundation or the floor. Design guidelines generally require that adequate anchorage should be provided at the supports. For example, UCRL-15910 (Kennedy, R. P., et al., 1990) specifies that "*equipment items and nonstructural elements must be adequately anchored to their supports*," and "*engineered anchorage of equipment or components is required for all usage categories*." There are situations where the equipment should not be anchored, so they will be solely retained by gravitational effect.

A variety of fixtures to be used either as temporary storage or as work tables have been designed and will be installed within the enclosed fuel-processing cell of the Integral Fast Reactor (IFR) project. The fuel-processing cell is an existing facility which has a steel liner. In order not to breach the liner and to keep operational flexibility of the fixtures, all new equipment to be installed within the fuel-processing cell are required to be unanchored. As a result, there are concerns about the potential for tipping and/or sliding during an earthquake, in addition to considerations about the structural integrity of these unanchored equipment.

Potential sliding of an unanchored piece of equipment will depend on the input load and the friction between the contacting surfaces of the equipment and the supporting floor. For equipment to be installed in the fuel-processing cell, the seismic qualification requirements (Moran and Seidensticker, 1992) specify that, during the design basis earthquake (DBE), the maximum sliding distance for an item of unanchored equipment is 6-in. Effects of sliding can be avoided when a fixture is positioned either 6-in. or 12-in., respectively, from other anchored or unanchored equipment. Therefore, the major concern for an unanchored item within the fuel-processing cell will be on the potential for tipping. Overturning could also be a possibility when the tipping becomes excessive.

Figures 1 and 2 show two such fixtures to be installed within the IFR's existing fuel-processing cell. Each of these fixtures has a heavy base plate supported by four leveling pads. On top of the base plate are tall and heavy component(s). When these fixtures are freely standing on the floor, there is a potential that they could tip or even overturn during the DBE. Tipping alone may not be necessarily detrimental to the fixture responses; however, an excessive amount of tipping could result in overturning. Furthermore, if tipping occurs in an unanchored fixture, a detailed analysis must be performed to assure that it will not overturn, and that any impact load from the rocking motion will not escalate the stress above its the allowable. This analysis is nonlinear and requires significant analytical effort; therefore, the optimum strategy is to avoid or minimize tipping. This is accomplished by designing a heavy and wide base plate to minimize the height of the center of gravity, and to maximize the tipping radius. Hence, with no tipping, a linear approach can be used in the analytical investigation.

When investigating the responses of a structure analytically, such as the finite-element method, appropriate boundary conditions must be incorporated in the modeling so that both the linear and angular motions of the model will remain finite, i.e., there will be no rigid-body motion. An unanchored structure by definition is allowed to have rigid-body motion. To facilitate the analysis, artificial boundary conditions that will restrain rigid-body motion have to be used.

In an anchored structure, boundary conditions are general imposed at locations where the structure is supported. Thus, it is logical to impose boundary conditions for an unanchored fixture also at the points which are in contact with the floor. Unlike the anchored structures or equipment where the boundary conditions can be clearly simulated, boundary conditions that will preclude rigid-body motion of a finite-element model of an unanchored structure on a smooth floor re not clearly defined. Furthermore, different boundary conditions will result in different dynamic characteristics of the structure and will yield different responses.

II. THE SIMULATED MODEL AND BOUNDARY CONDITIONS

The finite-element model shown in Fig. 3 is a simple generic model for some of the unanchored fixtures to be installed within the existing fuel-processing cell. This model has a 4-in. thick, 31-in.x57-in. rectangular base plate supported by four adjustable leveling pads. These leveling pads are located at the corners of the rectangular plate and are not anchored to the floor. From the middle of the base plate, a 84-in. tall tube with inside diameter of 4-in. and outside diameter of 6-in. extends vertically upward. The total weight of the plate and tube is about 2383 lb. In addition, a concentrated weight of 500 lb. that simulates other components to be installed on the fixture is assumed to be located at the midpoint of the tube.

ANSYS three-dimensional mass elements, three-dimensional beam elements, and elastic quadrilateral shell elements have been used in this simulation. To complete the finite-element-analysis model, proper boundary conditions must be supplemented.

In normal operation, an unanchored fixture is held to the floor by gravity. If there is no uplift by loadings, no relative vertical displacement between the floor and the supporting pads of the fixture will occur. Therefore, vertical displacements at these pads can be simulated as fixed. Additional boundary conditions are needed so that the finite-element model will have no rigid body motion.

Besides no vertical displacements at the supporting pads when there is no uplift, it is not clear what other boundary conditions could be assigned to the pads. In reality, an unanchored fixture on a smooth floor does not have other boundary conditions to restrain it from rigid-body motion. The following cases of artificial boundary conditions that will prevent the modeled structure shown in Fig. 3 from having a rigid-body motion have been used in this study:

(a) one pad fully fixed,
(b) two pads along the shorter side simply supported,
(c) two pads along the longer side simply supported,
(d) two pads along a diagonal simply supported,
(e) one pad simply supported, and its two neighboring pads constrained to avoid twisting,
(f) all pads are simply supported.

All pads are restrained against any vertical displacement in all of the cases.

The first three cases simulate conditions when one or two pads are obstructed. The fourth case is similar to and is an extension of the previous three cases, and may not be realistic. In Case (e), one of the pads does not have any linear moments, while its two neighboring pads are constrained against horizontal movements orthogonal to the respective edges of the rectangular base plate. Case (f) has assumed simply supported conditions for all four pads. The case with all four pads fully constrained has not been included. Such a condition will be over-constrained for unanchored equipment, and is expected to be more rigid.

III. RESPONSES TO DESIGN BASIS EARTHQUAKE

The DBE loads at the operating floor level where the fixtures will be installed are specified in the IFR guidelines. Figs. 4 through 6 are the floor-response spectra in the N-S, E-W, and vertical directions, respectively, of the DBE. Furthermore, the guidelines also states that the site specific DBE is equivalent to a safe-shutdown earthquake (SSE), and the operating-basis earthquakes are taken to be zero. The smoothed-design spectra shown in Figs. 4-6 are used as the input loads in this investigation.

The model shown in Fig. 3 has a total weight of 2883-lb. Its responses to the DBE have been obtained using the response-spectrum approach of the ANSYS computer program. Spectral responses are combined as per NRC Regulatory Guide 1.92 (U. S. Nuclear Regulatory Commission, 1976), i.e., 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 squares (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.

Table I summarizes the results when the model is incorporated with the boundary conditions (a)-(f). The fundamental frequency for Cases (a) and (c)-(f) are essentially the same and is about 26 Hz. The mode shapes of these cases are mainly flexural vibration of the tube as shown in Fig. 7 [from Case (e)]. The fundamental frequency of Case (b) is 16.2 Hz which is much lower than the 26 Hz frequency for the other cases. From the horizontal floor-response spectra in Figs. 4 and 5, the spectral acceleration at 16.2 Hz is higher that at 26 Hz. The mode shape for Case (b) is dominated by twisting motion (Fig. 8) which is quite different from the other cases.

The maximum vertical seismic-reaction force at the pads, which are assumed to be constrained to the floor, is 297.08-lb. and occurs in Case (e). This seismic-reaction force could either be tensile or compressive, but it is much less than one-fourth of the 2883-lb. total weight (dead and live) of the model. When the seismic effects are combined with the responses from dead and live loads, the overall vertical reaction force at the pads remains compressive during the DBE, i.e., the DBE will not introduce tipping at any of the pads. This result of no tipping at the pads also confirms the artificial boundary conditions at the unanchored pads. The results in Table I also suggest that when the major interest is to assess the potential for tipping of an unanchored fixture during the DBE, a conservative prediction can be obtained from the analysis model with boundary condition Case (e). In a previous investigation for a storage fixture (Wu, T. S., Blomquist, C. A., Haupt, H. J., and Herceg, J. E., 1993), boundary condition (e) was used to conclude that the storage fixture had no tipping during the DBE.

The peak stress of the modeled fixture occurs when it has boundary condition Case (b), but this stress is still within the material's yield stress. The fundamental mode for Case (b) is dominated by twisting as shown in Fig. 8. When an unanchored fixture is subjected to an appreciable twisting moment, it will most likely have rotation about an axis; a situation which is closer to boundary condition Case (a) than Case (b). The maximum stress for Case (a) is 19771 psi which is much lower than in Case (b). The peak horizontal resultant displacement at the top of the tube is about 0.03-in.

IV. CONCLUSIONS

In addition to the concerns for structural integrity, the potential for tipping of unanchored equipment during the design-basis earthquake is also of interest. Seismic responses for an unanchored generic fixture have been investigated using the response-spectrum method.

When analytical approaches such as the finite-element method are used to investigate the responses of a structure, the analysis model is generally required to have boundary conditions so that there will be no rigid-body motion. In the development of finite-element models for investigating unanchored structures, which inherently have rigid-body motions, it is uncertain as to what kind of boundary conditions will be appropriate so that the analysis model will have no rigid-body motion, and the results will be conservative.

A number of artificial boundary conditions have been used in studying the seismic responses of an unanchored generic fixture for the IFR project. Since sliding of such a fixture can be overcome by properly positioning the fixture, major interest is on the potential tipping of the fixture during the design basis earthquake, and which of the artificial boundary conditions will yield a conservative prediction.

Among the different boundary condition cases studied using the response-spectrum method, Case (e) gives the highest vertical reaction force during the design-basis earthquake; so it is the conservative case as far as tipping of an unanchored fixture is concerned. Results from this investigation also show that the generic fixture considered here will have no tipping during the design-basis earthquake. The maximum stress of the modeled fixture occurs when the fixture has boundary conditions simulated in Case (b), where twisting motion is found to be the dominate mode. When an unanchored fixture has a twisting motion, boundary condition Case (a) is more credible than Case (b). The maximum stress of Case (a) is smaller and is closer to that of Case (e).

All of the cases investigated here indicate that the modeled fixture will have no tipping. Although analytical efforts will be more complicated if there is tipping, the effect of tipping of the fixture will not be detrimental when the uplift is not excessive. It has been pointed out (Naeim, F., 1989) that some uplift may in fact be beneficial in reducing earthquake forces. Furthermore, an unanchored structure could have sliding motion during an earthquake, which will dissipate some of the seismic energy. Therefore, results based on the floor-response spectra such as Figs. 4-6 are conservative.

ACKNOWLEDGMENT

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TABLE 1. RESPONSES OF A GENERIC FIXTURE TO DBE

Case	Funda Freq	Max Vert Reaction Force at Pads	Max X-Disp Top of Tube	Max Z-Disp Top of Tube	Max Stress
(a)	26.83	115.14	$.7708 \cdot 10^{-2}$	$.5932 \cdot 10^{-2}$	19771
(b)	16.18	242.76	$.1359 \cdot 10^{-1}$	$.2523 \cdot 10^{-1}$	34458
(c)	25.60	182.05	$.1655 \cdot 10^{-1}$	$.1306 \cdot 10^{-1}$	28606
(d)	25.81	173.80	$.1583 \cdot 10^{-1}$	$.1312 \cdot 10^{-1}$	31769
(e)	25.81	297.08	$.1335 \cdot 10^{-1}$	$.2565 \cdot 10^{-1}$	17757
(f)	26.46	125.16	$.9863 \cdot 10^{-2}$	$.9680 \cdot 10^{-2}$	14865

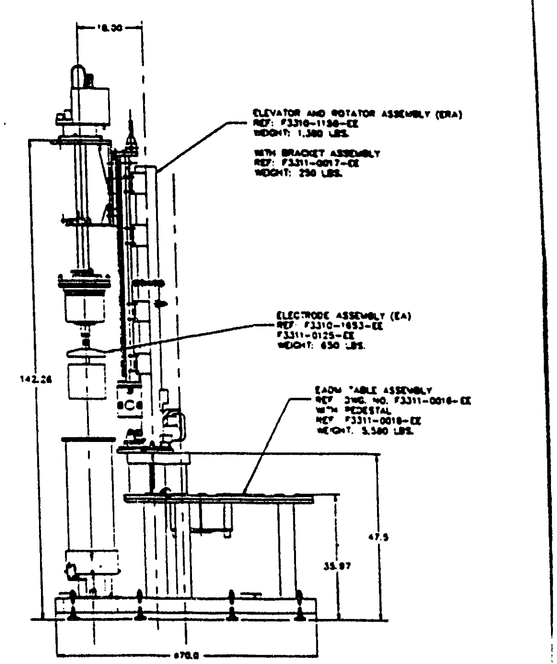

FIG. 1. ELECTRODE ASSEMBLY AND DISASSEMBLY MACHINE

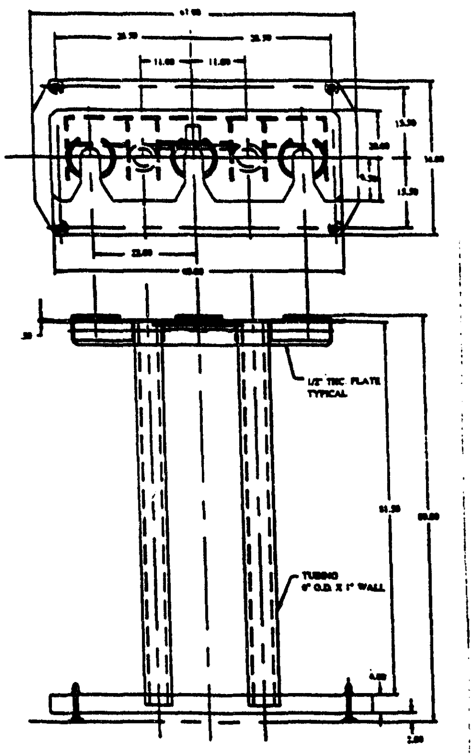

FIGURE 2. ELECTRODE STORAGE FIXTURE STRUCTURE

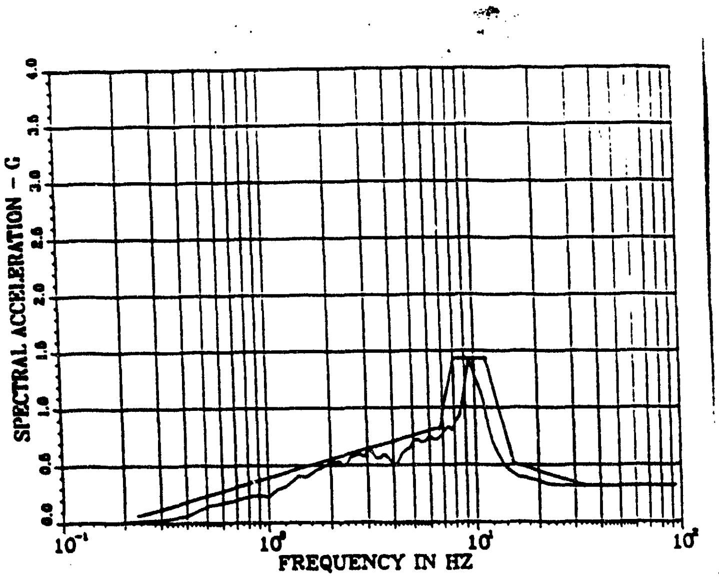

FIG. 4. N-S SPECTRUM AT OPERATING FLOOR

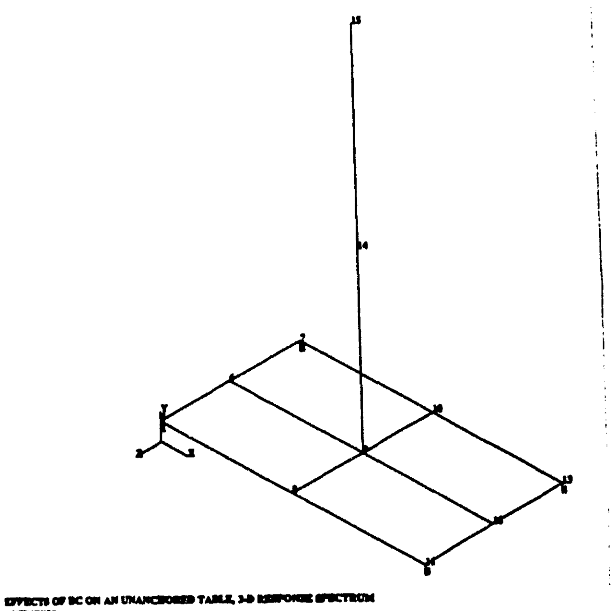

FIG. 3. FINITE ELEMENT MODEL OF A GENERIC FIXTURE

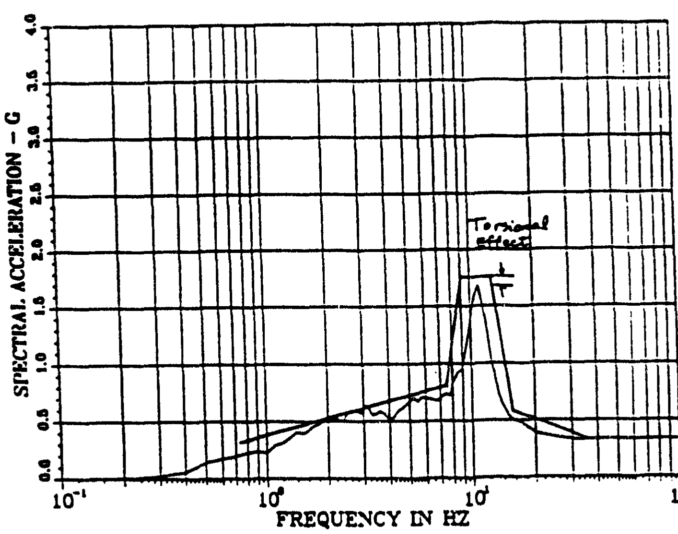

FIG. 5. E-W SPECTRUM AT OPERATING FLOOR

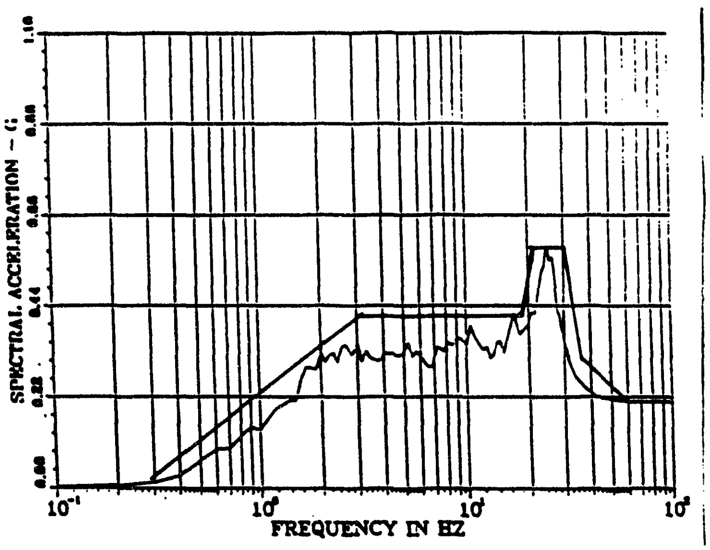

FIG. 6. VERTICAL SPECTRUM AT OPERATING FLOOR

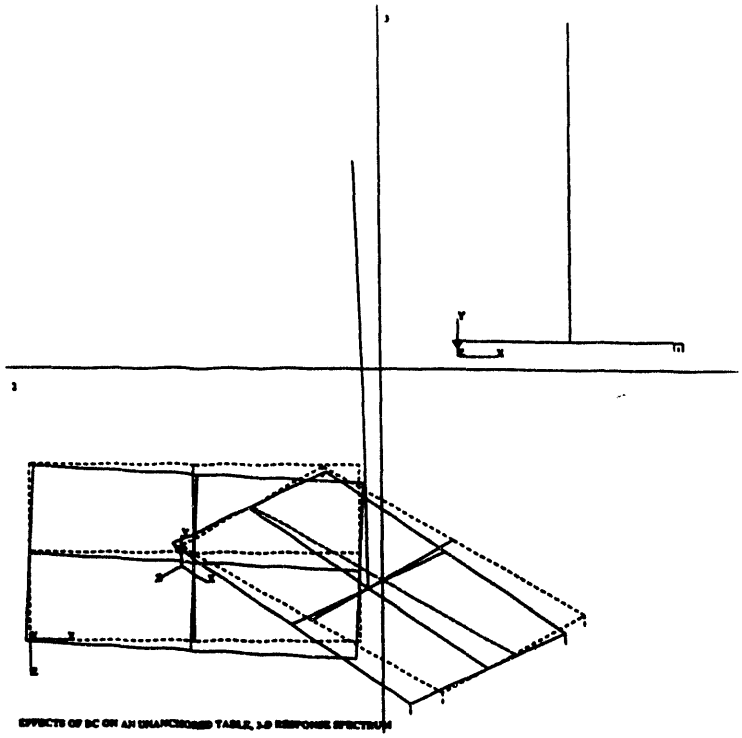

FIG. 8. MODE SHAPE WITH SIMULATED BOUNDARY CONDITION (b)

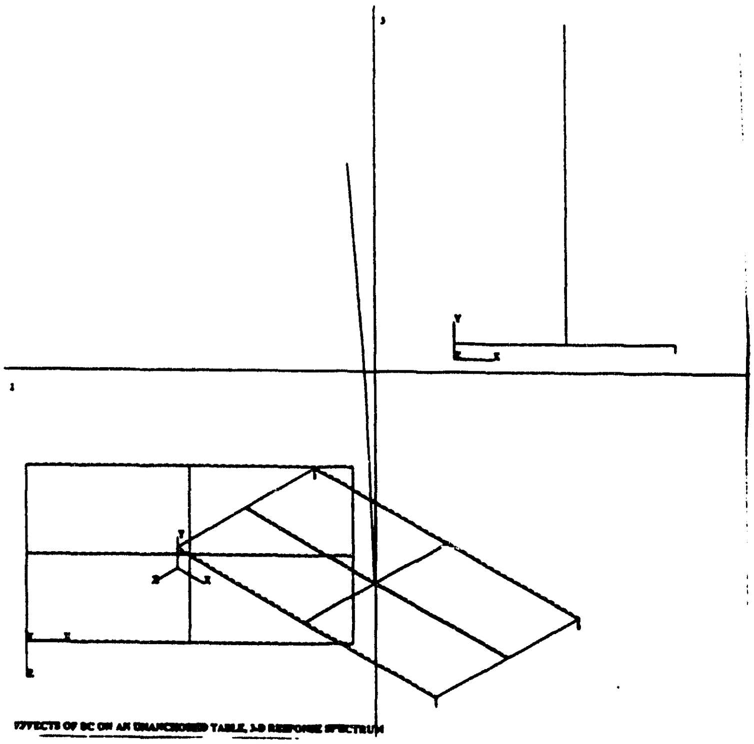

FIG. 7. MODE SHAPE WITH SIMULATED BOUNDARY CONDITION CASE (e)

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