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Seismic Responses of Unanchored Electrode Storage Fixtures

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ABSTRACT

Two unanchored electrode storage fixtures will be installed in the process cell of the Integral Fast Reactor's Fuel Cycle Facility at ANL-W in Idaho. In addition to the concerns for structural integrity, the potential for uplifting and tipping of the fixtures during the design basis earthquake must also be examined. In the analysis, a response-spectrum method was employed to investigate tipping, while a static approach was used for the structural-integrity evaluations. The results show that the combined stresses from seismic and other loads are within the allowables permitted by the design codes. The overall vertical seismic reaction forces at the leveling pads are compressive, implying that the fixtures will remain in contact with the floor. No uplifting or tipping of the fixture will occur during the design basis earthquake.

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I. INTRODUCTION

Two electrode storage fixtures (ESF) and an electrode assembly and disassembly machine (EADM) together form the electrorefiner mechanical handling system to be installed in the existing fuel process cell of the Integral Fast Reactor's (IFR's) Fuel Cycle Facility (FCF) at ANL-W in Idaho. For reasons associated with the integrity of the cell liners and operational flexibility, all equipment within the cell, including the electrorefiner mechanical handling system, are required to be unanchored.

The entire electrorefiner mechanical handling system (Fig. 1) is being qualified against loads including the design basis earthquake (DBE) in accordance with the Department of Energy guidelines (Kennedy, et. al., 1990) to the extent that its safety functions are not impaired, nor are those of the facility or other proximate equipment. Within the enclosed cell, an earthquake is the only natural hazard that should be considered in addition to dead and live loads.

Earthquake loads will introduce not only stresses to the fixtures and the EADM, but also the potential for sliding and tipping since they are not anchored. If sliding or tipping does occur, this equipment and their neighboring structures could be subjected to additional transient loads. Overturning is also a possibility when tipping becomes very excessive. To minimize the occurrences of these undesirable loads and situations, the electrorefiner mechanical handling system is designed so that there will be no relative sliding among its components, no impending tipping for each individual component, and no impairment of structural integrity.

In this paper, the response of an electrode storage fixture to various loadings is presented. A response-spectrum method has been used to investigate the impending tipping of a fixture during the DBE. Stresses from dead, live and the DBE loads are evaluated using a static approach, and are combined in accordance with the required codes and specifications to produce the maximum values. Results show that stresses are within their allowable limits, and the leveling pads supporting the structure remain in contact with the floor. Relative sliding among the fixtures and the EADM will not occur because of tie plates which interlock them. Stresses in a tie plate and its associated bolts were also calculated and found to be within the allowables.

II. STORAGE FIXTURE

The ESF shown in Fig. 2 is a support structure which accommodates storage of the electrorefiner electrode assemblies. It is part of the electrorefiner mechanical handling system shown in Fig. 1. Design requirements dictate that the fixtures, as well as other equipment in the fuel process cell, shall be unanchored structures.

Major components of the fixture include a top plate, two posts, and a base plate (Fig. 2). The slots and guide rings in the top plate are sized to store either electrode (standard cathode or anode) assemblies (EAs), electrode port plug assemblies (EPPAs), or liquid cadmium cathode (LCC) assemblies. The posts of length 82-in. are made of tubes with a 6-in. outside diameter and a 1-in. wall thickness. The 4-in. thick base plate provides stability for the fixture and the suspended assemblies. Total weight of the fixture without an electrode assembly is about 3,550-lb.

Different assemblies have different weights and centers of gravity. The EA has three different configurations, and each configuration has a different center of gravity. Assemblies suspended on the fixture can rotate and swing freely. During the DBE, the suspended assemblies would have pendular motions. If the pendular movement of the assemblies becomes non-trivial, the overall center of gravity of the loaded fixture could shift to a position higher than when the fixture was in static equilibrium, and increase the potential of tipping.

An electrode storage fixture is supported on four leveling pads which are not anchored to the floor. Tie plates have been designed to connect the fixtures with the EADM to eliminate the relative sliding among them. The unanchored ESF and EADM are to be positioned in the existing fuel process cell such that they will not collide with the cell wall or any other structures within the cell during the DBE.

III. SEISMIC TIPPING

When an unanchored rigid body is resting on a horizontal floor and subjected to gravitational and seismic loads which pass through the center of gravity of the body, its property for tipping can be characterized by a dimensionless parameter $k=r/h$, where h is the elevation of the center of gravity of the body above the floor, and r is the minimum tipping radius of the body measured horizontally from the projection of the center of gravity on the horizontal floor to the potential tipping axis. When two rigid bodies are subjected to the same loadings, the one with larger value of k is less vulnerable to tipping.

Let H(t) and V(t), with gravitational unit g, denote the horizontal and vertical seismic floor accelerations, respectively. Then for $|V(t)|<1$, a rigid body will not have impending tipping if its dimensionless tipping parameter k satisfies

$$k > \mathrm{Max}|H(t)/[1-V(t)]| \qquad (1)$$

Seismic accelerations are time dependent and oscillatory. Once a rigid body has started tipping, the subsequent motion could be very complex and difficult to predict. The body will rock if the motion is sufficiently small and stable. If the motion is sufficiently large, it could become unstable and the body will overturn. There is also a possibility that the rigid body will rock about more than two axes, and could even have a rolling motion.

Eq. (1) can be applied to equipment if it can be simulated as a rigid body. When an unanchored equipment has very flexible components, effects such as structural amplification and the shifting of the center of gravity should also be considered. The value of the parameter k for an unanchored equipment with flexible components in its initial static equilibrium state however remains to be an important parameter in the investigating of the equipment's tipping.

The unanchored ESF to be investigated weighs 3,550-lb.. Its center of gravity is 18.87-in. above the floor, and 0.32-in. from the major line of symmetry of the base plate. When the fixture is loaded with assemblies whose total weight could reach 1,950-lb, it would have a different center of gravity, and its tipping potential will be different as well.

Four cases with different assemblies and various configurations have been identified. They are: (1) normal storage of three complete EAs (Fig. 3), (2) storage of three EAs in the compressed form (Fig. 4), (3) storage of three EAs without the lower housing and lower shaft assembly (Fig. 5), and (4) storage of three EPPAs (Fig. 6). The weight and geometry of an LCC are similar to a complete EA, and the system has only two LCCs. Thus, Case 1 envelopes the storage arrangement when an LCC is involved.

The weight and location of the center of gravity of each assembly identified in the above four cases are summarized in Table I. Also included in the table are values for the tipping parameter k and the frequency of a simple pendulum equivalent to a suspended assembly.

From the values listed in Table I, Case 2 has the lowest value for the tipping parameter k. This means that, when the fixture has three EAs in compressed form, it has the greatest potential to tip. The assembly weight and pendulum frequency for this case are also very high. A heavier assembly could introduce a higher tipping moment when the assembly has a non-trivial displacement. From the floor design response spectra of the DBE, spectral accelerations are directly proportional to the frequency for frequencies less than 1 Hz. Therefore, Case 2 is most vulnerable to tipping during the DBE, and its potential for impending tipping was investigated using the response-spectrum method.

IV. TIPPING ANALYSIS MODEL

Overturning of an ESF during the DBE is definitely not acceptable. Stable rocking should be avoided also since it would introduce complicated loads to the equipment. It is therefore preferred to design an equipment without impending tipping during the DBE.

A finite element model has been developed to investigate the impending tipping of a loaded fixture. The model, which simulates Case 2 that has the highest tipping potential during the DBE, consists of three dimensional beam, three dimensional mass, and elastic quadrilateral shell elements of the ANSYS computer program.

In this tipping analysis model, the three assemblies are lumped into one as shown in Fig. 7. If these three assemblies are modeled individually, their responses to the DBE may not all be in phase, and the tipping potential will not be as conservative (i.e., it may be under--estimated) as a lumped one.

The upper plate of an ESF is simulated by beam elements. Areas of these elements have been adjusted such that the total weight or mass of these elements is the same as the upper plate itself. This model will yield the correct responses for the impending tipping investigation, although it may not produce accurate stresses for all of the fixture components.

The fixture is supported by four adjustable leveling pads which are not anchored to the floor. Nodes 1 through 4 in the finite element model simulate the contact points of these pads with the floor. In this tipping analysis model, linear displacements UX, UY, UZ of node 1, UX, UY of node 2, UY, UZ of node 3, and UY of node 4 in Fig. 7 are constrained. These conditions are valid if nodes 1 through 4 remain in contact with the floor, that is, the electrode storage fixture has no tipping if none of these leveling pads has uplifting.

V. SEISMIC LOADINGS AND RESPONSES FROM TIPPING MODEL

The ESF and the EADM will be installed within the enclosed fuel process cell of the FCF, where temperature and pressure fluctuations are limited. The only loads other than dead and live loads are those from earthquakes. In accordance with the guidelines for qualifying components and equipment within the cell, the site specific DBE is equivalent to a safe shutdown earthquake (SSE), and the operating basis earthquakes (OBE) are taken to be zero.

The DBE loads at the operating floor level where the fixtures and the EADM will be installed were specified in the guidelines and expressed in different forms. In Table II, the equivalent static load factors for the DBE are given, in gravitational unit g, in both horizontal and vertical directions. Figs. 8 through 10 are the floor-response spectra in the N-S, E-W, and vertical directions, respectively. In addition, the guidelines also specified that any unanchored equipment on the operating floor should be assumed to slide a distance of 6-in. in any direction from its initial location, with a maximum sliding velocity of 13-in/sec.

Unanchored equipment sliding 6-in. in any direction implies that a minimum clearance of 12-in. should be provided between any two unanchored neighboring pieces of equipment if they are not to collide with each other during the DBE. With the limited space available in the existing cell, the maximum clearance available between an ESF and the EADM can be no more than 6-in.. Tie plates were designed to unite the fixtures with the EADM, such that they form a single unit (Fig. 1) with no relative sliding between them. When none of the components of the electrorefiner mechanical handling system has impending tipping during the DBE, the only function of these tie plates is to eliminate relative sliding between any two of them. The tie plates are thus neglected in the modeling of the impending tipping of a fixture. Stresses in these plates and their associated bolts however must be evaluated to ensure that their structural integrity will not be impaired during the DBE.

When an unanchored equipment in equilibrium is subjected to gravitational and seismic loads, moments from downward vertical forces tend to preserve the equipment in its equilibrium configuration. Upward vertical forces, on the other hand, will enhance the tipping movement. The DBE has an equivalent static load factor of 1.2 in the vertical direction (Table II), which exceeds the gravitational effect. The total vertical force resulting from seismic and gravitational loads therefore could be in the upward direction, or the static method will predict that any unanchored equipment will overturn during the DBE.

The spectral representation of the DBE shows that the peak spectral acceleration in the vertical direction (Fig. 10) is less than 0.65 g, so that the resultant vertical force from gravitational and DBE loads is downward. There will be possibility that the horizontal (spectral) component of the DBE will not cause an unanchored equipment within the FCF to have uplift. The response-spectrum method is therefore used to investigate the impending tipping of an electrode storage fixture during the DBE.

When a fixture is installed in the cell, its major and minor axes of symmetry are essentially in the N-S and E-W directions, respectively (see Fig. 1). The smoothed floor-response spectra in Figs. 8 through 10 are applied to the appropriate directions of the finite element model in Fig. 7 in this tipping investigation.

A total of 15 modes have been included in the ANSYS response spectrum analysis. Natural frequencies of these modes range from 0.553 to 302 Hz. The first five natural frequencies from the analysis models are 0.553, 0.553, 18.0, 26.5 and 31.9 Hz, respectively. When these frequencies are compared with the frequencies in Table I, it is clear that the first two frequencies from the finite element model correspond to the orthogonal motions of the lumped assembly responding as a pendulum. The fact that the third natural frequency is much higher than the first two indicates clearly that the fixture itself behaves as a rigid body. The mode shapes of the first three modes given in Figs. 11 through 13 confirm the dynamic behavior of the system. Note that displacements in these figures are greatly exaggerated to show the deformed configuration of the fixture.

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 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.

Magnitudes of the vertical seismic reaction forces at the leveling-pad bolts, which were assumed to be constrained to the floor, are found to be 615-lb. or less. These seismic forces could be either tensile or compressive, but they are much less than one-fourth of the equipment's dead weight (3,550-lb for the fixture itself, and 1,445-lb for the assemblies of Case 2 modeled in the analysis). When these seismic effects are combined with contributions from other loads, the overall vertical reaction forces at the bolts are all compressive during the DBE, i.e., the DBE will not introduce uplift to any of the pads. This result of no uplift at the pads also affirms the artificial boundary conditions at the unanchored leveling pads.

The maximum horizontal displacement from the response-spectrum analysis for the model is 7.56-in. and occurs at the node simulating the center of gravity of the lumped assemblies. The maximum horizontal displacement of the remaining fixture is less than 0.026-in. The 7.56-in horizontal displacement exceeds the 0.44-in clearance between a post and the housing flange of an assembly, so there is a possibility that a suspended assembly could strike a nearby post during the DBE. The additional stress resulting from this impact was evaluated and included in the structural integrity evaluation for the post. No other structure is within the striking range of a suspended assembly.

VI. STRESS EVALUATION

Allowable stresses in shear, tension, compression, and bending are established following the guidelines provided in N690 (ANSI/AISC N690, 1984). The only loads to which an ESF will be subjected are dead load D, live load L (including impact) and the DBE which is equivalent to SSE. Only two of the load combination cases of N690 (ANSI/AISC N690, 1984) must be considered for the ESFs which are within an enclosed cell. Load combinations for these two cases, together with their respective stress coefficient limits, are expressed as

Normal: $D+L < 1.0$ (2)

Extreme: $D+L+DBE < 1.6$ (1.4 for shear) (3)

A static method was used to evaluate stresses including the seismic stresses introduced by the DBE. The seismic loads used in the stress evaluation are based on the maximum equivalent static load factors in Table II, that is, 1.2 in the vertical direction, and $3\sqrt{2}$ in the horizontal direction, assuming that the two orthogonal horizontal components have the same maximum value.

The dead load considered is the 3,550-lb weight of the structure. Since the 650-lb weight of a complete EA is the heaviest assembly in Table I, it will be used as the basis in determining the live loads. Live loads consist of the 1,950-lb weight for three complete EAs and 650-lb of impact forces in the horizontal and vertical directions which might occur when an EA is loaded into the fixture. The impact load exerted on a post from the 7.56-in horizontal displacement of an assembly during the DBE has also been included in the live load.

In evaluating stresses in the four leveling-pad bolts due to dead and live loads, all vertical loads are assumed to be evenly distributed. Horizontal loads are assumed to be resisted only by two bolts on the tipping axis assuming that the fixture had impending tipping. Since the response-spectrum analysis has shown that all four leveling bolts remain in contact with the floor, stresses in the leveling pads as evaluated will be conservative.

As noted above, the 6-in. diameter support posts could be subjected to additional impact loads from a swinging assembly during the DBE. Based on the assumptions of elastic responses and no loss of energy, stresses from the 7.56-in horizontal displacement of an assembly to a post were evaluated and combined with other stresses in the post.

Stresses in the tie plates and the associated bolts also have been evaluated. In the perfect frictionless environment, small unanchored structures connected together will move as a single body during earthquakes, and seismic loads exerted on the connector are trivial. Stresses will arise in the tie plate and bolts when there are relative linear and angular movements between an ESF and the EADM during the DBE. In the stress evaluations, relative angular movement is observed to introduce much higher stresses to the tie plate and bolts than the relative linear movement.

Stress coefficients for different components of an ESF have been calculated and are summarized in Table III. They are all within the respective allowable limits.

VII. CONCLUSION

The electrode storage fixture investigated here is part of the electrorefiner mechanical handling system. The system, consisting of two fixtures and the EADM, will be installed unanchored within the FCF process cell. All of the three pieces of the system are unanchored. Thus, in addition to structural integrity, there are concerns regarding sliding and tipping of the equipment during the DBE.

The space within the existing cell is very limited. Maximum clearance between a fixture and the EADM is only a fraction of the slide displacement prescribed in the seismic design specifications. To avoid potential impact and any ensuing instability, tie plates have been designed to unite the fixtures with the EADM, such that there will be no relative sliding among them.

Tipping of a fixture during the DBE has been investigated using finite element method with simulated fixity at the supports. The case of a loaded fixture with the smallest tipping parameter (i.e., most vulnerable to tipping) has been modeled without the tie plate. Results from a response-spectrum analysis show that all of the four supports on the electrode storage fixture will remain in contact with the cell floor, which indicates that impending tipping will not occur during the DBE.

The structural integrity investigation considered dead, live, and the DBE loads. All stresses coefficients are found to be within the allowable limits. The ESF, including the tie plate assembly, thus satisfies the design specifications of N690.

REFERENCES

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

2. Kennedy, R. P., et al., 1990, "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards," UCRL-15910.

3. U. S. Nuclear Regulatory Commission, 1976, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Regulatory Guide 1.92.

Table I. Weights and Centers of Gravity of Different Assemblies in Various Configurations

Case	Description	Assembly Weight (lb)	c.g. from Suspension (in.)	Tipping Parameter (Three Assemblies)	Equivalent Pendulum Freq. (Hz)
1	Complete EA	650	41.09	0.582	0.49
2	EA in Compressed Configuration	515	30.09	0.546	0.57
3	EA w/o Lower Housing and Lower Shaft	346	25.15	0.581	0.62
4	EPPA	300	38.36	0.667	0.50

Table II. Equivalent Static Load Factor (g) at Operating Floor

	Fundamental Vibration Frequency		
	4-20 Hz	>20 Hz	Unknown
Horizontal	3.0	0.8	3.0
Vertical	1.2	1.2	1.2

Table III. Stress Coefficients for Electrode Storage Fixture, Static Analysis

	Normal Condition (allowable = 1.0)	Extreme Condition (allowable = 1.6*)
Leveling Bolts	0.27	1.21
Base Plate	--	0.47
Posts	0.08	1.32
Upper Plate	0.22	0.47
Tie Plate	--	0.26
Tie Bolts	--	0.94

*1.4 for shear

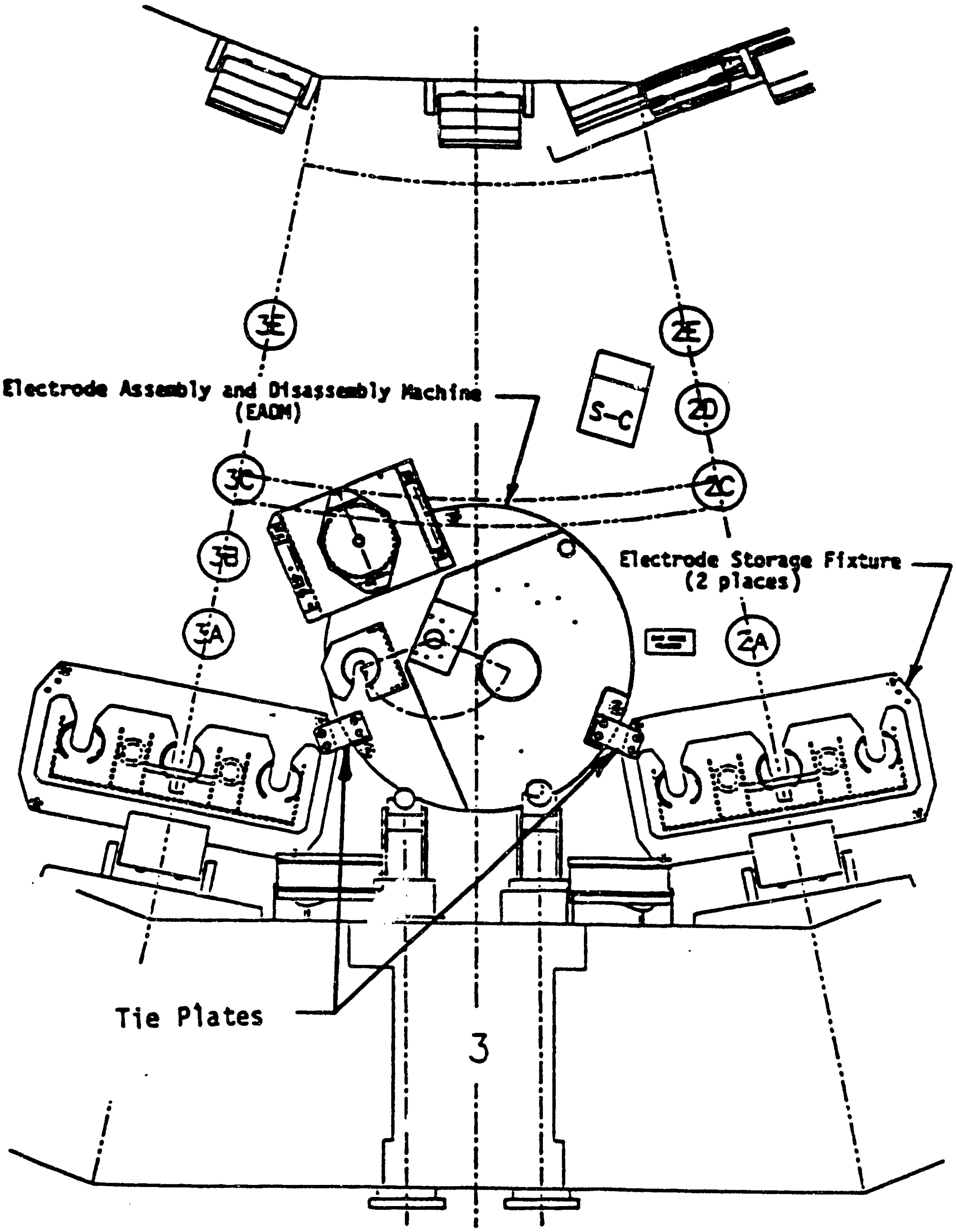

Figure 1 Electrorefiner Mechanical Handling System

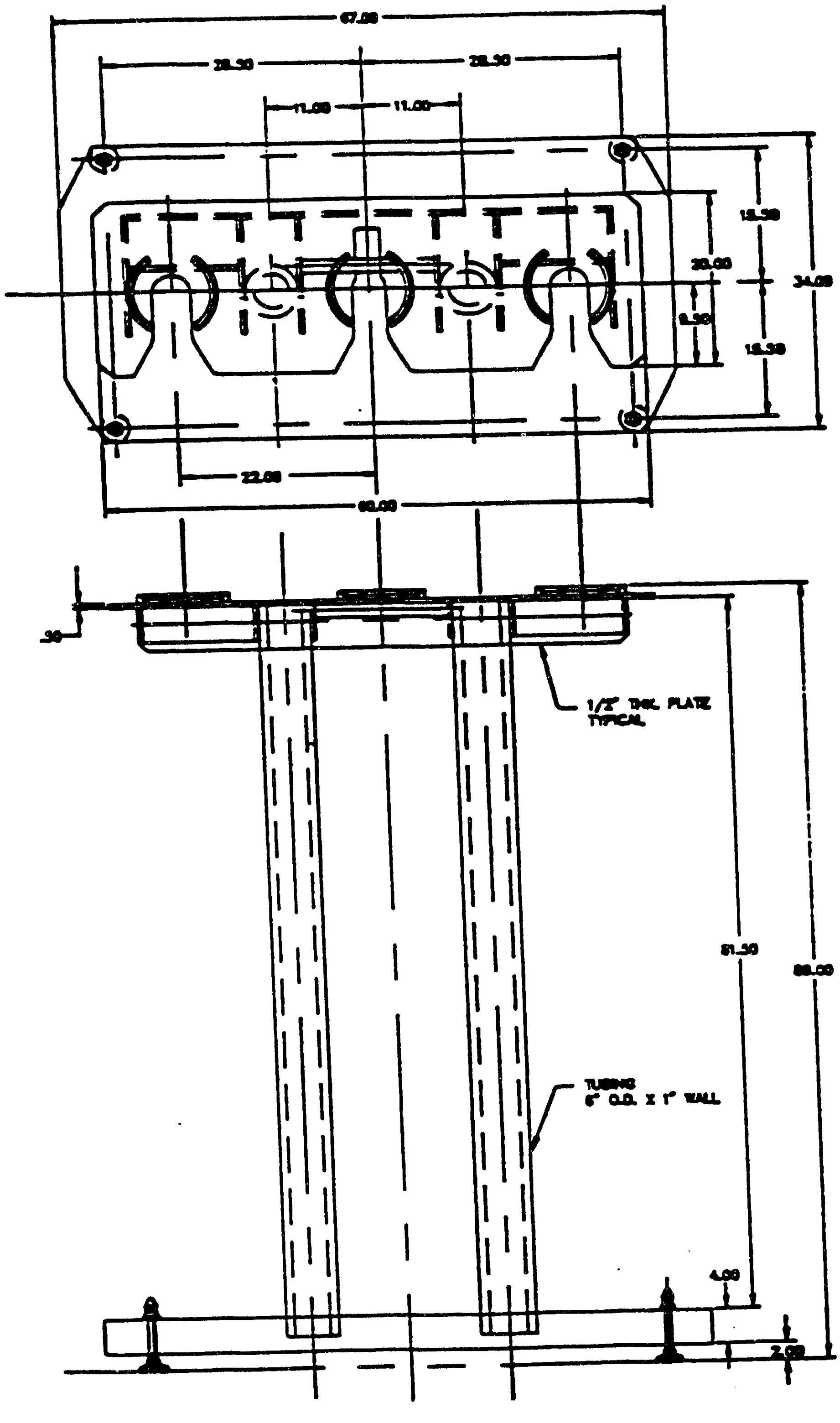

Fig. 2   Electrode Storage Fixture Structure

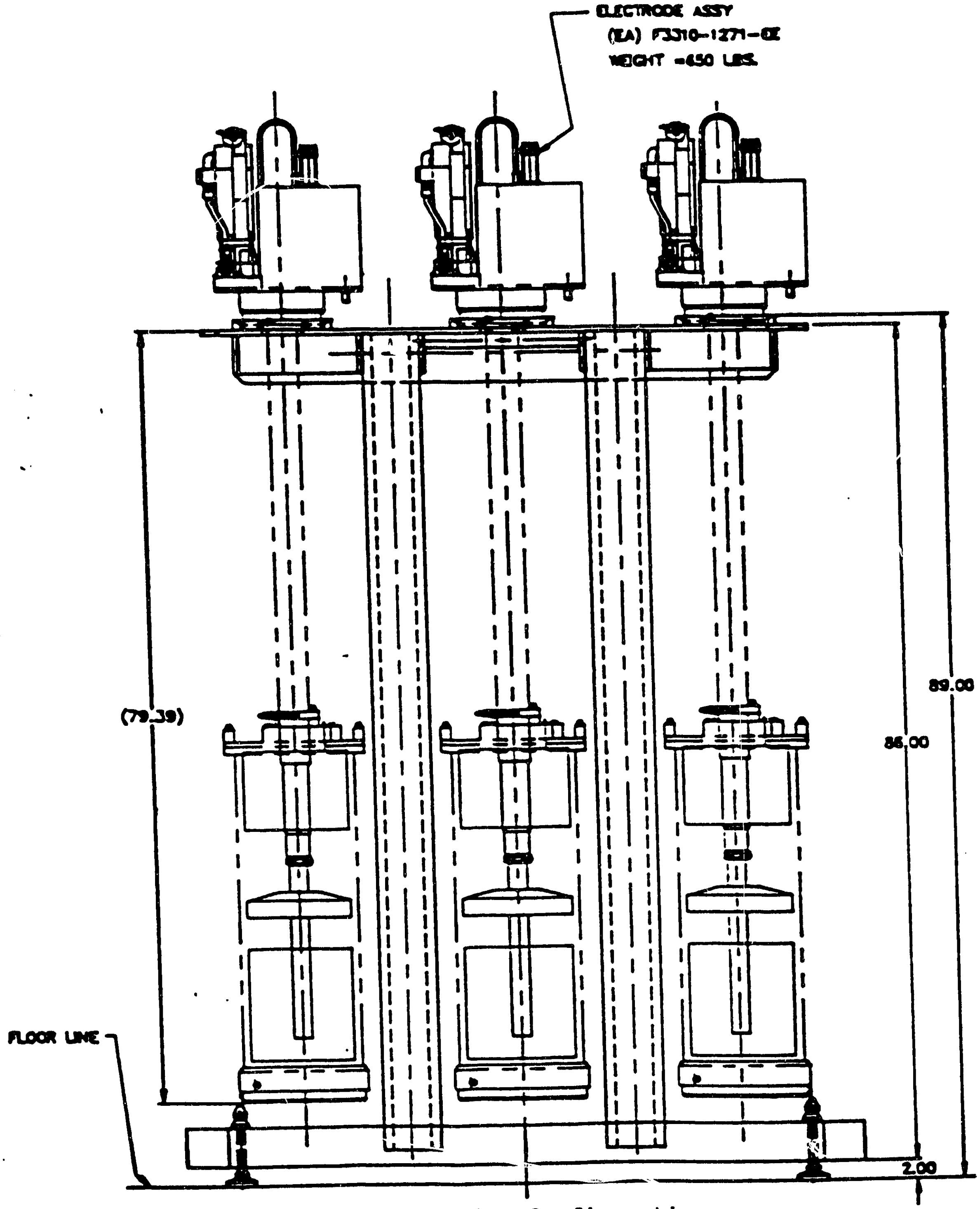

Fig. 3. Case 1 Load Tipping Configuration

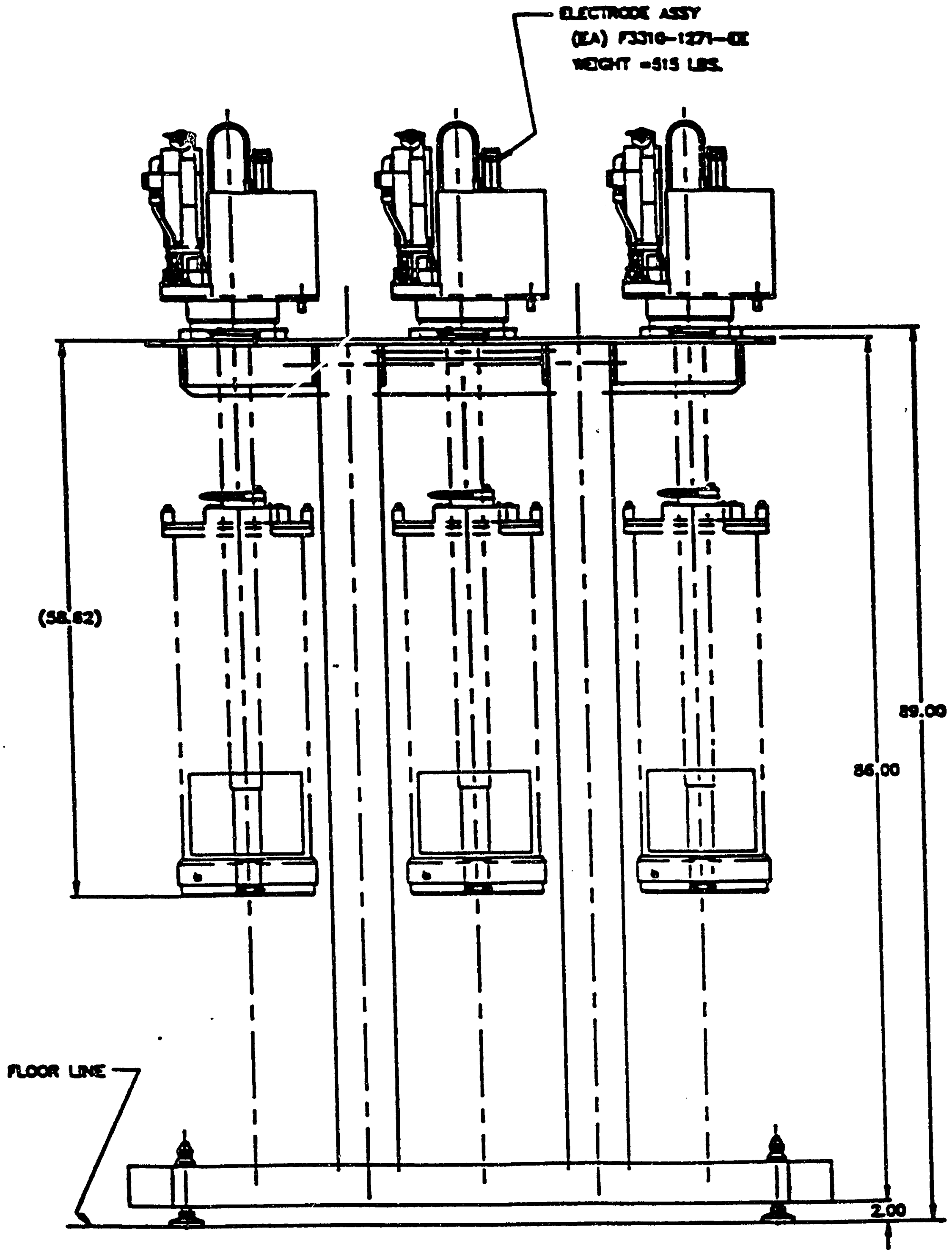

Fig. 4. Case 2 Load Tipping Configuration

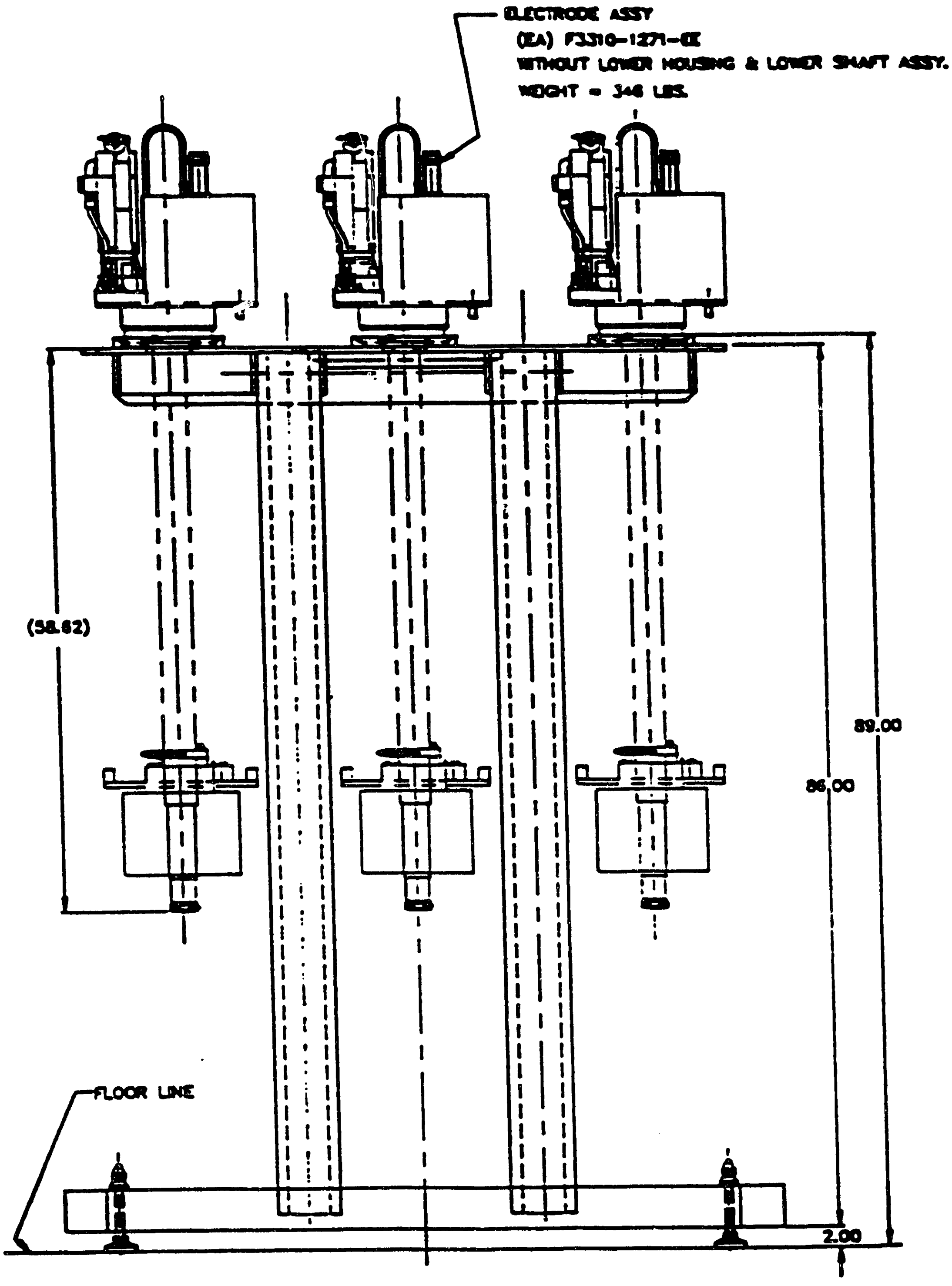

Fig. 5. Case 3 Load Tipping Configuration

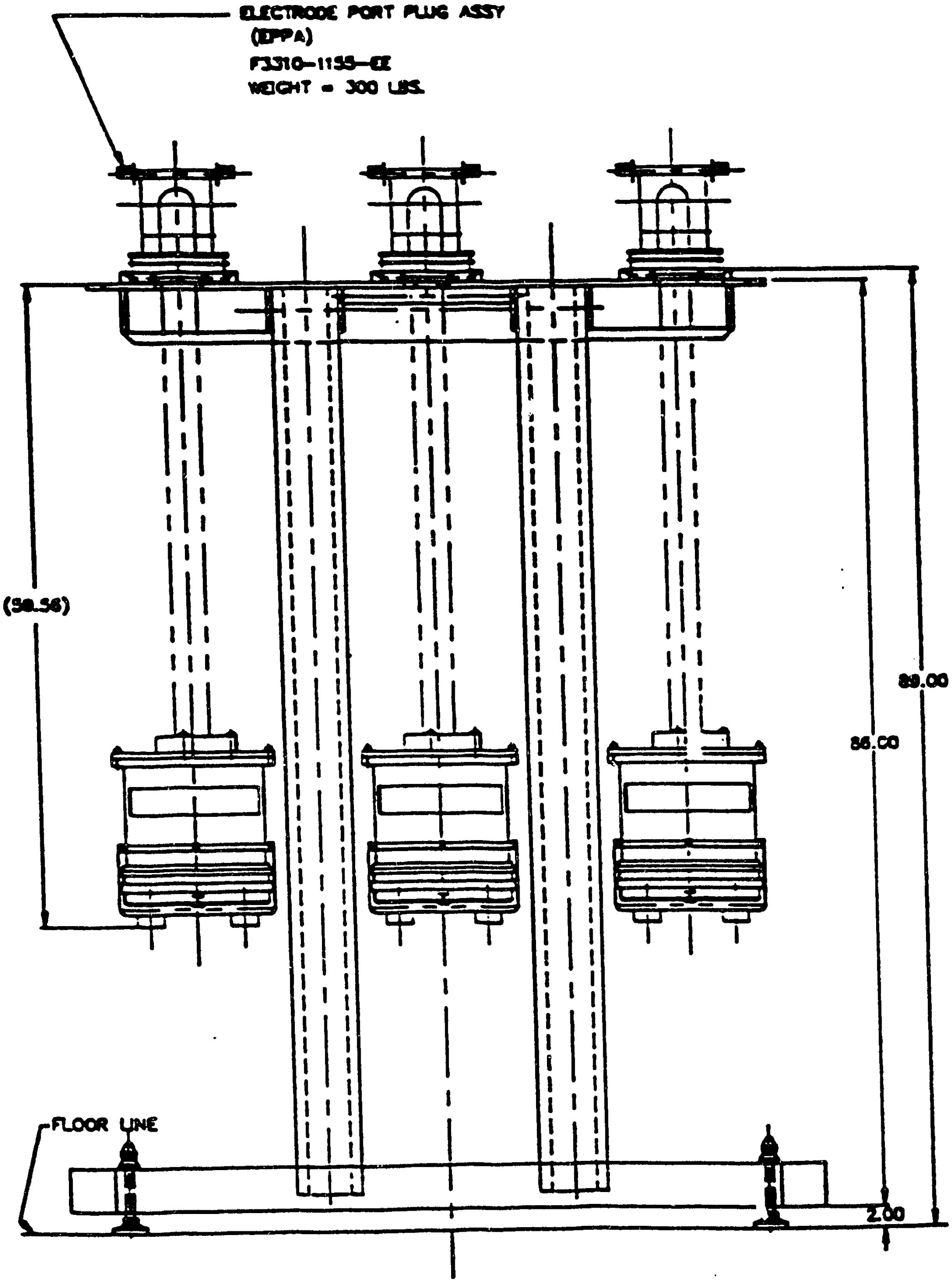

Fig. 6. Case 4 Load Tipping Configuration

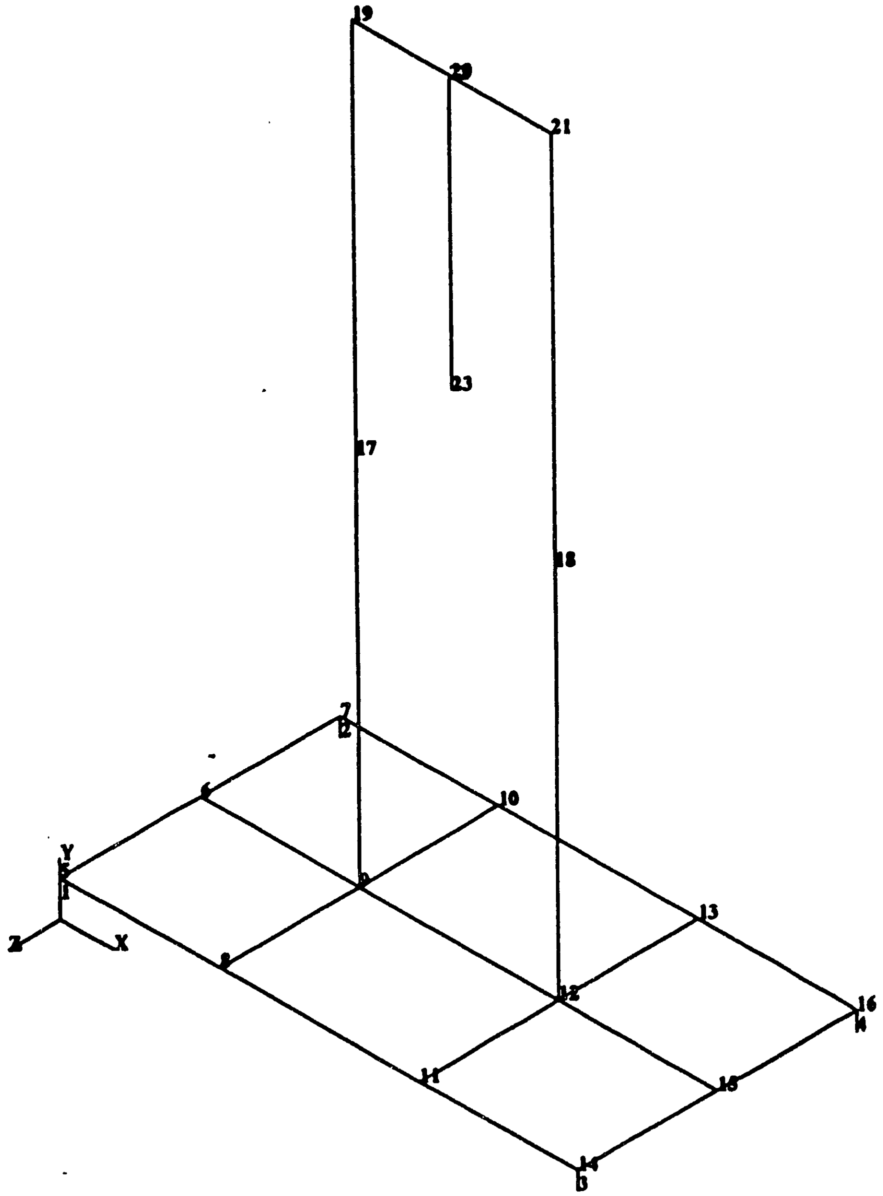

Fig. 7. Finite Element Model Simulating
an Electrode Storage Fixture

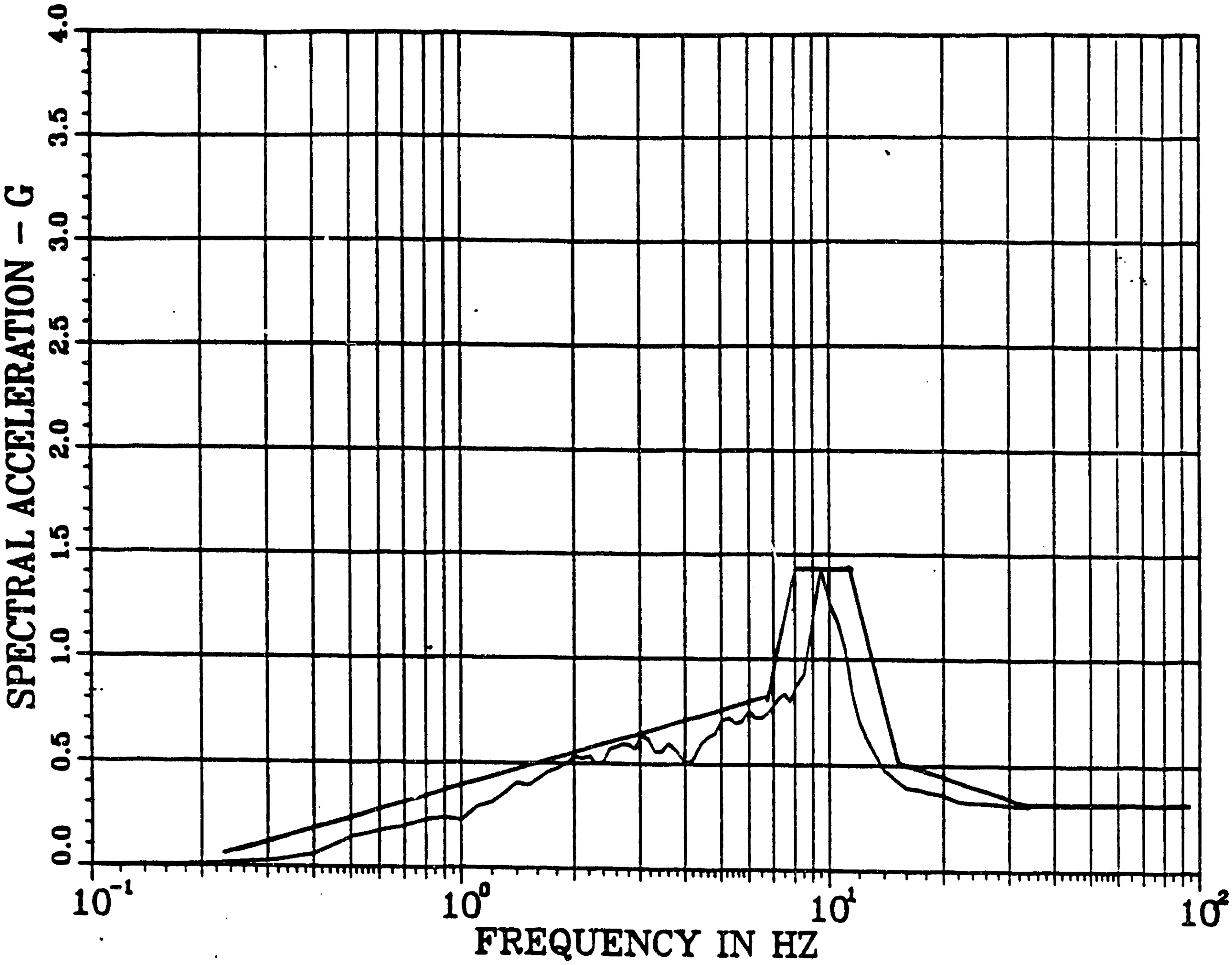

Fig. 8. N-S Spectrum at Operating Floor

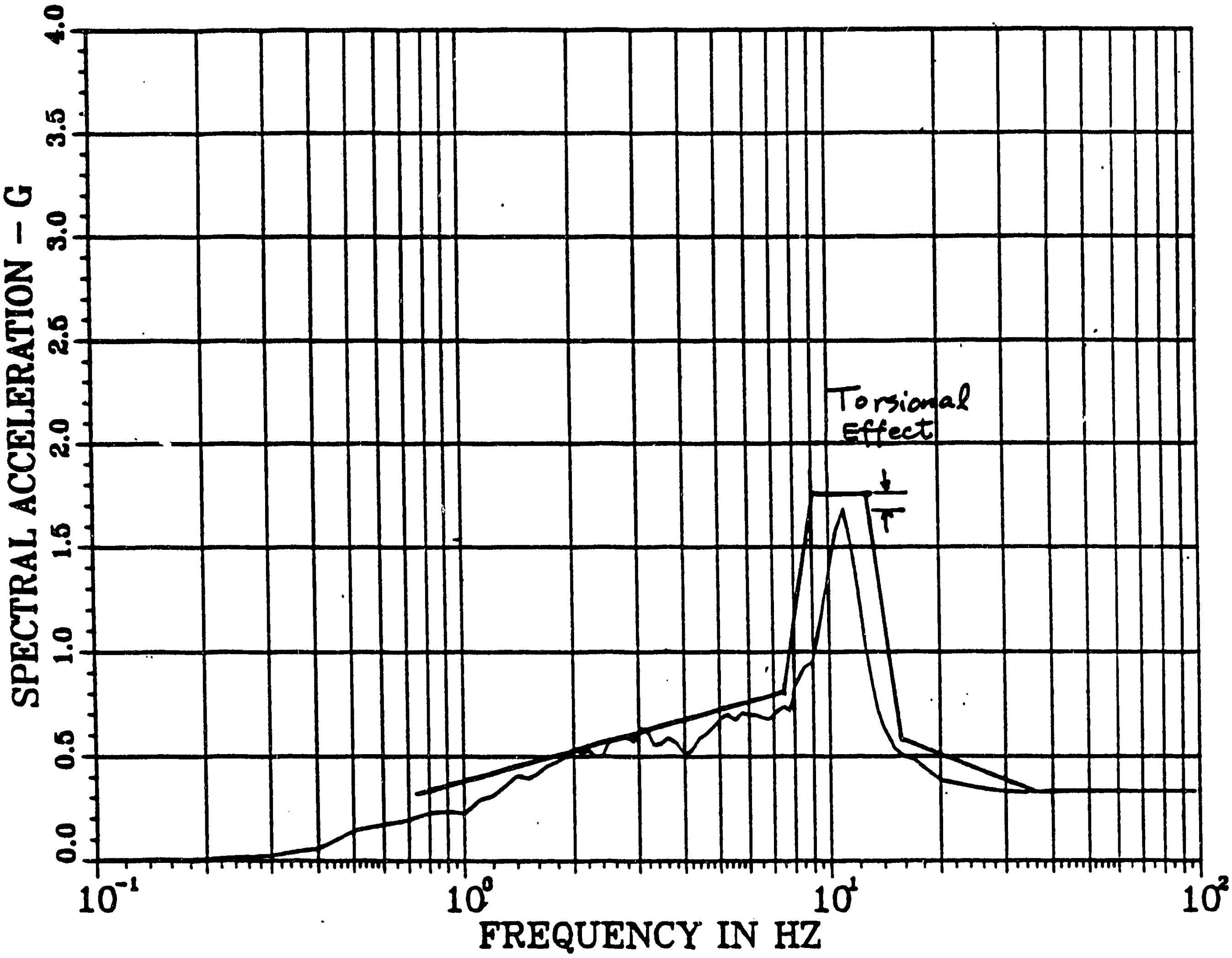

Fig. 9. E-W Spectrum at Operating Floor

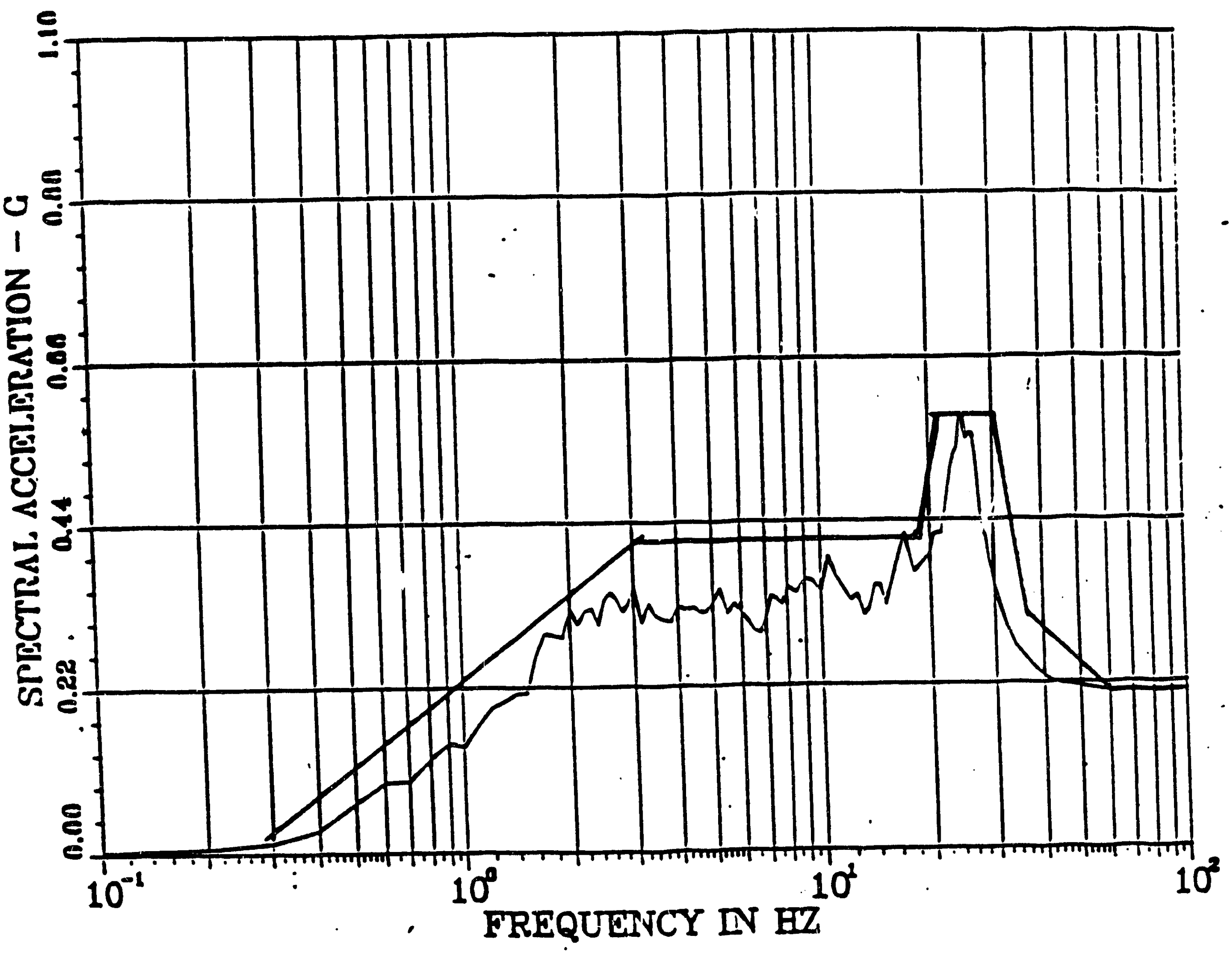

Fig. 10. Vertical Spectrum at Operating Floor

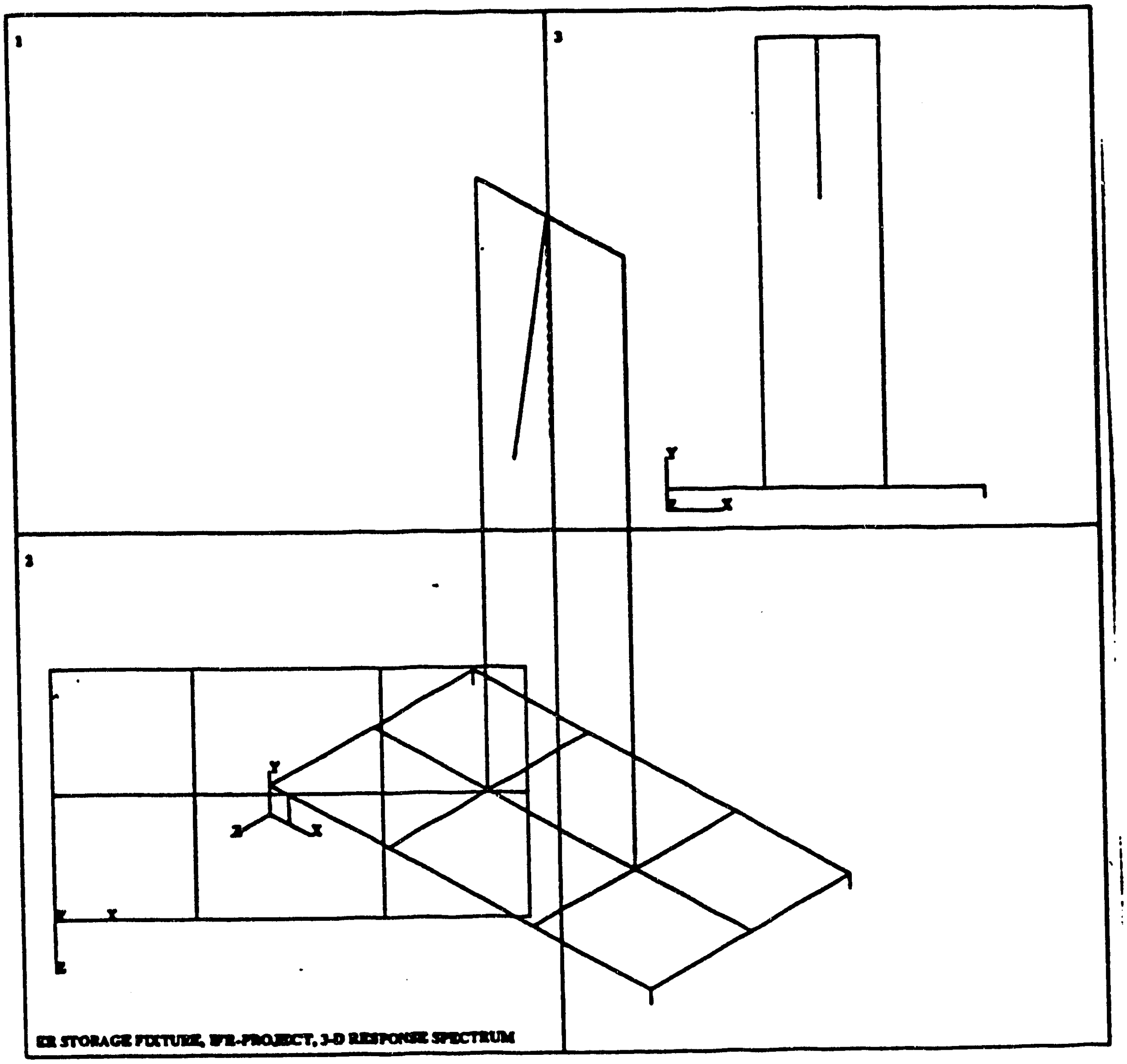

Fig. 11. First Mode Shape, Electrorefiner Storage Fixture with Assemblies

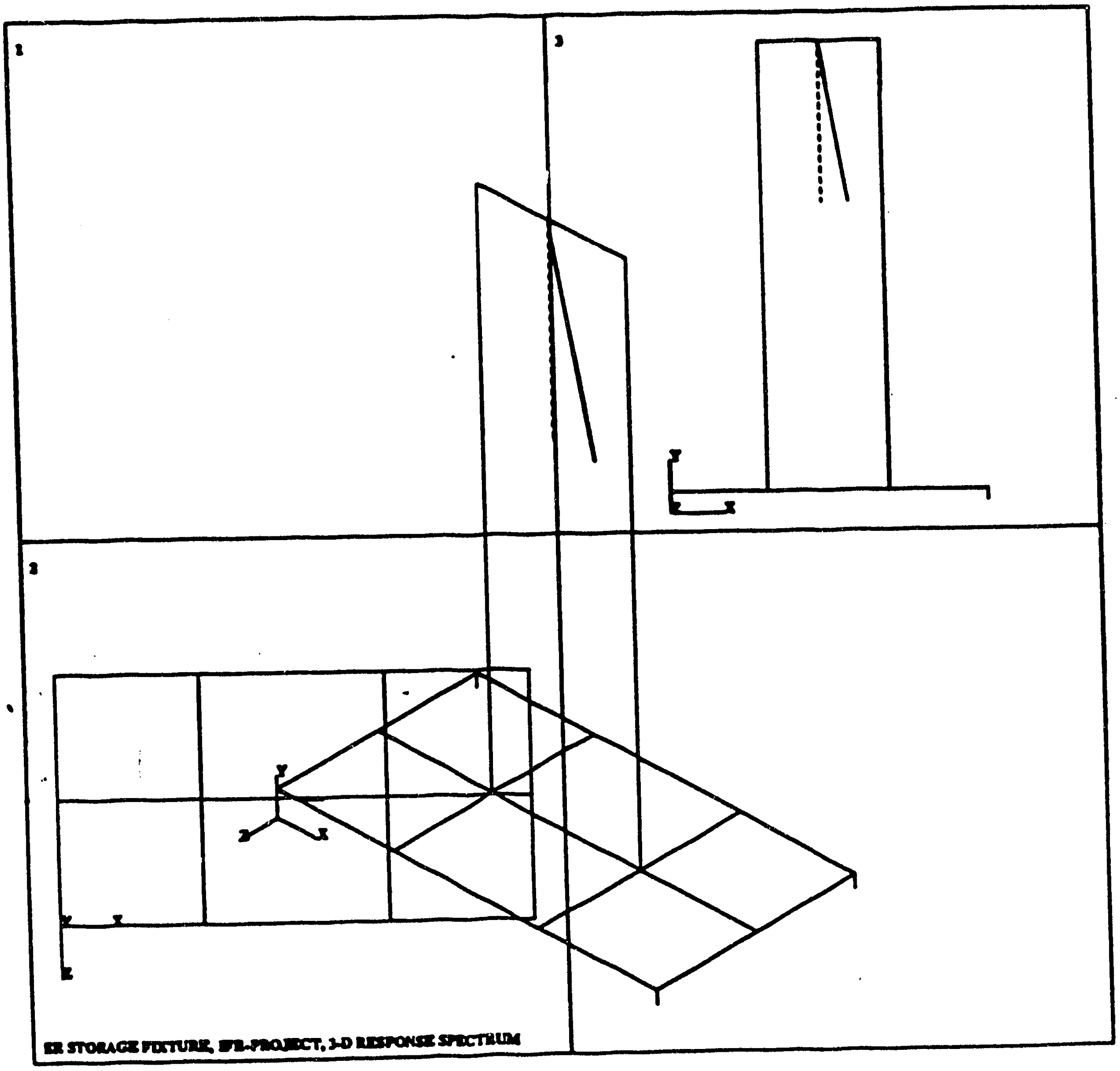

Fig. 12. Second Mode Shape, Electrorefiner Storage Fixture with Assemblies

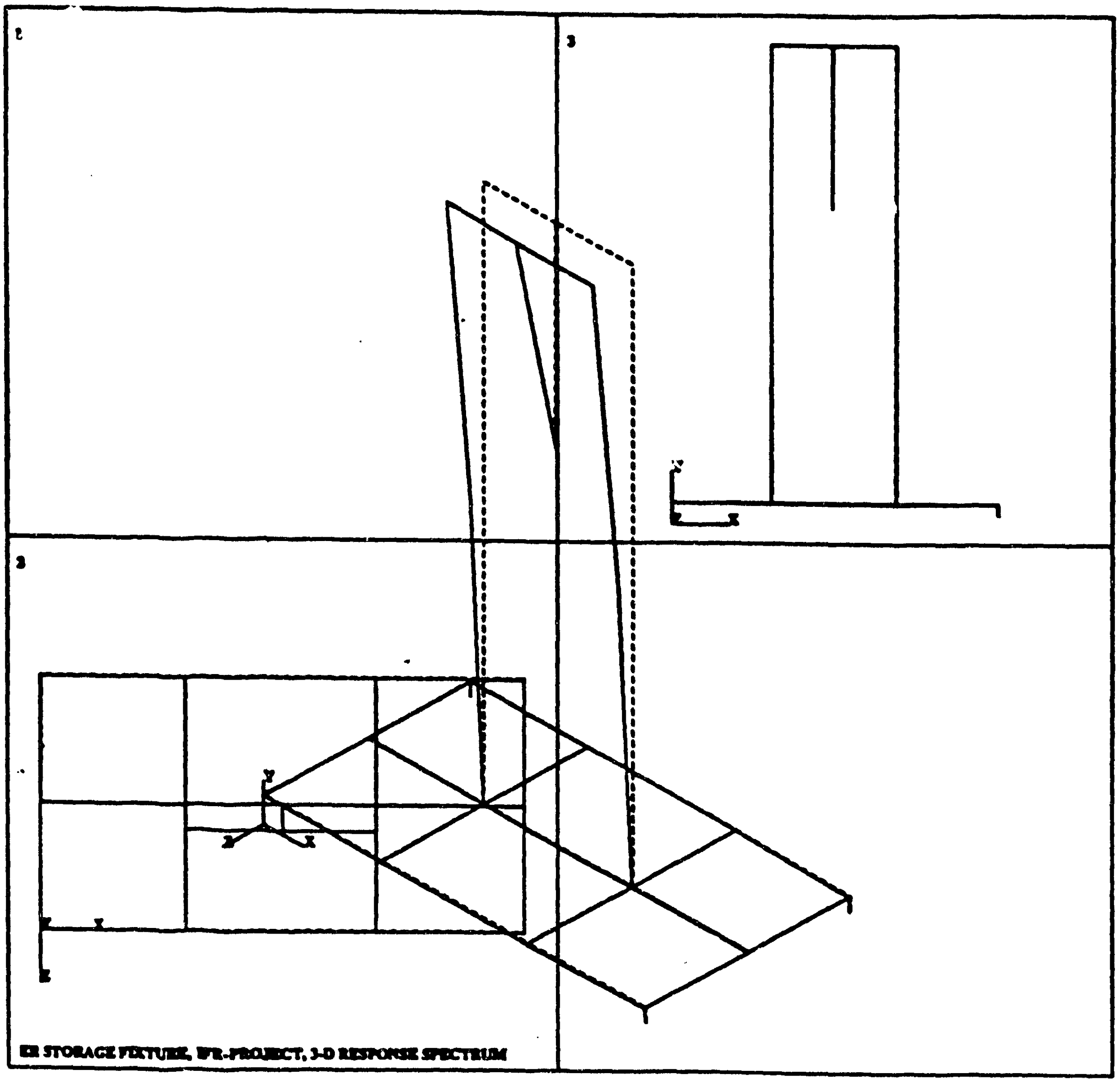

Fig. 13. Third Mode Shape, Electrorefiner Storage Fixture with Assemblies

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