NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

State University of New York at Buffalo

Study of Seismic Isolation Systems for Computer Floors

by

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Technical Report NCEER-94-0020

July 19, 1994

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NOTICE

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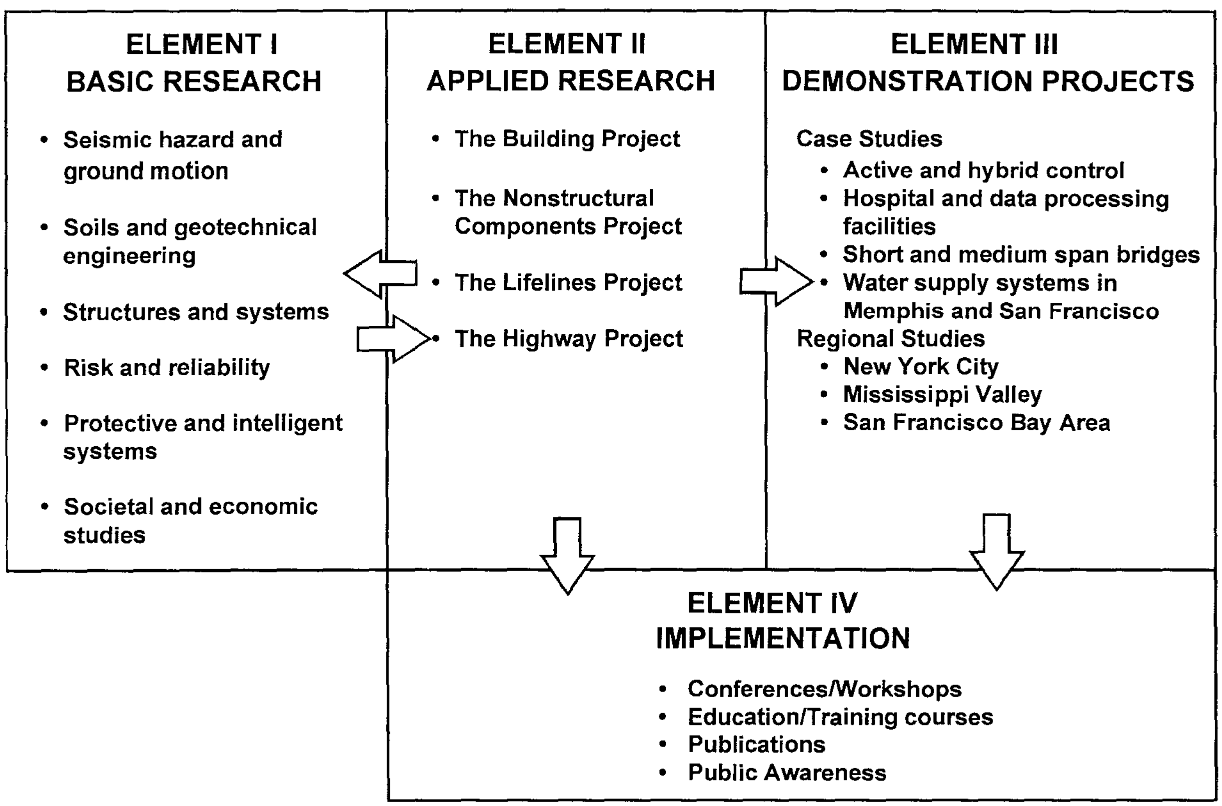
PREFACE

The National Center for Earthquake Engineering Research (NCEER) was established to expand and disseminate knowledge about earthquakes, improve earthquake-resistant design, and implement seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures in the eastern and central United States and lifelines throughout the country that are found in zones of low, moderate, and high seismicity.

NCEER's research and implementation plan in years six through ten (1991-1996) comprises four interlocked elements, as shown in the figure below. Element I, Basic Research, is carried out to support projects in the Applied Research area. Element II, Applied Research, is the major focus of work for years six through ten. Element III, Demonstration Projects, have been planned to support Applied Research projects, and will be either case studies or regional studies. Element IV, Implementation, will result from activity in the four Applied Research projects, and from Demonstration Projects.



Research tasks in the **Nonstructural Components Project** focus on analytical and experimental investigations of seismic behavior of secondary systems, investigating hazard mitigation through optimization and protection, and developing rational criteria and procedures for seismic design and performance evaluation. Specifically, tasks are being performed to: (1) provide a risk analysis of a selected group of nonstructural elements; (2) improve simplified analysis so that research results can be readily used by practicing engineers; (3) protect sensitive equipment and critical subsystems using passive, active or hybrid systems; and (4) develop design and performance evaluation guidelines.

The end product of the **Nonstructural Components Project** will be a set of simple guidelines for design, performance evaluation, support design, and protection and mitigation measures in the form of handbooks or computer codes, and software and hardware associated with innovative protection technology.

The **protective and intelligent systems program** constitutes one of the important areas of research in the **Nonstructural Components Project**. Current tasks include the following:

1. Evaluate the performance of full-scale active bracing and active mass dampers already in place in terms of performance, power requirements, maintenance, reliability and cost.
2. Compare passive and active control strategies in terms of structural type, degree of effectiveness, cost and long-term reliability.
3. Perform fundamental studies of hybrid control.
4. Develop and test hybrid control systems.

The objective of the test program described in this report was to investigate seismic effectiveness of computer floor isolation systems by utilizing devices which have been found to be effective in seismic isolation of buildings or shock isolation of military equipment. The isolation systems tested in the laboratory consisted of spherically shaped sliding bearings which were highly damped either by utilizing high friction in the bearings or by installing fluid viscous dampers. The experimental results demonstrated substantial reductions in the response of a generic computer cabinet on top of the isolated floor subject to simulated ground motions. Under non-isolated conditions, the cabinet underwent rocking and experienced acceleration which could cause either interruption of operation or failure. In contrast, the cabinet on the isolated floor with long isolation periods did not experience rocking and developed substantially less acceleration. An analytical model of the tested system was also developed and shown to be capable of predicting the experimental results with good accuracy.

ABSTRACT

The work described in this report concentrated on the development and testing of computer floor seismic isolation systems by utilizing devices of established effectiveness in the seismic isolation of buildings and shock isolation of military equipment. A computer floor system with raised floor and a generic slender equipment was constructed. It was isolated by spherically shaped sliding bearings and was highly damped either by utilizing high friction in the bearings or by installing fluid viscous dampers. The spherically shaped bearings provided the simplest means of achieving long period in the isolation system under low gravity load. The isolation system prevented rocking of the cabinet on top of the isolated floor and substantially reduced its acceleration response in comparison to that of a conventional computer floor. An analytical study was also conducted in order to extend the results to a range of parameters which could not be tested.

ACKNOWLEDGEMENTS

Financial support for this project has been provided by the National Center for Earthquake Engineering Research, Project No. 925201B.

Earthquake Protection Systems, Inc. of San Francisco, California supplied the FPS bearings and Taylor Devices, Inc. of North Tonawanda, NY supplied the fluid viscous dampers. The raised floor system was a Tate Access Floor system, supplied by Rochester Davis-Fetch Corporation of Lancaster, NY.

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SECTION 1

INTRODUCTION

Provisions for the design of buildings intend to provide protection against major structural failure and loss of life. They are not intended to limit damage, maintain function, or provide for easy repair (SEAOC, 1990). Yet, structures house equipment, such as computers and data processing systems, on which businesses and industries rely. Interruption or failure of these systems in an earthquake may result in chaos and substantial economic loss.

Moreover, the safety of computers and other equipment is a concern when they perform life saving operations such as in hospitals. Also, the protection of invaluable artifacts in museums is important.

Protection of important equipment and artifacts in buildings may be accomplished in a variety of ways, with varying degrees of success:

(a) Seismic Isolation of Building.

Seismic isolation of the entire building offers the benefits of reduction or elimination of damage to the structural system, nonstructural components and housed equipment and artifacts. In this construction technique the entire structure is supported on horizontally flexible bearings (may be elastomeric or sliding bearings) so that its fundamental period increases to values beyond the predominant one in the seismic excitation. Effectively, seismic energy is deflected, leading to reduced inertia forces on the structure. The approach is particularly attractive for new construction. It has been used in the United States and Japan in a number of critical facilities, such as hospitals, fire command centers and computer manufacturing facilities (Kelly 1993, Soong and Constantinou 1994).

(b) Innovative Installation Procedures for Equipment.

These installation procedures may take the form of seismic isolation systems or a form of combined limited isolation and energy dissipation systems. Typically, seismic isolation of equipment is confronted with a number of problems, such as extreme difficulty to achieve the desired long period and large displacements in comparison to the dimensions of equipment.

For example, consider the problem of providing effective isolation for a motion such as the 1940 El Centro earthquake, of which the response spectrum is given by Figure 3-14 herein. For bearings with a damping ratio of 5 % of critical and isolation period of 2 secs will result in an acceleration of 0.2 g with bearing displacement of about 200 mm. Bearings for these requirements are easily designed for buildings, but are very difficult or impossible to meet for equipment, which have small weight.

Furthermore, equipment in the upper floors of a building experience motions which are amplified in acceleration and contain strong components at long periods. Figure 3-16 herein presents the response spectrum of motion at the 7th floor of a building excited at its base by the same 1940 El Centro motion. For an isolated equipment at the 7th floor to achieve an acceleration of 0.2 g , it requires an isolation period of 2.8 secs , for which the bearing displacement is about 390 mm. Apart from the extreme difficulty in achieving this period (most types of bearings will be unstable under the gravity load), the required displacement capacity of the isolation system is of the same order as that of the equipment itself. Typically, to achieve effective isolation of single equipment under these conditions it is required to use either spherically shaped sliding bearings, or multi-stage rubber bearings, or pneumatic isolators. In any case, the cost is prohibitively high.

Alternatively, systems consisting of locked casters and restoring force/damping devices, such as wire rope springs and viscoelastic elements, and stiff helical spring-viscous damper systems were respectively tested by Demetriades 1992 , Kosar 1993 and Makris 1992. The systems were found to improve the seismic response of single equipment either by reducing accelerations at the expense of limited displacements or by maintaining accelerations at the same level and substantially reducing the sliding displacements of conventionally mounted equipment. However, the systems required the use of rather complex arrangements of elements, which could constrain normal operations in a computer room.

(c) Seismic Isolation of Computer Floors.

Problems with seismic isolation or innovative installation procedures of single equipment can be alleviated by providing seismic isolation to entire computer floors. In this way, the seismic forces may be substantially reduced while normal operations in the computer room are not affected.

The Japanese construction industry developed a number of such computer floor systems by utilizing combinations of devices, such as sliding bearings, springs, dampers, multi-stage rubber bearings, pneumatic isolators and even active components (Fujita 1991).

The work described in this report concentrated on the development and testing of computer floor seismic isolation systems by utilizing devices of established effectiveness in the seismic isolation of buildings and shock isolation of military equipment. A computer floor system with raised floor and a generic slender equipment cabinet was constructed. It was isolated by spherically shaped sliding bearings and was highly damped either by utilizing high friction in the bearings or by installing fluid viscous dampers. The spherically shaped bearings provided, in our opinion, the simplest means of achieving long period in the isolation system under low gravity load.

The isolation system prevented rocking of the cabinet on top of the isolated floor and substantially reduced its acceleration response in comparison to that of a conventional computer floor. An analytical study was also conducted in order to extend the results to a range of parameters which could not be tested.

SECTION 2

DESCRIPTION OF COMPONENTS OF FLOOR ISOLATION SYSTEM

2.1 Introduction

The behavior of three isolation systems was investigated during these series of tests. All three systems had as a basic isolation device the Friction Pendulum System (FPS) bearing, a form of spherical sliding bearing. This bearing was selected because it can be designed to deliver a large isolation period and accommodate large displacements under low gravity load without any instability problems. In one tested configuration, only FPS bearings of high friction were used. In two other configurations, better performance was sought by utilizing lower friction bearings and by enhancing the ability of the isolation system to dissipate energy through the use of fluid viscous dampers. The various components of the isolation system are described in the following sections.

2.2 Friction Pendulum System Bearings (FPS)

A cross section view of a FPS bearing used in testing is shown in Figure 2-1. The bearing consists of a spherical sliding surface and an articulated slider which is faced with a high pressure capacity bearing material. The bearing is constructed of steel with the articulated slider and the spherical surface made of stainless steel. Specifically, the spherical sliding surface consists of highly polished austenitic, type 316 stainless steel. All sliding interfaces, that is those of the articulated slider with the spherical surface and the supporting column, are faced with a high bearing capacity, self lubricating, PTFE-based composite material.

The bearing used in testing of the floor isolation system (Figure 2-1) is identical to the one used in testing of an isolated bridge model (Constantinou 1993). This bearing was designed for vertical loads in excess of 50 kN. The load carried by the bearing in the floor system tests was only 7 kN.

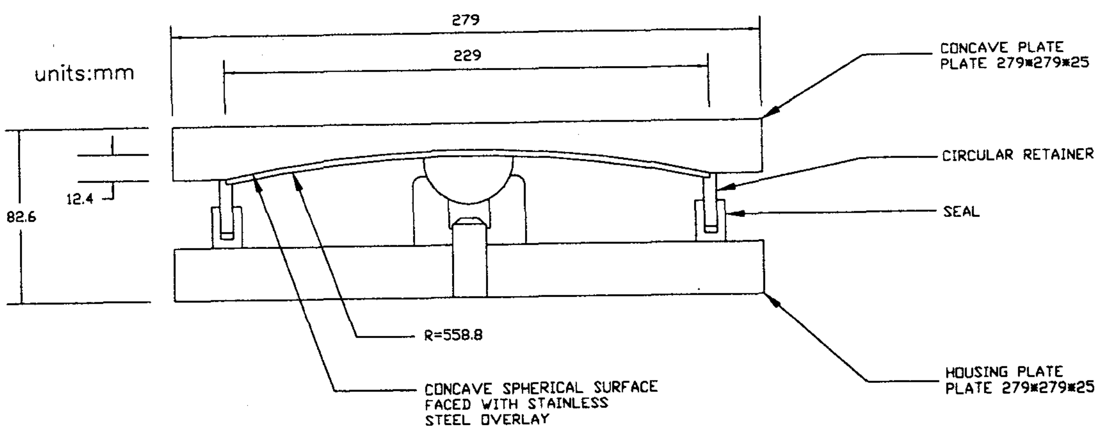


Figure 2-1 Construction of Friction Pendulum System (FPS) Bearing

2.2.1 Principles of Operation

The FPS isolation bearings produce the isolation effect by introducing flexibility and energy absorption capability at an interface between the structure (or raised floor system in this case) and the moving ground (or floor in this case). The principles of operation of the FPS bearing have been established by Zayas 1987 and Mokha 1990, and more recently described in a more general form by Constantinou 1993. As illustrated in Figure 2-2, a structure on FPS bearings behaves as a pendulum of length R, where R is the radius of curvature of the spherical sliding surface.

For a typical design of this bearing the displacement capacity is less than 0.2R, so that angle θ (see Figure 2-2) is small. Under this condition the lateral force, F, at displacement u is

$$F = \frac{W}{R}u + \mu W sgn(\dot{u}) \tag{2-1}$$

where W = load on bearing, μ = coefficient of friction and $\dot{u}$ = velocity. The form of equation (2-1) reveals the following unique properties of this isolation system:

(1) The period of vibration of the isolated structure is

$$T = 2\pi\sqrt{\frac{R}{g}} \tag{2-2}$$

This is independent of the supported mass and dependent only on the geometry of the bearings.

(2) The lateral force is directly proportional to the weight they carry and, thus, the isolation system force always develops at the center of mass of the supported

structure. This property minimizes adverse torsional motions. This is important in computer floor systems where equipment can be moved to arbitrary locations on the floor without affecting the behavior of the isolation system.

(3) The bearings provide rigidity to service and minor earthquake loads. This is accomplished by the friction in the bearings which does not allow motion until the static friction limit is exceeded.

(4) The bearings have high vertical load capacity and stability. Owing to their unique construction they do not exhibit $P\text{-}\Delta$ effects at large displacements.

(5) Their properties of flexibility and energy absorption capability are not interrelated. The first is entirely controlled by geometry (radius R) and the second is controlled by friction at the sliding interface. This property allows for optimum design of the isolation system.

In Figure 2-3 an open FPS bearing can be seen. During these series of tests the bearings were installed with their spherical surface facing down. The radius of curvature of the spherical sliding surface was $R = 558.8$ mm (22 inches) providing a period of vibration to the isolation system of 1.5 sec. The maximum displacement to be accommodated by these bearings was 89 mm (3.5 inches) in all directions.

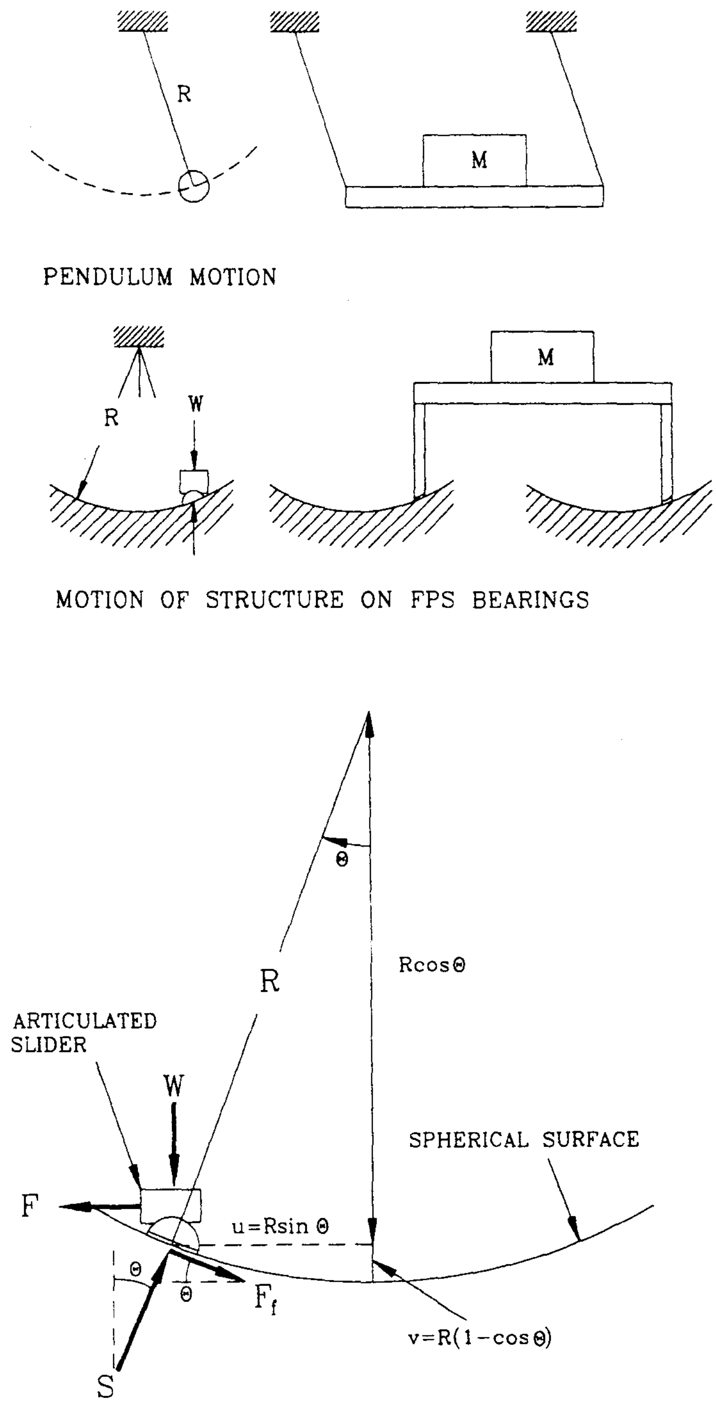


Figure 2-2 Basic Principle of Operation of FPS Bearing

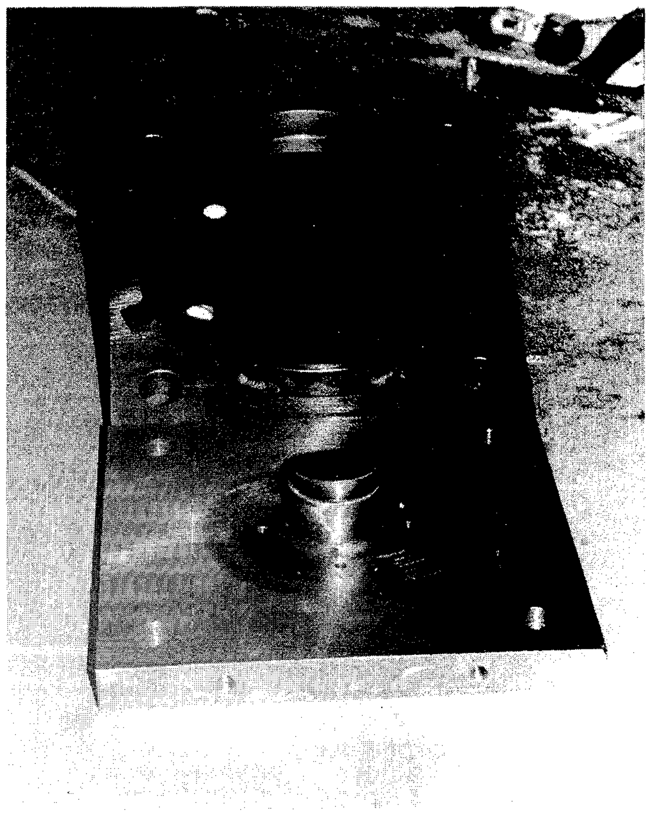


Figure 2-3 View of FPS Bearing

2.3 Fluid Viscous Dampers

Fluid viscous dampers operate on the principle of fluid flow through orifices. The particular device used in these tests has been previously used in the testing of a steel model structure (Constantinou 1992) and an isolated bridge model (Tsopelas 1994). The construction of these devices is shown in Figure 2-4. It consists of a stainless steel piston, with a bronze orifice head and an accumulator. It is filled with silicone oil.

2.3.1 Operation of Fluid Dampers

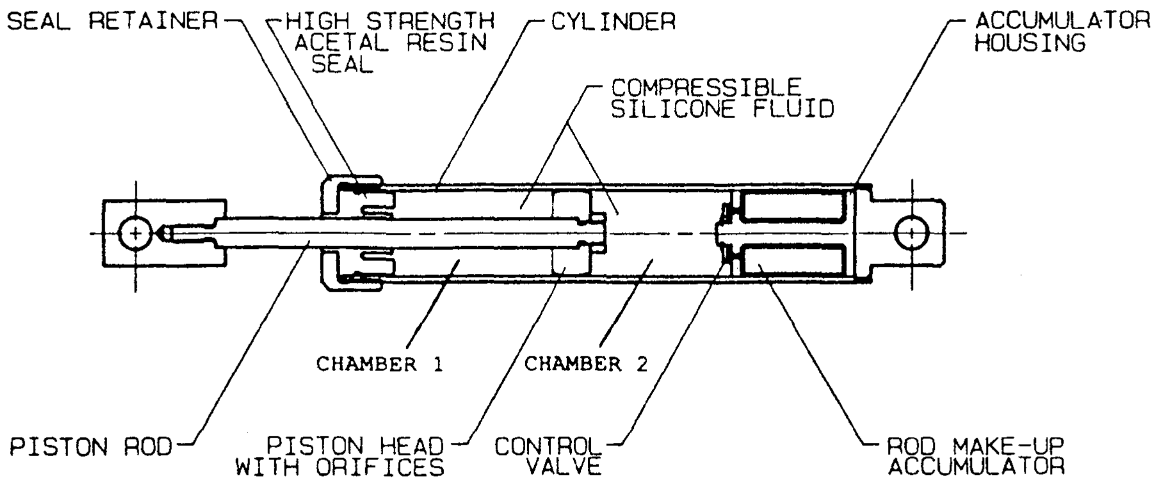
The force that is generated by the fluid damper is due to a pressure differential across the piston head. Consider that the piston head moves from left to right in Figure 2-4 (device subjected to compressive force). Fluid flows from chamber 2 towards chamber 1. Accordingly, the damping force is proportional to the pressure differential in these two chambers. However, the fluid volume is reduced by the product of travel and piston rod area. Since the fluid is compressible, this reduction in fluid volume is accompanied by the development of a restoring (spring like) force. This is prevented by the use of the accumulator.

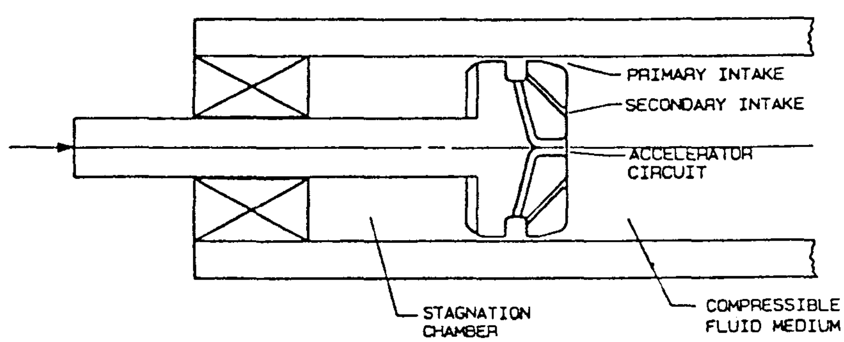
The force generated by the differential of pressure is proportional to a power of the piston rod velocity. Typical designs with cylindrical orifices produce force proportional to velocity squared. This is usually unacceptable performance. A variety of designs have been produced, which can alter the flow characteristics in order to produce acceptable performance. Details of these designs may be found in Soong and Constantinou, 1994. The particular damper used in these tests has been fitted with a fluidic control orifice, a design which can produce force proportional to powers of velocity in the range of 0.4 to 2.0.

In these tests, the dampers were designed to have linear viscous behavior, that is

$$P = C_0 \dot{u} \quad (2\text{-}3)$$

where P = force, $\dot{u}$ = velocity, and C_o = damping constant. The damping constant was experimentally determined to be equal to 14 Ns/mm at room temperature. Typically, these dampers are insensitive to variations of ambient temperature (Constantinou 1992, Soong and Constantinou, 1994).





Fluidic Control Orifice

Figure 2-4 Construction of Fluid Viscous Damper

SECTION 3

TESTED SYSTEM

3.1 Description of Tested System

The tested system consisted of an electronic equipment cabinet (termed the Cabinet) on top of a raised floor system (termed the Raised Floor). The columns of the Raised Floor were supported by beams, which formed the Base Floor. The isolation system was placed between the Base Floor and the shake table, as it would have been installed on a typical floor of a building. Figure 3-1 presents a view of the tested system on the shake table.

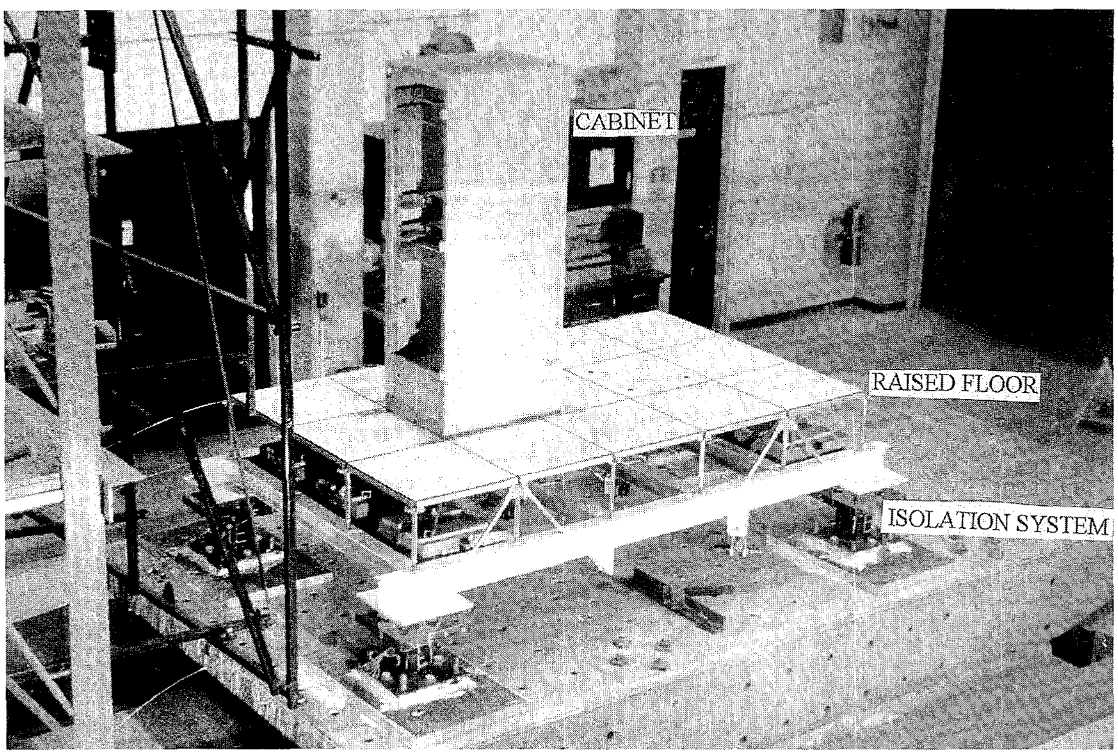


Figure 3-1 View of Tested System on Shake Table

The Raised Floor had plan dimensions of 1.83 m by 3.05 m (6 by 10 feet). Typically, computer floors are crowded with equipment with total load of about 100 psf (48 kN/m^2). To properly simulate the load on the bearings, extra weights have been added at the Base Floor to reach a total weight (Base Floor plus Raised Floor plus Cabinet) of 27.59 kN (6.2 kips).

3.2 Description of Cabinet

The tested Cabinet is shown in Figure 3-2, whereas Figure 3-3 presents a schematic of the Cabinet. It was placed on the Raised Floor having its center of mass at a distance of 0.91m (3 feet) from the south side and 2.13m (7 feet) from the north side of the Raised Floor. It was stranded with standard bungee cords on the Base Floor. The bungee cords were attached to the frame of the Cabinet, run through holes in the tiles of the Raised Floor and were attached to holes in the beams of the Base Floor. This arrangement allows for easy relocation of the equipment, a typical requirement in computer floor systems. It also allows for sliding and rocking of the equipment in seismic excitation but prevents overturning of the equipment.

The Cabinet is 1.88m (74 in) in height and 0.56m by 0.76m (22 in by 30 in) in plan. It consists of four horizontal diaphragms (levels 1, 2, 3 and top). These diaphragms are connected together by side walls, which extend only in the longitudinal direction. At level 1, where the center of mass is located, a 111 N (25 lbs) weight was rigidly mounted on the diaphragm. At levels 2 and 3, weights of 116 N and 178 N (26 and 40 lbs) were respectively mounted on trays which were supported by wire rope springs on top of the

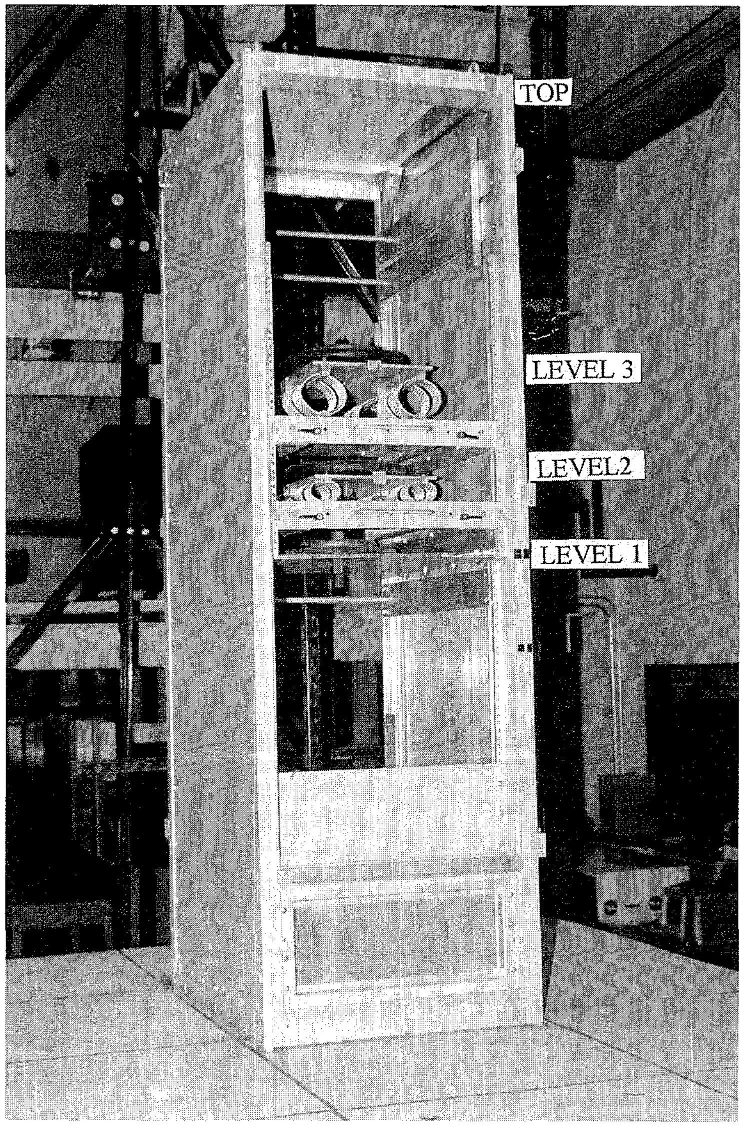


Figure 3-2 View of Cabinet on Raised Floor

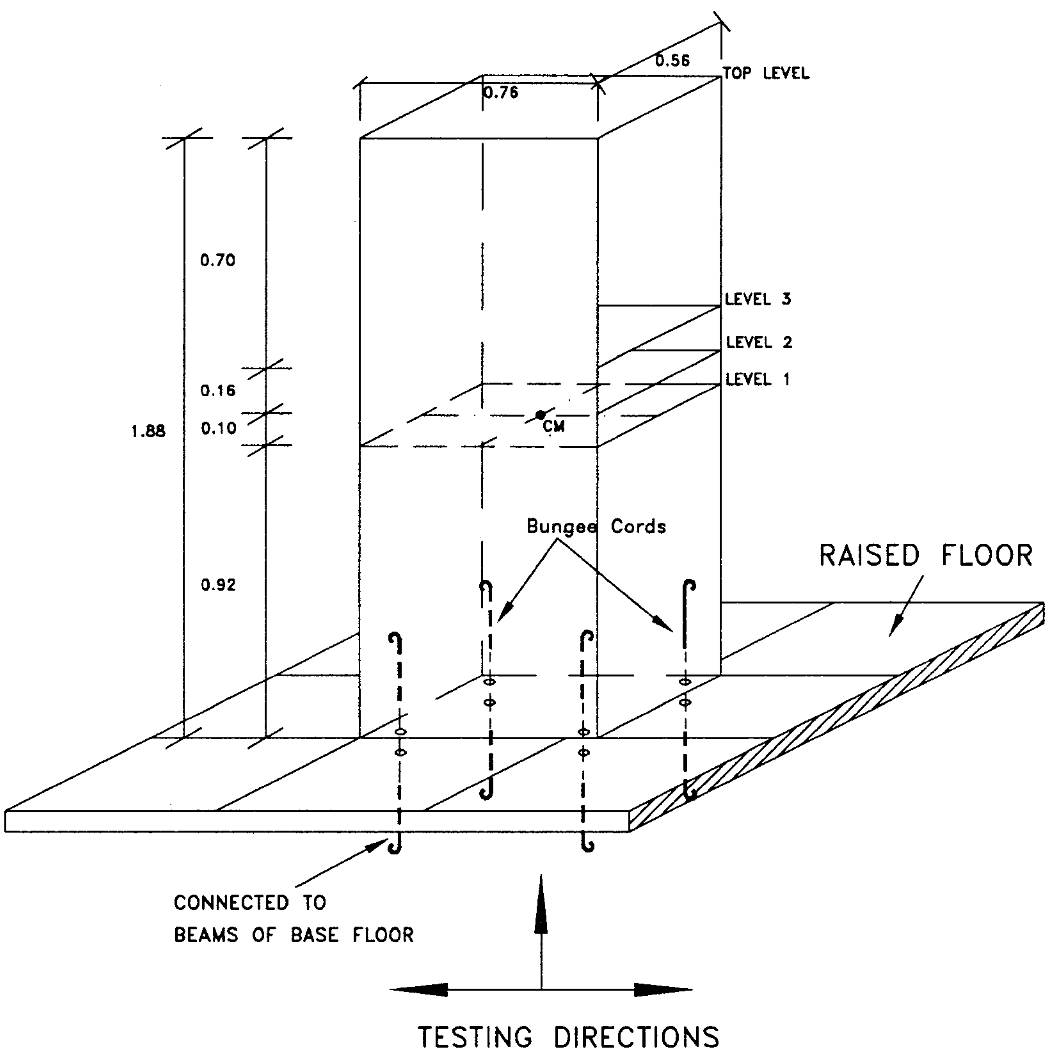


Figure 3-3 Tested Equipment Cabinet (Units: m)

diaphragms. These arrangements represented flexible internal components of an equipment cabinet. The arrangements may be seen in Figure 3-2.

Identification tests were conducted to establish the dynamic characteristics of the Cabinet itself and of the two flexible internal arrangements. The Cabinet had a total weight of 1780 N (400 lbs), and its center of mass was at height of 920 mm from its base, and at the level 1 diaphragm. From transfer functions, obtained in low level white noise excitation and using the acceleration records at level 1 (center of mass), it was determined that the Cabinet, in its fixed base condition, had a frequency of 40 Hz and damping ratio of about 2 %.

The two flexible internal oscillators exhibited highly non-linear behavior due to the hysteretic nature of the wire rope springs (Demetriades 1992). The dynamic characteristics were determined in pull release tests from records of acceleration of the masses. For level 2 (stiff system), its fundamental frequency was found to be 6.7 Hz for acceleration of about 0.5 g, and 9.4 Hz for accelerations less than 0.1 g. For level 3 (soft system), its fundamental frequency was found to be 4.8 Hz for accelerations greater than 0.5 g, and 8 Hz for accelerations less than 0.1 g. Due to the highly non-linear behavior of the internal systems, and the interaction of all the connected parts of the Cabinet, the damping ratio of the internal oscillators could not be accurately determined. It was estimated to be of the order of 20 % of critical.

3.3 Description of Base Floor

The Base Floor consisted of two AISC W6x9 sections which spanned 3.05 m (10 feet). These beams were transversely connected by AISC W4x13 sections at centers of 0.61 m (2 feet), which spanned 1.88 m (6 feet). In order to facilitate the addition of extra weight on the Base Floor, two steel plates 12.7 mm thick were welded at the two edge bays. On these steel plates lead bricks were added to reach the total weight of 27.59 kN (6.2 kips) of the floor system. Care was taken in detailing and manufacturing of the connections of the Base Floor to the FPS bearings. At the four corners of the Base Floor, steel plates, 19.05 mm thick and 406.4 by 406.4 mm in plan, were attached. The surface in contact with the FPS bearings (bottom side) was machined flat so that a perfect fit could be achieved without the need for grouting.

For the attachment of the Fluid Dampers, four steel brackets were welded at the bottom of the W6x9 sections.

The total weight of the Base Floor was 23.94 kN (5.38 kips).

3.4 Description of Raised Floor

At the top of the Base Floor, the Raised Floor was erected. Aluminum pedestals were welded to form a 609.6 by 609.6 mm (24 by 24 in) grid. The Raised Floor was assembled together as a "bolted stringer system", according to the manufacturer's specifications. The pedestals were connected with aluminum stringers and at the top "all steel computer floor panels" with hard surface coverings were placed. The finished height of the Raised

Computer Floor was 355.6 mm (14 in), and had plan dimensions of 1.83 by 3.05 m (6 by 10 feet). Standard seismic braces, provided by the manufacturer, were used to support the pedestals of the Raised Floor (see Figure 3-1).

The total weight of the Raised Floor was 1.875 kN (0.422 kips). Identification tests showed that the first frequency of the Raised Floor was 31.2 Hz, and the damping ratio was 3.6%.

3.5 Tested Configurations

Three different isolation configurations were tested. The Friction Pendulum System (FPS) bearing was the basic component in all three. Four FPS bearings were placed on the top of load cells and supported the Base Floor. The bearings were installed with the spherical surface facing down. The schematic of the floor system is shown in Figure 3-4.

The frictional properties of the material attached on the articulated slider were determined in identification tests prior to and following the seismic testing. The coefficient of friction was extracted from recorded loops of force vs bearing displacement. The coefficient of friction followed the relation proposed by Constantinou 1990:

$$\mu = f_{\max} - (f_{\max} - f_{\min})\exp(-a|\dot{U}|) \tag{3-1}$$

where f_{max} is the coefficient of friction at high velocity of sliding, f_{min} is the coefficient of friction at essentially zero velocity of sliding and a is a parameter controlling the variation of the coefficient with velocity of sliding.

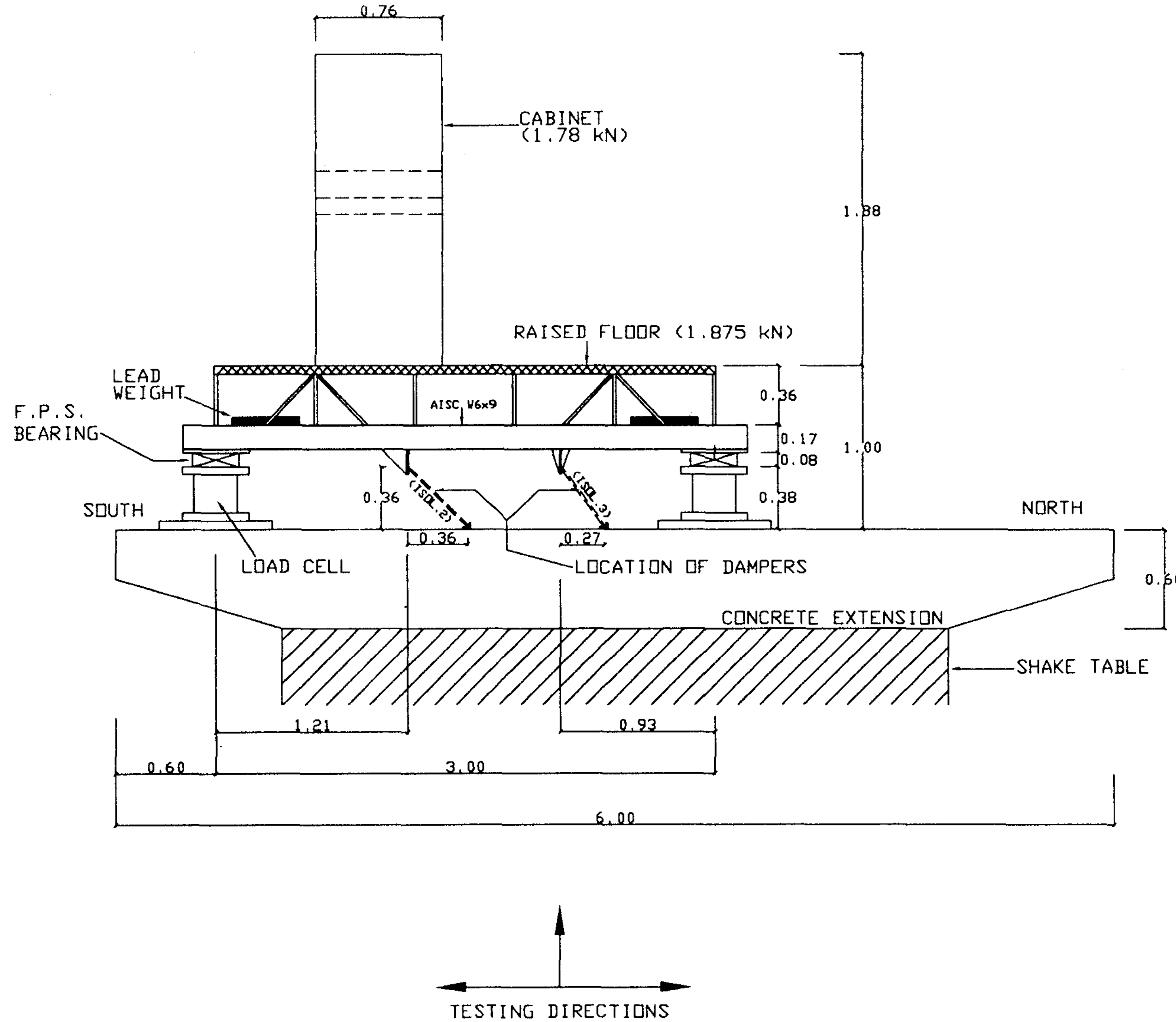


Figure 3-4 Schematic of Tested Isolation Floor System (Units: m)

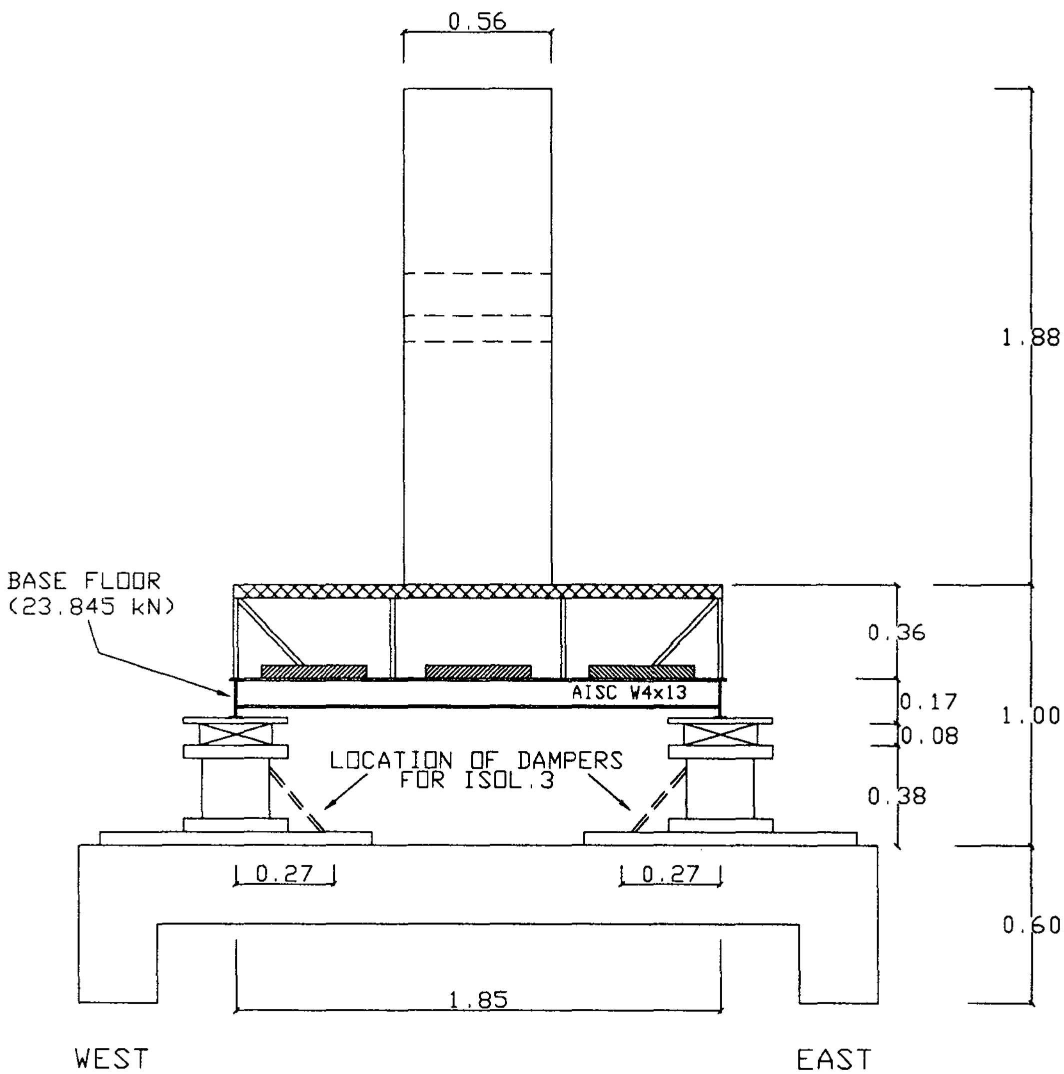


Figure 3-4 Continued

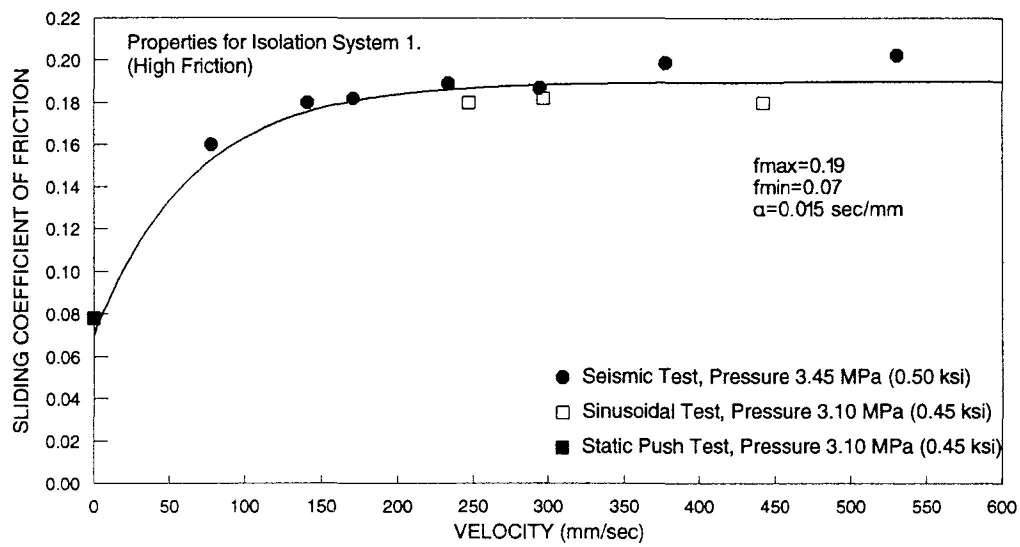
In the identification tests the Cabinet was removed from the Raised Floor and the shake table was driven at sinusoidal motion of specified frequency and amplitude. The essentially rigid isolated structure responded in harmonic motion of the same amplitude. The coefficient of friction was then extracted from recorded force-displacement loops of the FPS bearings.

Furthermore, recorded force-displacement loops of the bearings during seismic testing were used to obtain values of the coefficient of friction. These values were related to the peak velocity at the sliding interface, which was determined from the recorded time history of bearing displacement by numerical differentiation. Moreover, static push tests were conducted in order to determine the coefficient of friction at initiation of motion. The results are presented in Figure 3-5 together with those of the calibrated model of equation (3-1). The parameters of the model of friction are presented in Table 3-I.

Of interest is to note in Figure 3-5 that the minimum value of the coefficient of friction in the static push test is equal to 0.035 for the lower friction bearings. The static value of friction is actually higher because the bearings were tested just after installation, and not after sufficient load dwell (see Soong and Constantinou, 1994 for discussion on this phenomenon). Typically, the static value of friction for these bearings is larger than f_{min} but less than f_{max}. If we use the value of 0.035 we conservatively calculate the resistance of the isolation system against service loads as 0.035W (W= total weight= 27.59 kN or 6.2 kips) or about 1 kN (220 lbs). This is sufficient to prevent any motion during normal use of the computer floor.

Table 3-I : Frictional Properties of FPS Bearings and Viscous Damping Ratio of Isolation System

ISOLATION SYSTEM	f_{max}	f_{min}	a (sec/mm)	Viscous Damping Ratio (%)
1	0.19	0.07	0.015	0.00
2	0.13	0.03	0.015	0.60
3	0.13	0.03	0.015	0.35



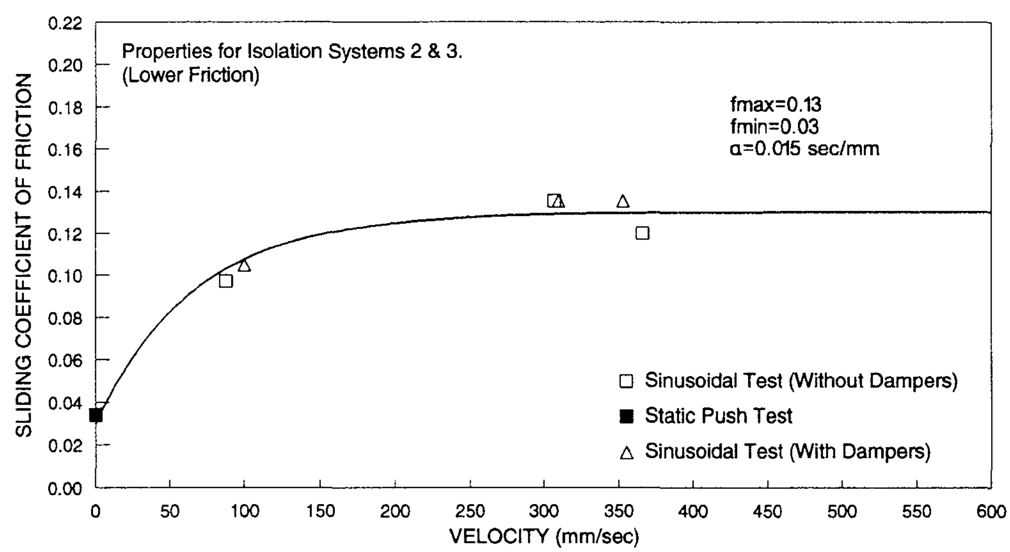


Figure 3-5 Coefficient of Sliding Friction as a Function of Bearing Pressure and Sliding Velocity

3.5.1 Isolation System 1

This system consisted of the four FPS bearings. The pressure on the bearings was 3.45MPa during seismic tests and 3.10MPa during sinusoidal tests. Isolation System 1 is characterized as "High Friction" with f_{max} = 19 % and f_{min} = 7 %. Figure 3-6 shows recorded isolation force-displacement loops (combined, as recorded from the four bearings) of the system in an identification test with harmonic motion of 1 Hz frequency. The "thickness" of the hysteresis loop is equal to 2μW, where W = weight of 25.8 kN (Cabinet removed) and μ = coefficient of sliding friction. It is equal to 0.187.

3.5.2 Isolation System 2

In order to reduce the friction coefficient of the FPS bearings, small backing plates were inserted between the articulated slider and the bearing material. Therefore, the pressure would increase resulting in a lower coefficient of friction. These "Lower Friction" bearings were used in Isolation Systems 2 and 3. The low load on the bearings prevented the FPS to behave as expected to. The presence of backing plates was not fully utilized and the "Lower Friction" bearings gave a friction coefficient higher than expected (f_{max}=0.13). In combination with FPS bearings, two fluid dampers were used. They connected the Base Floor to the shaking table at an angle of 45° to the vertical. A view of Isolation System 2 on the shake table is shown in Figure 3-7. By having the dampers in an angle, the damping constant was reduced by a factor of $\cos^2 45°$ (=0.5). The damping constant of each damper was 14 Ns/mm. Therefore, the effective damping constant for Isolation System 2 was 14 Ns/mm (2 dampers at 45° angle).

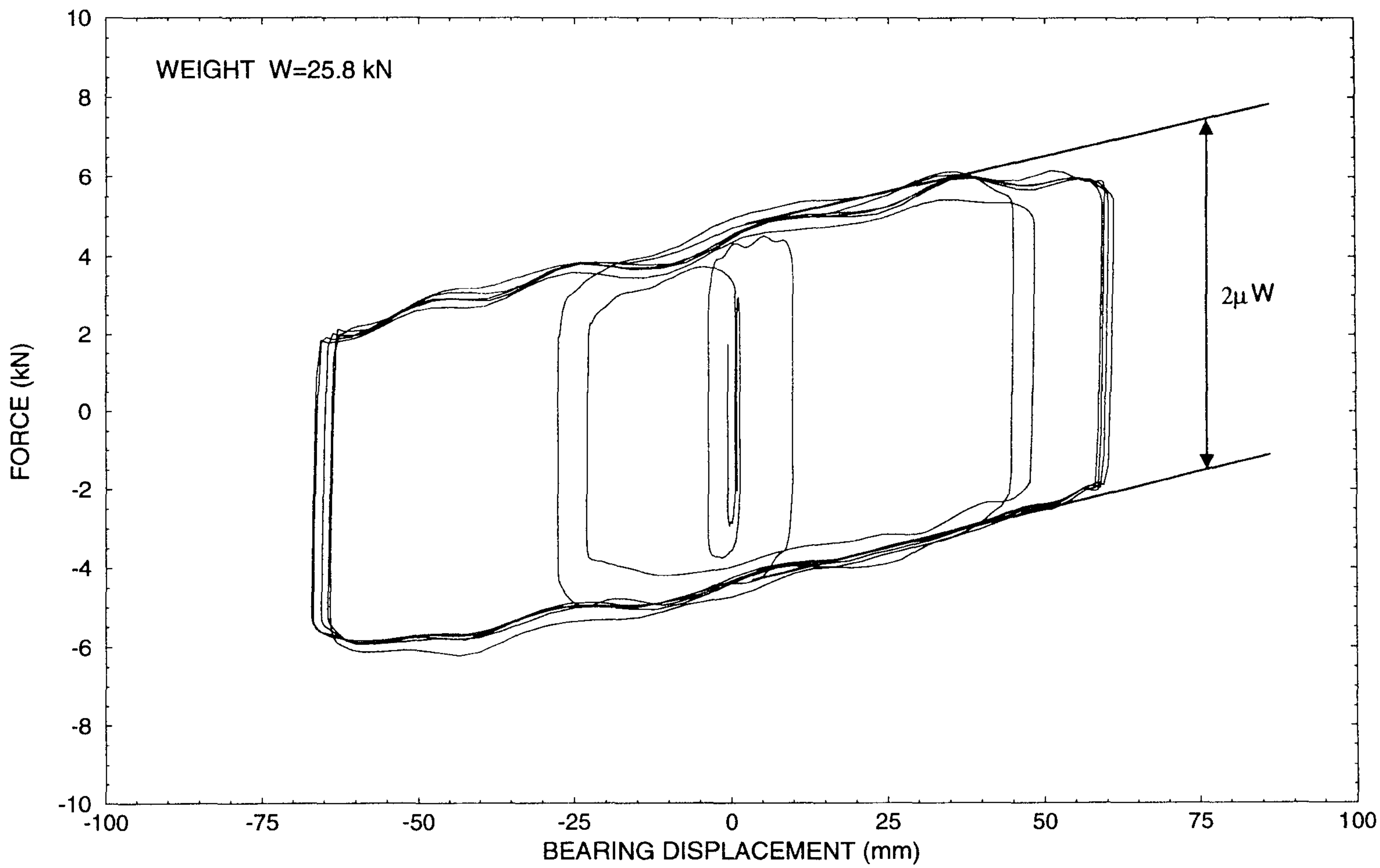


Figure 3-6 Recorded Isolation System 1 Force-Displacement Loops in Identification Test at 1 Hz Frequency

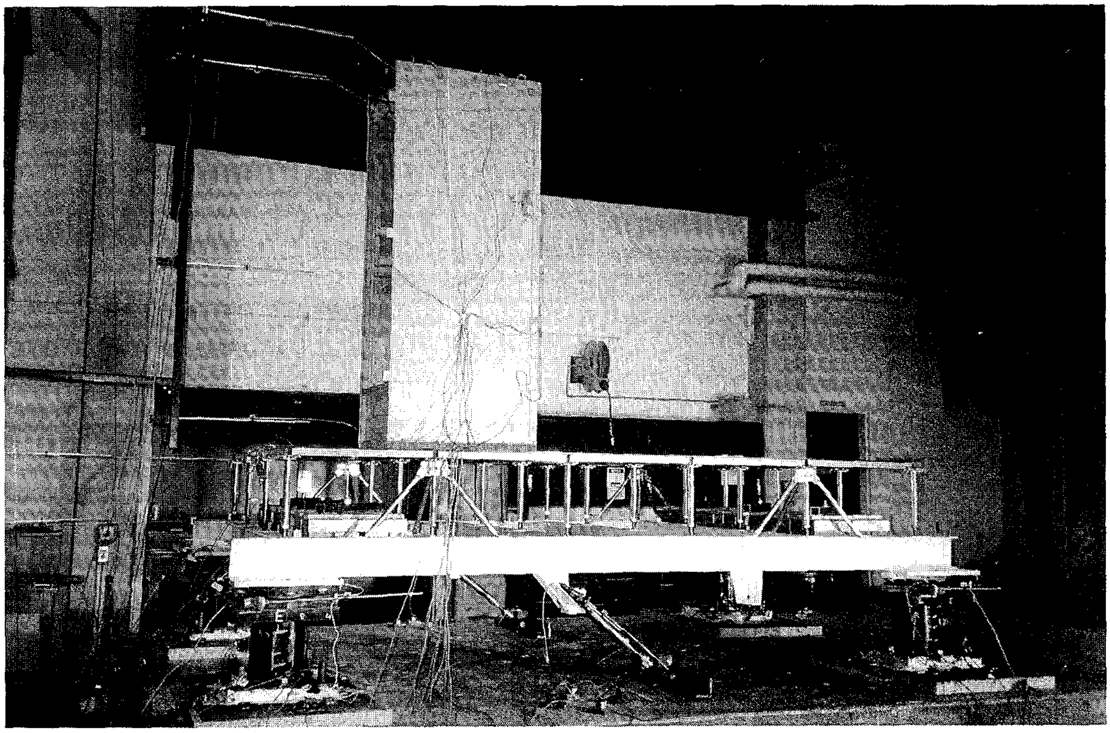


Figure 3-7 View of Isolation System 2

The viscous damping ratio of the isolation system is determined from

$$\beta = \frac{C}{2m\omega} = \frac{C}{2W}\sqrt{Rg} \tag{3-2}$$

where m = mass (W/g), C = effective damping constant from the two dampers and ω = natural frequency. For C = 14 Ns/mm, $\beta = 0.6$. This value is listed in Table 3-I.

Figure 3-8 shows recorded force-displacement loops of Isolation System 2 in a test with harmonic motion of 1 Hz frequency. The top figure shows the combined loops from the four FPS bearings. The next figure shows loops from the two fluid dampers (see Figure 3-4), whereas the bottom figure shows the total isolation system force-displacement loop. It has been obtained by adding the horizontal component of the fluid damper forces to the forces in the four FPS bearings and plotting the total force vs the bearing displacement.

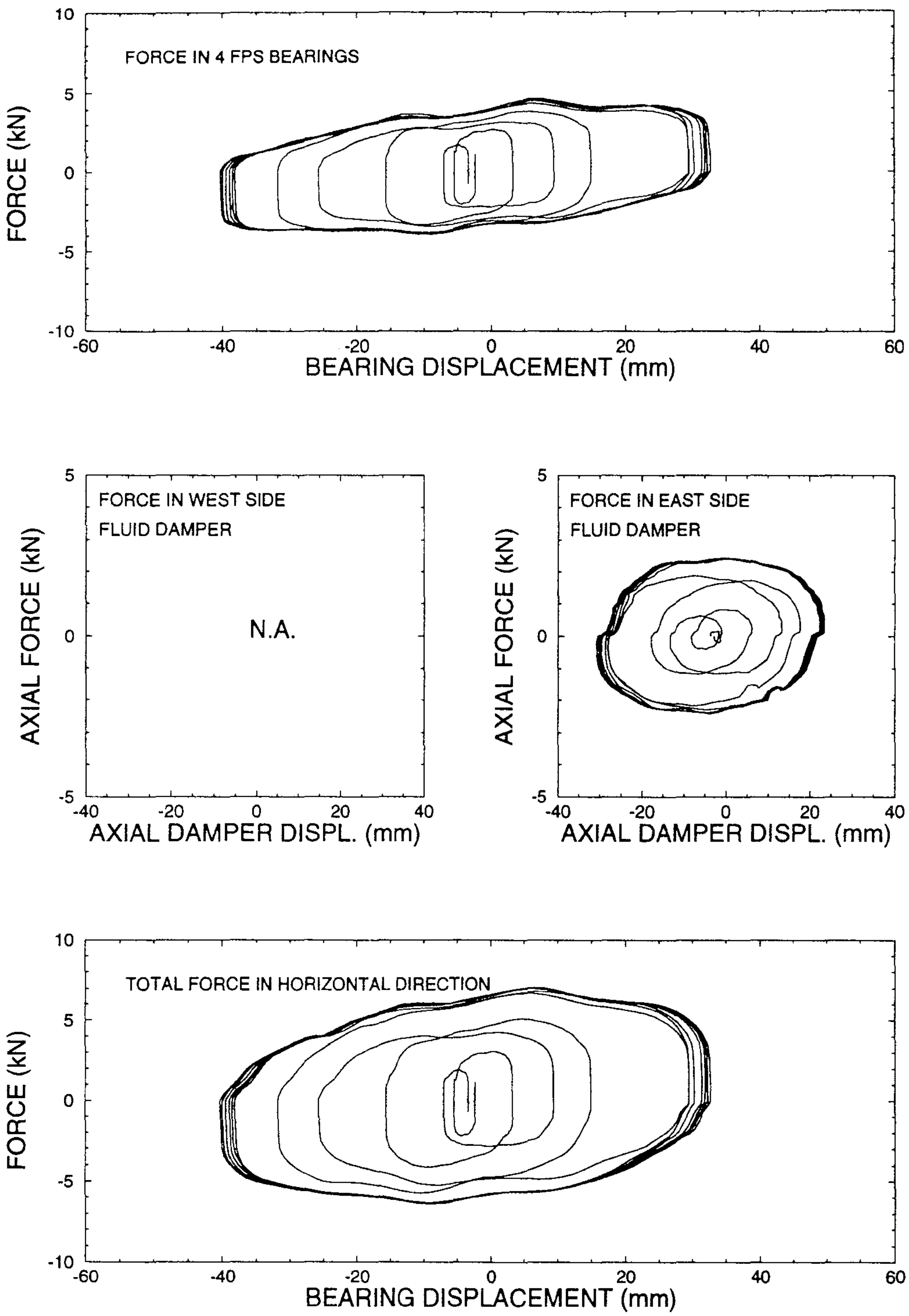


Figure 3-8 Recorded Isolation System 2 Force-Displacement Loops in Identification Test at 1 Hz Frequency

3.5.3 Isolation System 3

The only difference between this system and Isolation System 2 is in the placement of the dampers. They were placed so that their axis formed approximately equal angles with respect to vertical, longitudinal and transverse directions. Using the direction cosines rule of analytic geometry, and calculating the angle between two lines, the reduction factor of the coefficient of damping was $\cos^2 57.5°$ (=0.289). Therefore, the effective damping constant of the isolation system was 8.09 Ns/mm. This corresponds to a viscous damping ratio of 0.35. Thus systems 2 and 3 differed only in the viscous damping ratio. A view of Isolation System 3 on the shake table is shown in Figure 3-9.

Recorded force-displacement loops of Isolation System 3 in a test with harmonic motion of 1 Hz frequency are shown in Figure 3-10.

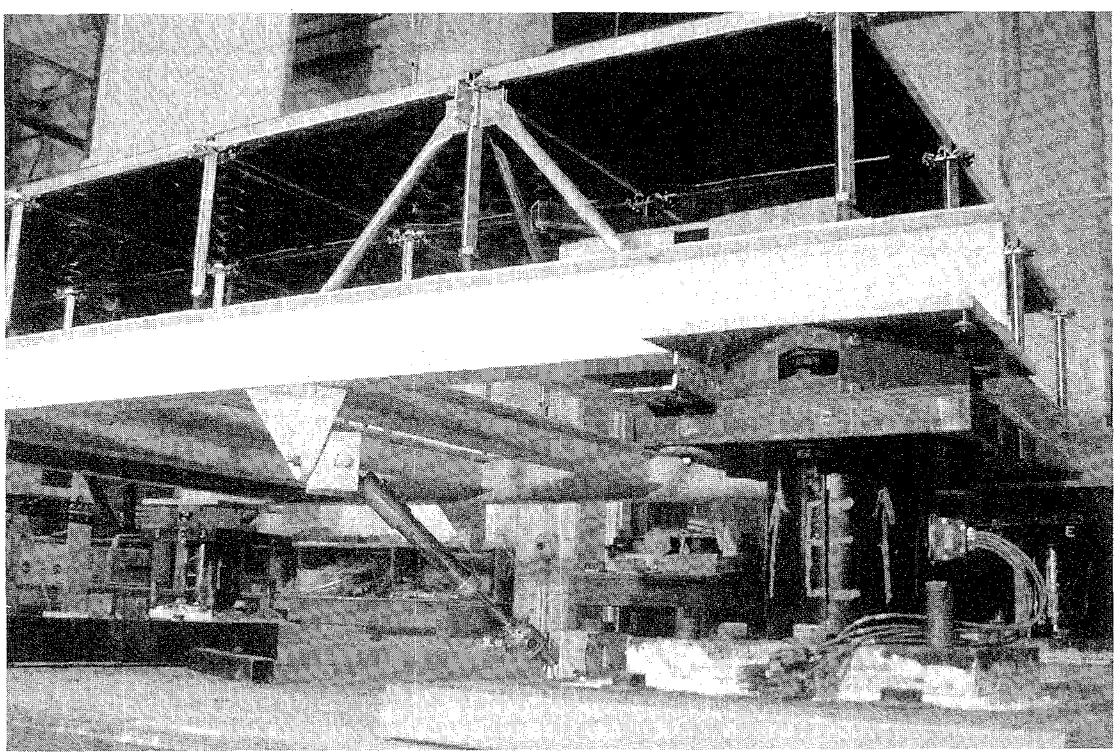


Figure 3-9 View of Isolation System 3

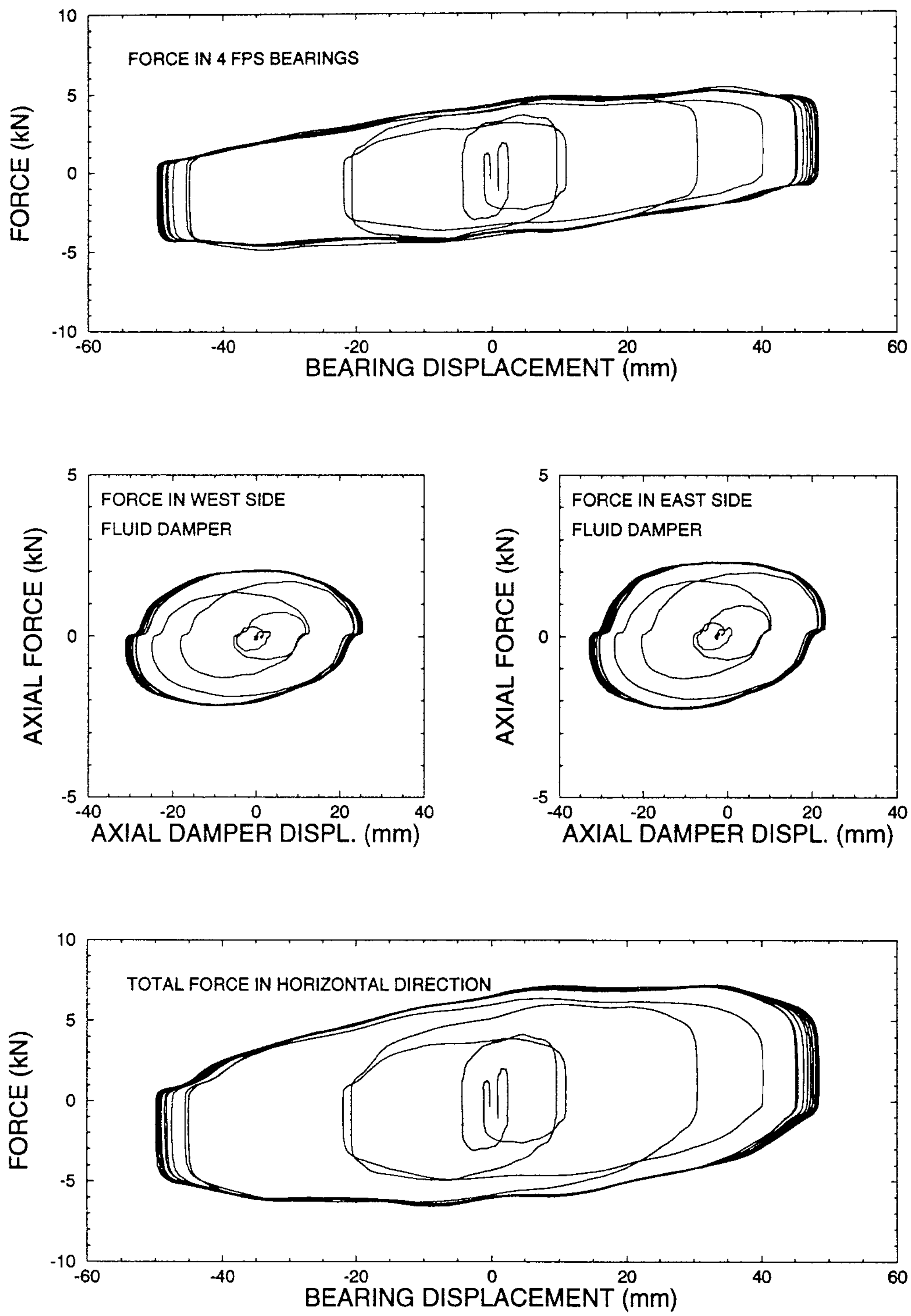


Figure 3-10 Recorded Isolation System 3 Force-Displacement Loops in Identification Test at 1 Hz Frequency

3.6 Experimental Program

The computer floor was tested in four different configurations: Non-isolated and isolated with systems 1, 2 and 3. The test program was as follows:

(1) The bearings were locked by side plates to represent a non-isolated floor. Identification tests with banded white noise in the frequency range of 0 - 50 Hz, without the Cabinet, were performed. This established the properties of the Raised Floor.

(2) The FPS bearings were released and the Isolation System 1 was in effect. Sinusoidal tests with 1 Hz frequency, without the Cabinet on the floor, were conducted to determine the properties of the isolation system. Furthermore, static pull tests were performed to determine f_{min}. The Cabinet was then placed on the Raised Floor and seismic tests were performed.

(3) The bearings were locked again (non-isolated configuration) and a number of seismic tests was performed.

(4) The bearings were unlocked and static pull tests were conducted. Then the bearing material was replaced with the "Lower Friction" one. Static pull tests with this material were performed. These tests established the coefficient of friction of the bearings under static conditions (f_{min}).

(5) Sinusoidal tests with 1 Hz frequency, without the Cabinet, were conducted. These tests revealed the frictional properties of the "Lower Friction" FPS bearings.

(6) Isolation System 3 was put in effect. Fluid dampers were attached to the Base Floor. Sinusoidal and seismic tests were performed.

(7) Isolation System 2 was established by reconfiguring the fluid dampers. Sinusoidal and seismic tests were conducted.

The seismic tests were conducted with only horizontal input and with combined horizontal and vertical input. The earthquake signals and their characteristics are listed in Table 3-II. The earthquake signals consisted of historic earthquakes and artificial motions. The historic earthquakes were applied as recorded (termed ground motions) and after filtering through an actual R/C 7-story structure in order to generate floor motions. Details for the generation of these floor motions are given in Demetriades 1992. The generated motions at the 5th and 7th floors of the 7-story structure were used in the tests. The vertical component of motion over the height of the 7-story building was assumed to remain the same as at the ground level.

Table 3-II contains the peak values of recorded table motion in the tests at length scale of 1 (prototype). Nearly identical peak values of acceleration and velocity, when extrapolated to prototype scale, were obtained in tests at length scale of 2 , 3 and 4 (see Appendix A). The shake table simulated peak horizontal accelerations and velocities are comparable with those of the actual (target) motions. However, the shake table simulated displacements were lower than those of the target motions. The discrepancy is significant at length scale of 1 , but it is less at the larger length scales (see Appendix A for values in each test).

Table 3-II : Earthquake Motions Used in Test Program and Peak Motion Characteristics in Prototype Scale

NOTATION	RECORD	SHAKE TABLE SIMULATED MOTION						ACTUAL MOTION					
		HORIZONTAL			VERTICAL			HORIZONTAL			VERTICAL		
		ACC (g)	VEL (mm/s)	DIS (mm)	ACC (g)	VEL (mm/s)	DIS (mm)	ACC (g)	VEL (mm/s)	DIS (mm)	ACC (g)	VEL (mm/s)	DIS (mm)
EL CENTRO S00E	Imperial Valley, May 18, 1940. Hor.Comp. S00E	0.37	295.9	59.4	0.33	74.1	13.5	0.34	334.5	108.7	0.21	108.5	55.6
TAFT N21E	Kern County, July 21, 1952. Hor.Comp. N21E	0.16	148.3	31.3	0.12	53.3	12.2	0.16	157.2	67.1	0.11	66.8	50.3
PACOIMA S74W	San Fernando, February 9, 1971. Hor.Comp. S74W	1.01	586.1	103.4	1.60	354.5	72.0	1.08	568.2	108.2	0.71	583.1	193.2
BELLCORE	Artificial Motion	0.88	563.9	58.7	0.33	237.5	18.1	NOT APPLICABLE					
IBM LEVEL - 1	Artificial Motion	0.43	456.9	55.6	0.21	128.9	17.1						
IBM LEVEL - 2	Artificial Motion	0.98	720.1	91.4	0.59	268.0	32.5						

It should be noted in Table 3-II that the simulated motion by the shake table had significantly stronger vertical components than the actual (target) motions. For example, the simulated vertical component of the Pacoima Dam record had a peak acceleration of 1.6 g , whereas it should have only 0.71 g .

The artificial earthquakes were compatible with a proposed test input by Bellcore 1988 for upper stories in Zone 4 earthquakes and two IBM developed inputs (IBM 1992). The IBM inputs, denoted by IBM Level 1 and IBM Level 2, represent two functional test levels. At the first level, a machine is expected to operate normally, and at the second level, also referred to as the structure/safety level, gross structural failures should not occur although the machine may not remain functional (Kosar 1993). The vertical components of motion were taken as equal to 1/3 of the simulated horizontal component. The motions were identical to those used in the tests of Demetriades 1992 and Kosar 1993.

Figures 3-11 to 3-23 present time histories of acceleration, velocity and displacement in prototype time scale and response spectra of the seismic motions. The acceleration and displacement histories were obtained from the tests at length scale of one, whereas the velocity history was obtained by numerical differentiation of the displacement record. Evidently, the horizontal components of these records contain long period components, as expected to be the case of floor seismic motions (Singh 1988, Lin 1985). However, it should be noted that the simulated motions for the Bellcore and IBM inputs do not contain any significant components at periods above 2 secs.

It may be observed in Figures 3-11 to 3-23 that the response spectra of the table motions are in good agreement with the spectra of the actual (target) motions, except for the vertical spectral components in the low period range, This unfaithful reproduction by the table of the target vertical motions affected the outcome of the experiments. Particularly, in the Pacoima motion tests the vertical table acceleration substantially exceeded 1 g, resulting in uplift of the bearings and Cabinet.

Testing was conducted at four different length scales S_L (prototype/model) equal to 1, 2, 3 and 4. The tests were conducted by compressing time by factor equal to $\sqrt{S_L}$. The recorded results were thus valid for four different isolation system periods (in prototype scale): 1.5, 2.12, 2.60 and 3.0 seconds, as listed in Table 3-III.

Table 3-III : Length Scales in Testing Program and Corresponding Isolation System Properties

Properties in Prototype Scale	Isolation System 1	Isolation System 2	Isolation System 3
Length Scale 4			
Coef. of Friction f_{max}	0.19	0.13	0.13
Viscous Damping Ratio	0.00	0.60	0.35
Isolation System Period (secs)	3.00	3.00	3.00
Length Scale 3			
Coef. of Friction f_{max}	0.19	0.13	0.13
Viscous Damping Ratio	0.00	0.60	0.35
Isolation System Period (secs)	2.60	2.60	2.60
Length Scale 2			
Coef. of Friction f_{max}	0.19	0.13	0.13
Viscous Damping Ratio	0.00	0.60	0.35
Isolation System Period (secs)	2.12	2.12	2.12
Length Scale 1			
Coef. of Friction f_{max}	0.19	0.13	0.13
Viscous Damping Ratio	0.00	0.60	0.35
Isolation System Period (secs)	1.50	1.50	1.50

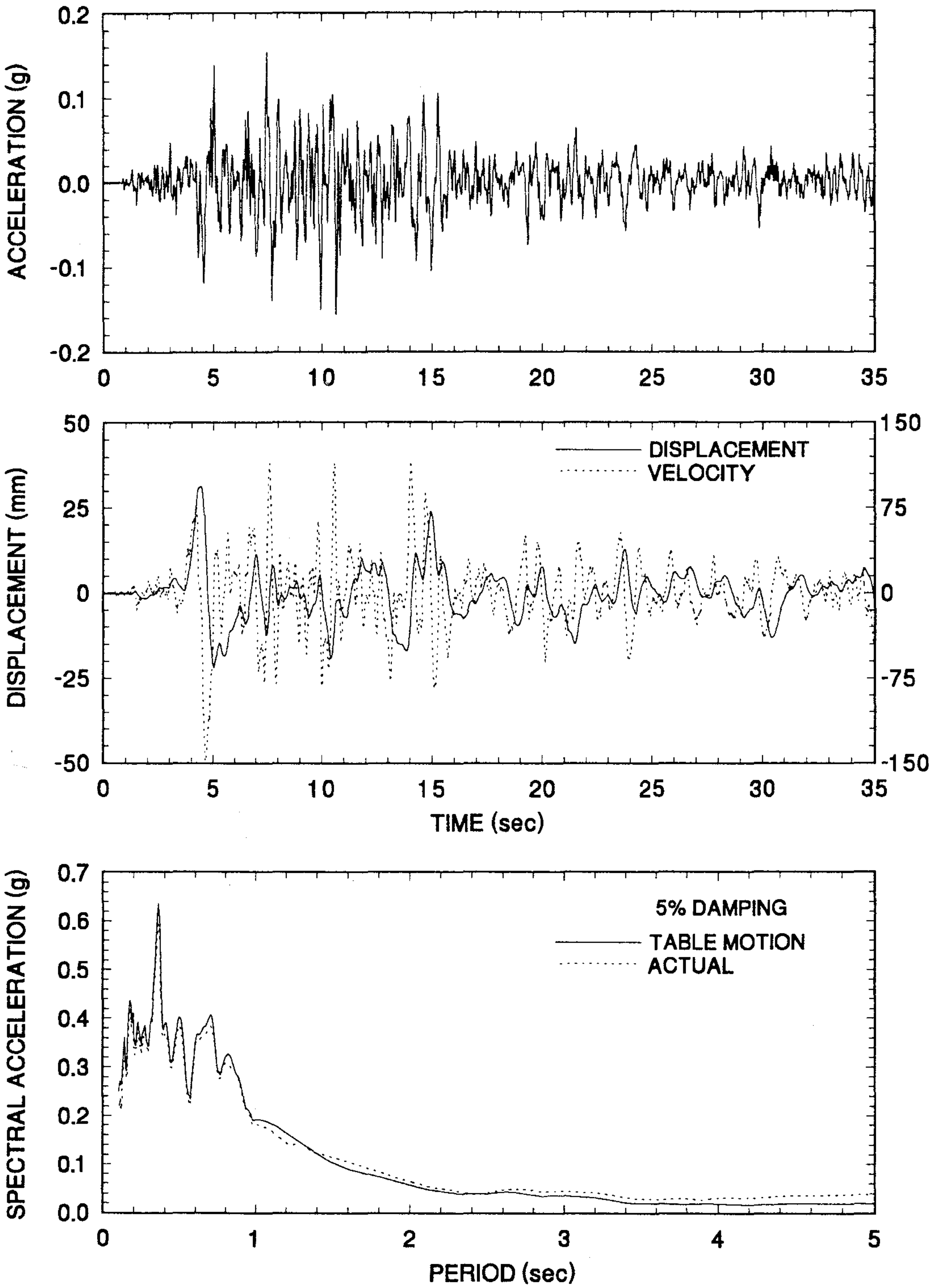


Figure 3-11 Acceleration, Velocity and Displacement Histories and Response Spectrum of Taft (Horizontal) - Ground in Prototype Scale

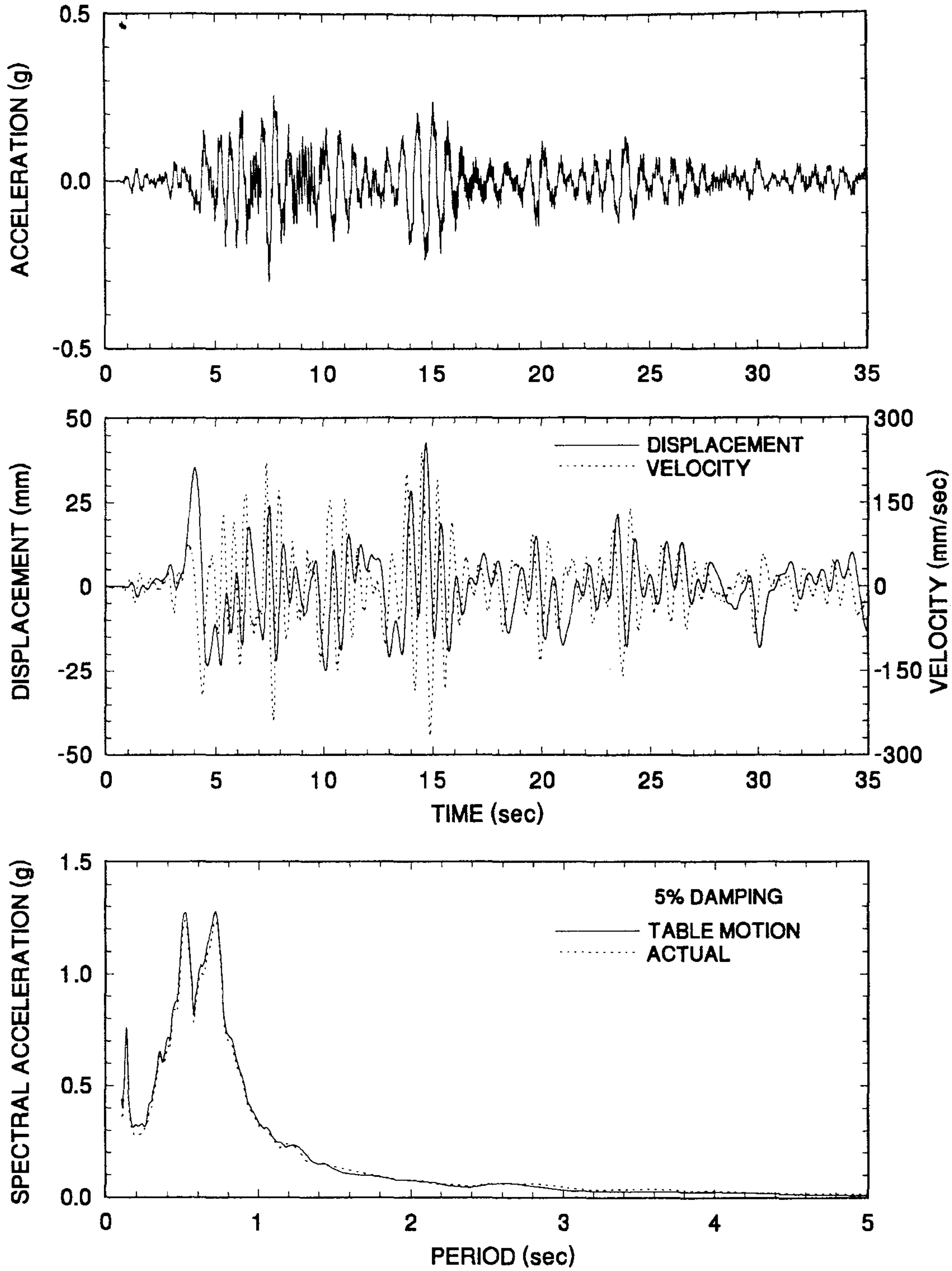


Figure 3-12 Acceleration, Velocity and Displacement Histories and Response Spectrum of Taft (Horizontal) - 5th Floor in Prototype Scale

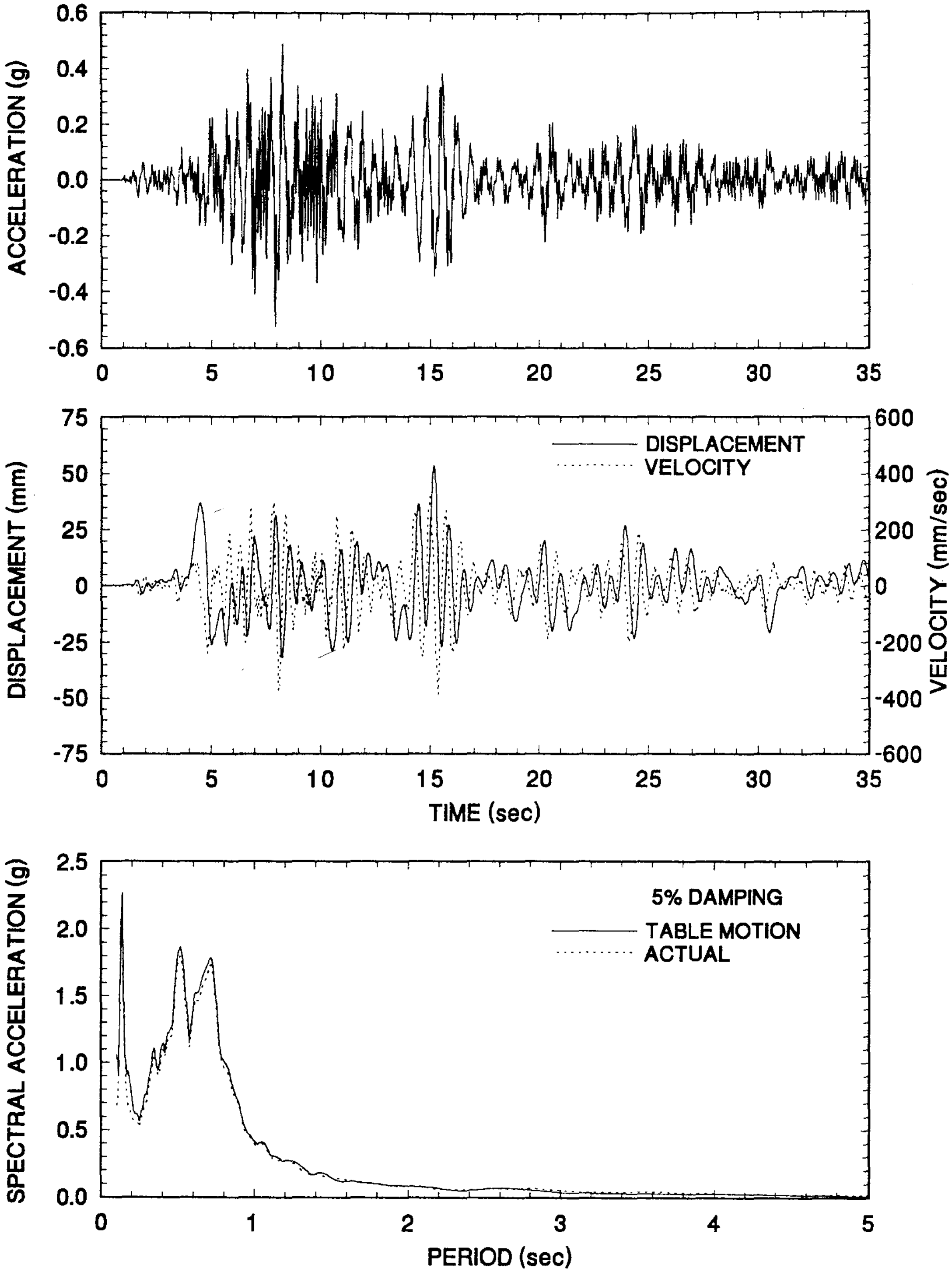


Figure 3-13 Acceleration, Velocity and Displacement Histories and Response Spectrum of Taft (Horizontal) - 7th Floor in Prototype Scale

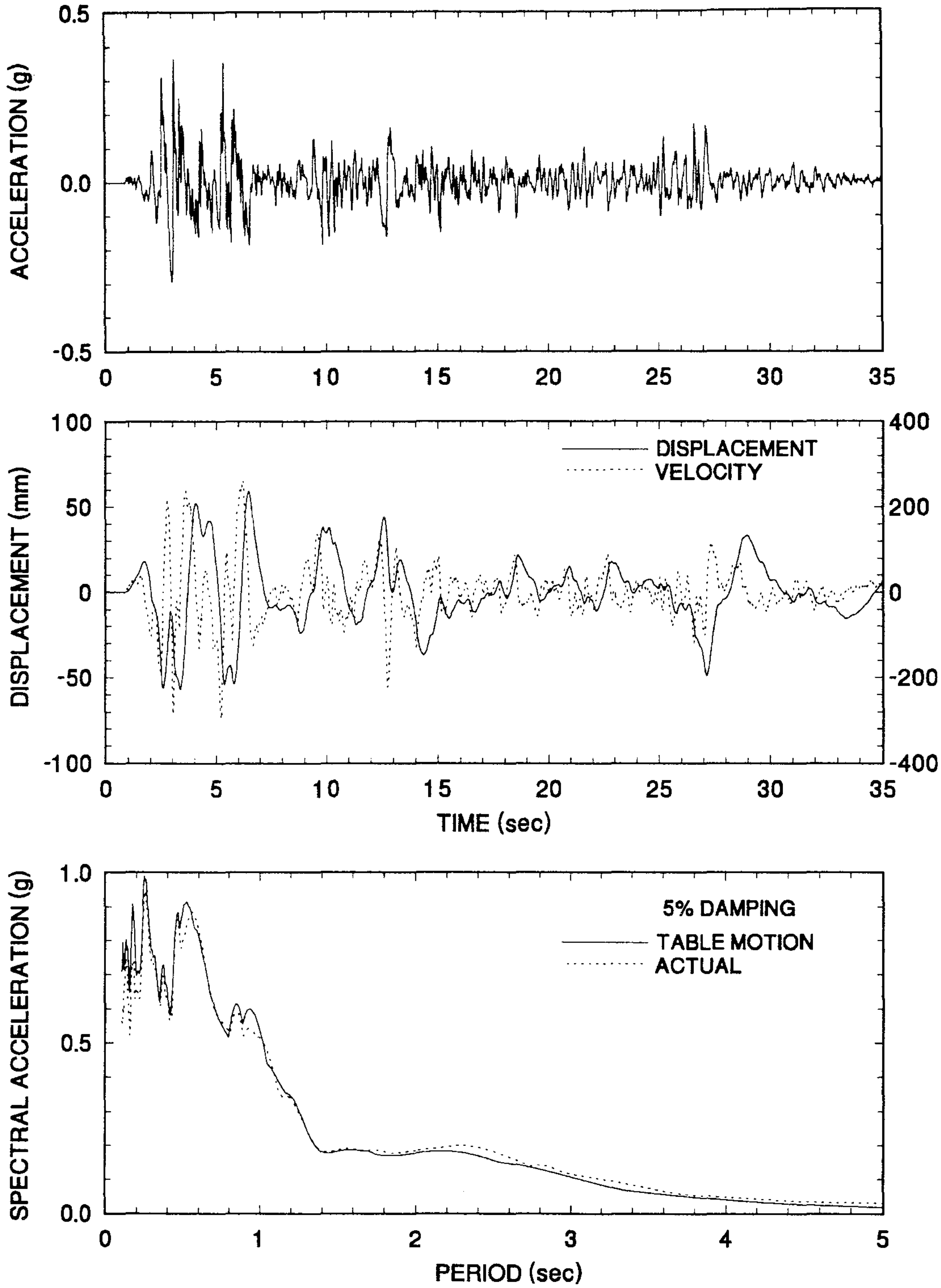


Figure 3-14 **Acceleration, Velocity and Displacement Histories and Response Spectrum of El Centro (Horizontal) - Ground in Prototype Scale**

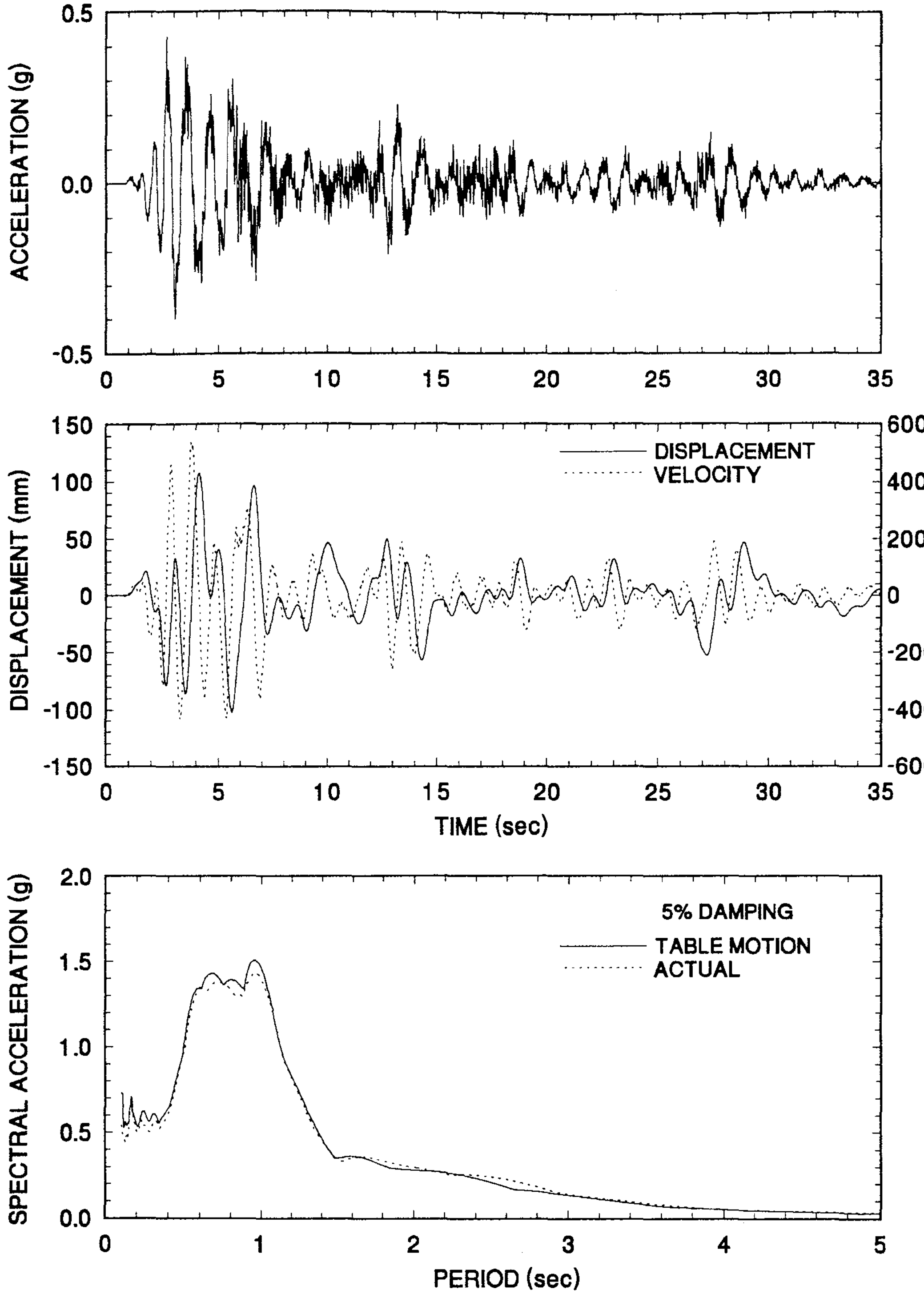


Figure 3-15 Acceleration, Velocity and Displacement Histories and Response Spectrum of El Centro (Horizontal) - 5th Floor in Prototype Scale

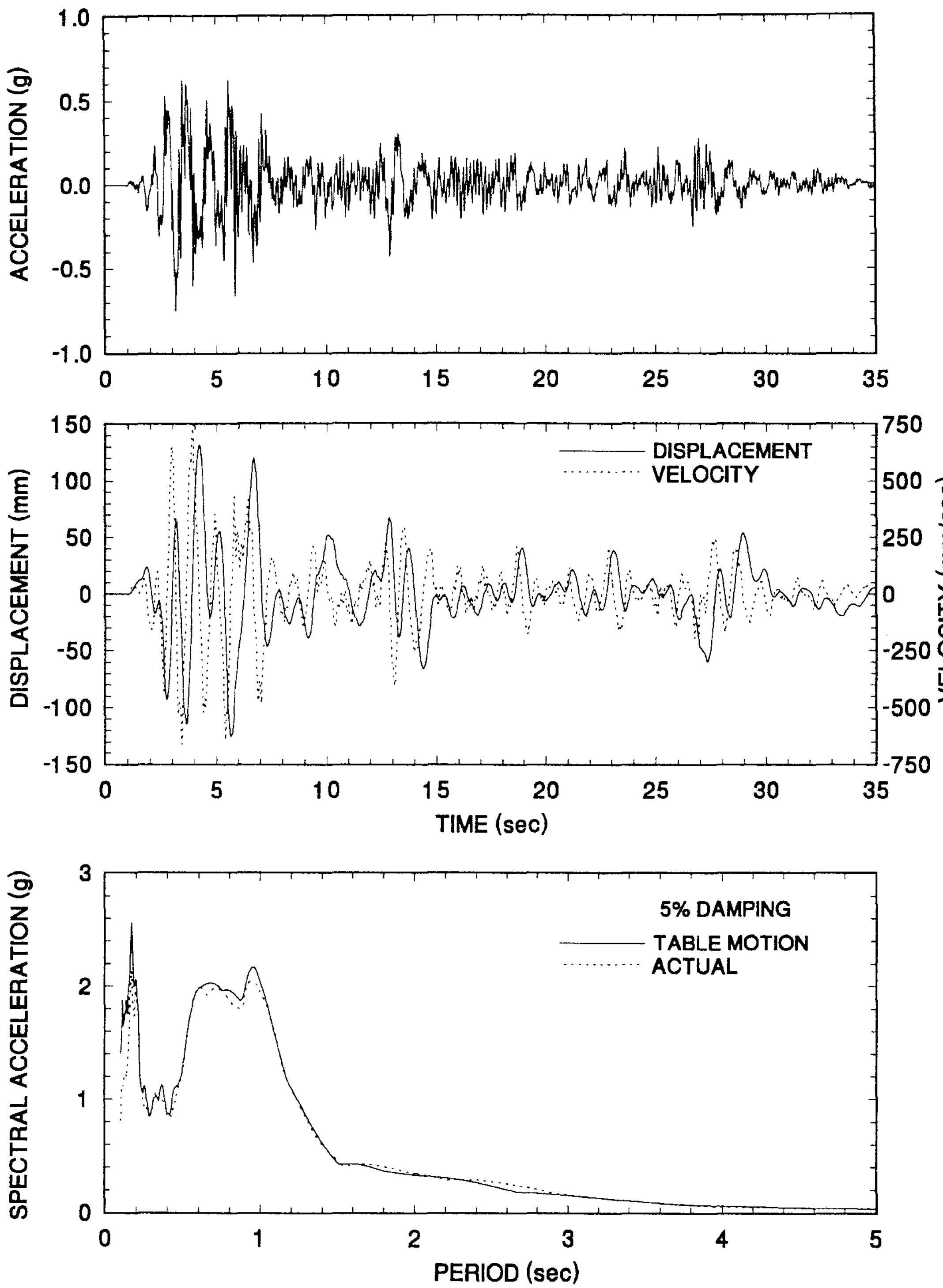


Figure 3-16 Acceleration, Velocity and Displacement Histories and Response Spectrum of El Centro (Horizontal) - 7th Floor in Prototype Scale

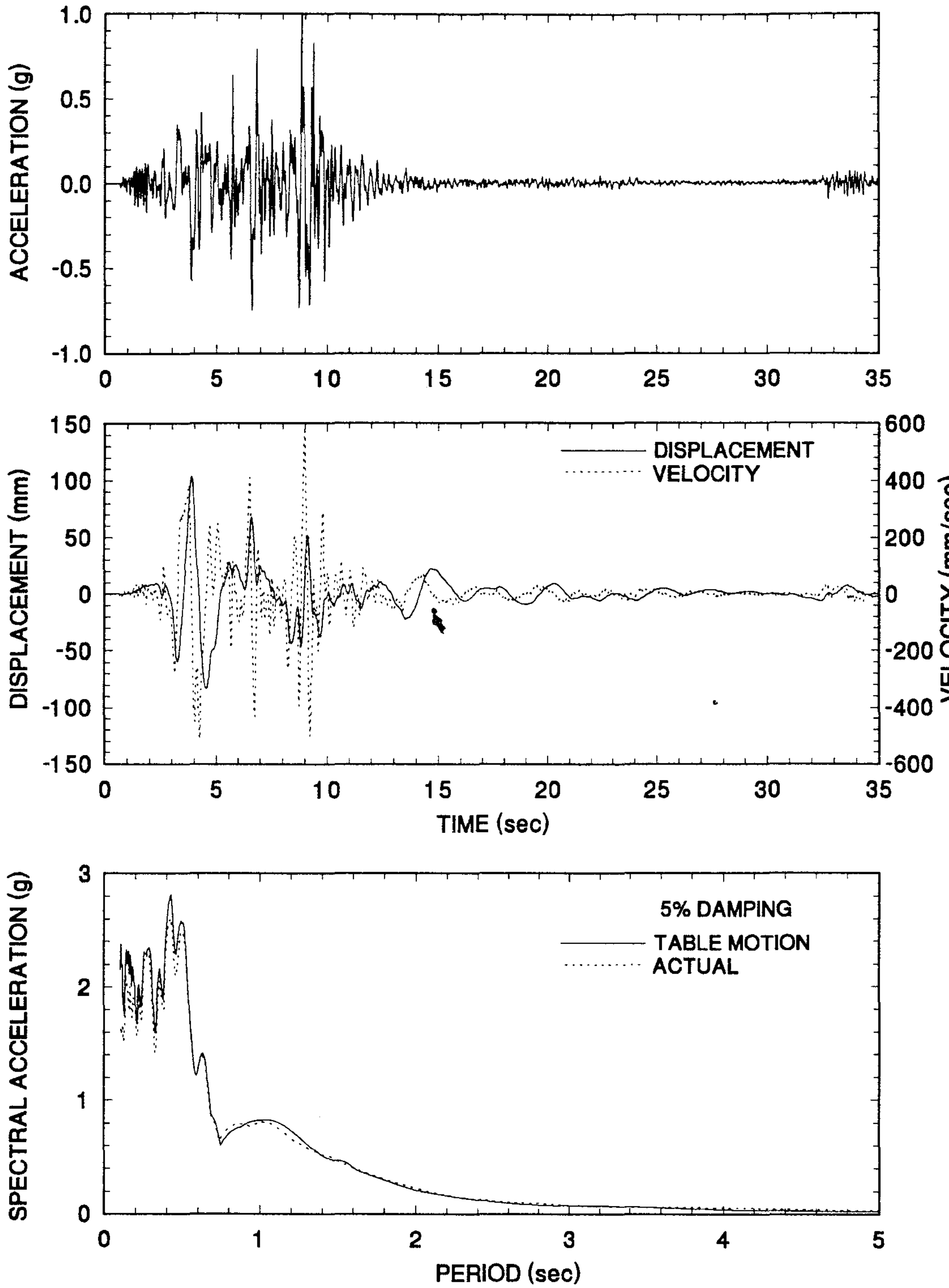


Figure 3-17 Acceleration, Velocity and Displacement Histories and Response Spectrum of Pacoima Dam (Horizontal) - Ground in Prototype Scale

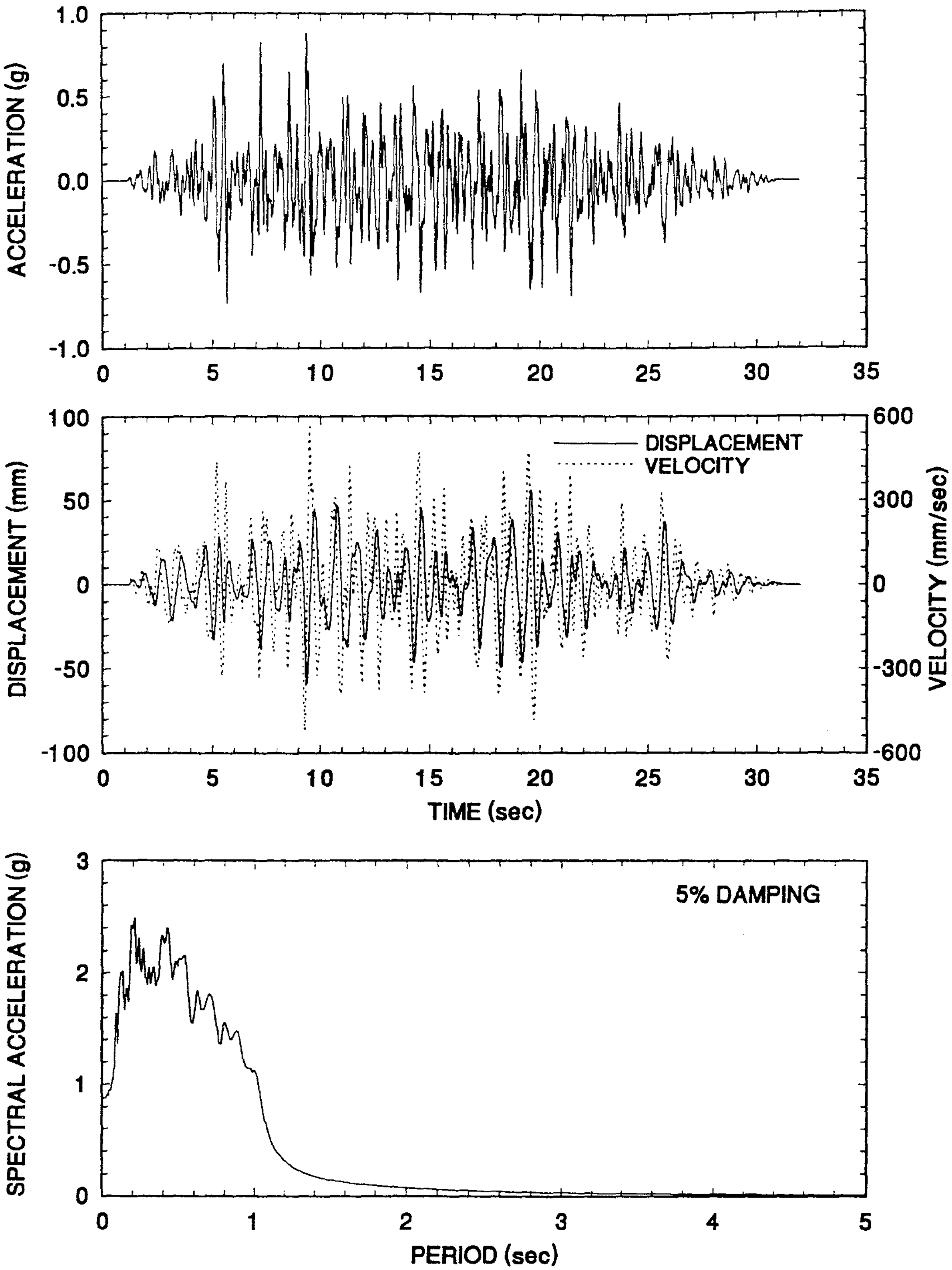


Figure 3-18 Acceleration, Velocity and Displacement Histories and Response Spectrum of Bellcore (Horizontal) in Prototype Scale

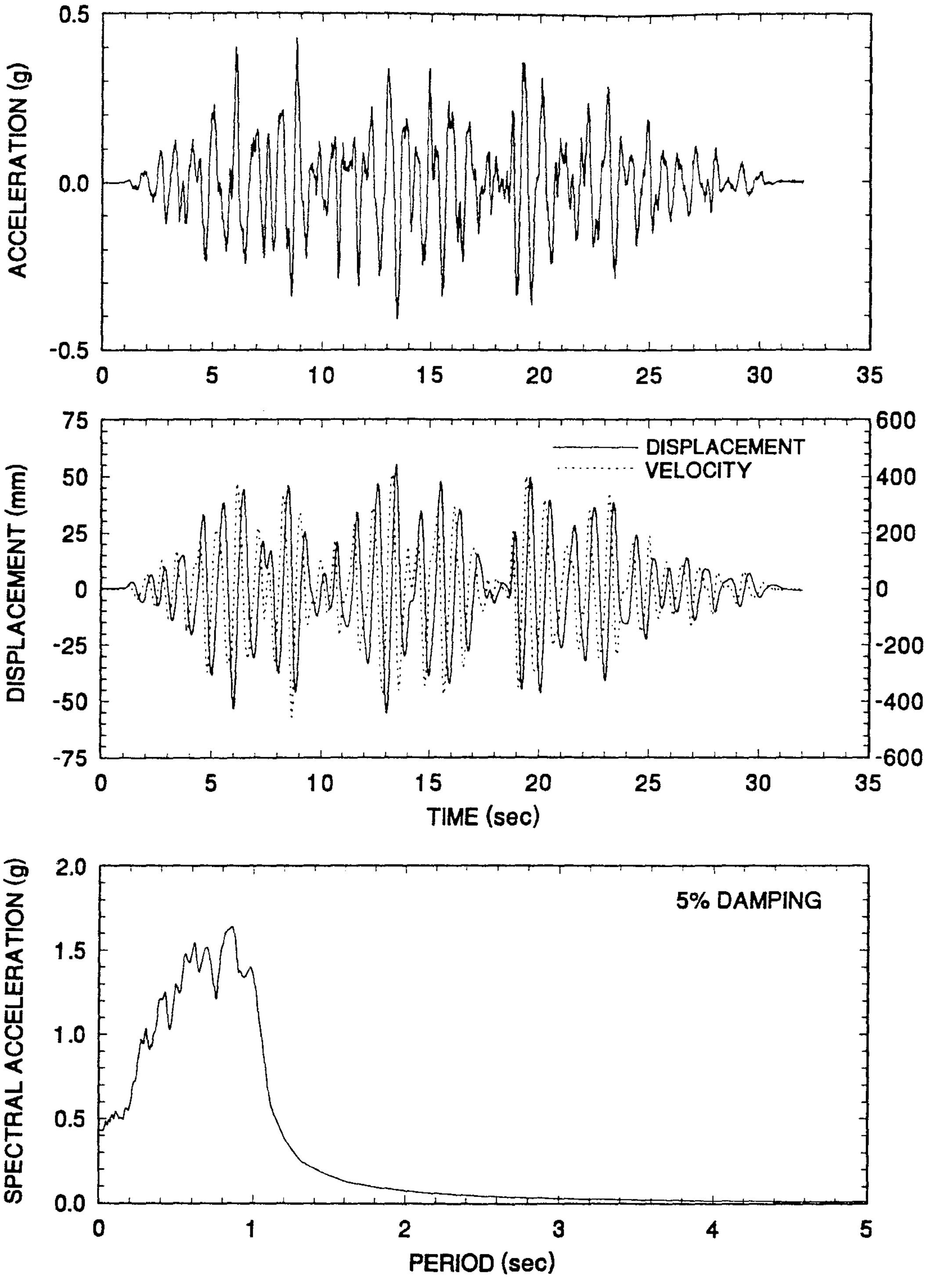


Figure 3-19 Acceleration, Velocity and Displacement Histories and Response Spectrum of IBM 1 (Horizontal) in Prototype Scale

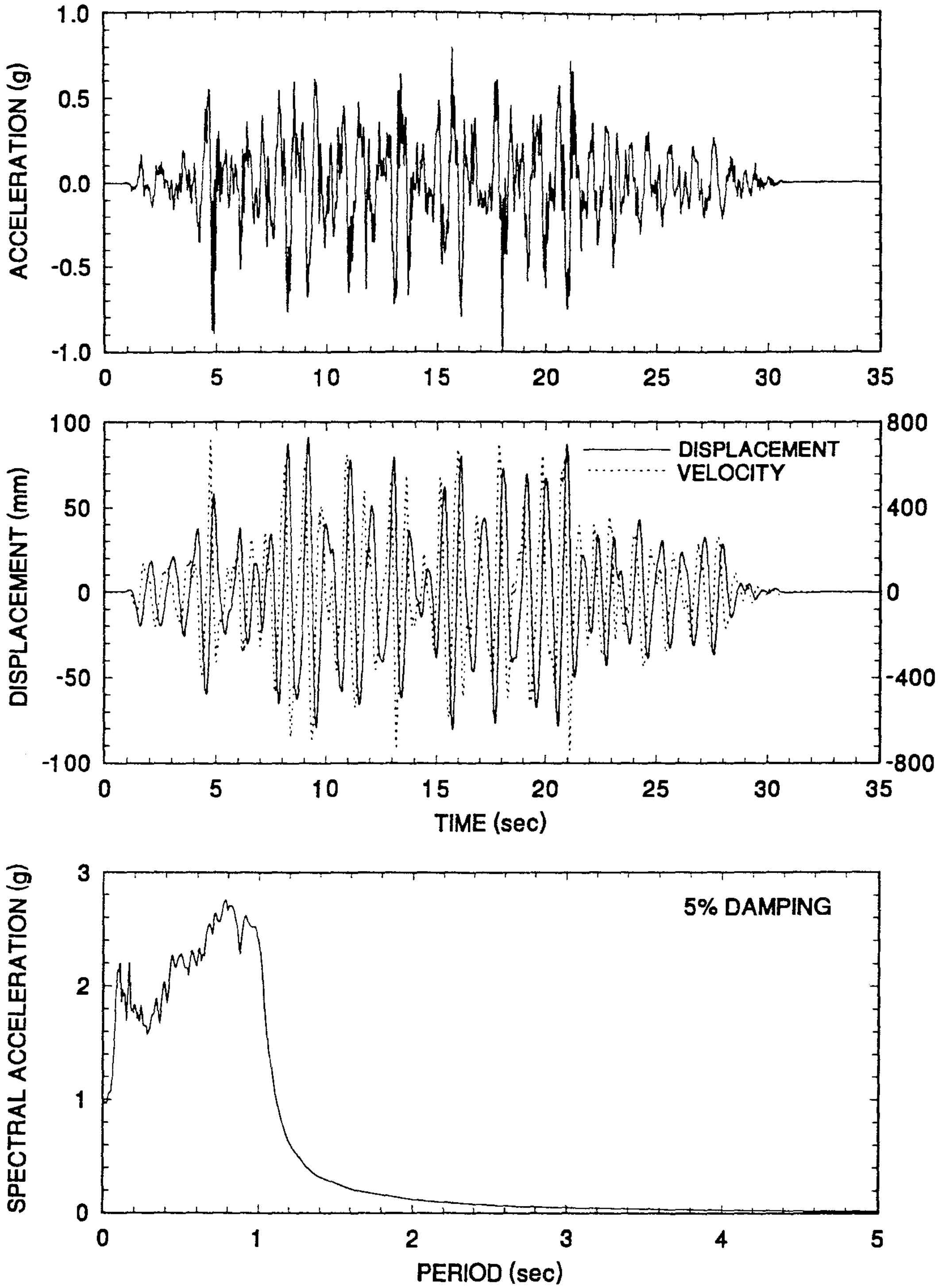


Figure 3-20 Acceleration, Velocity and Displacement Histories and Response Spectrum of IBM 2 (Horizontal) in Prototype Scale

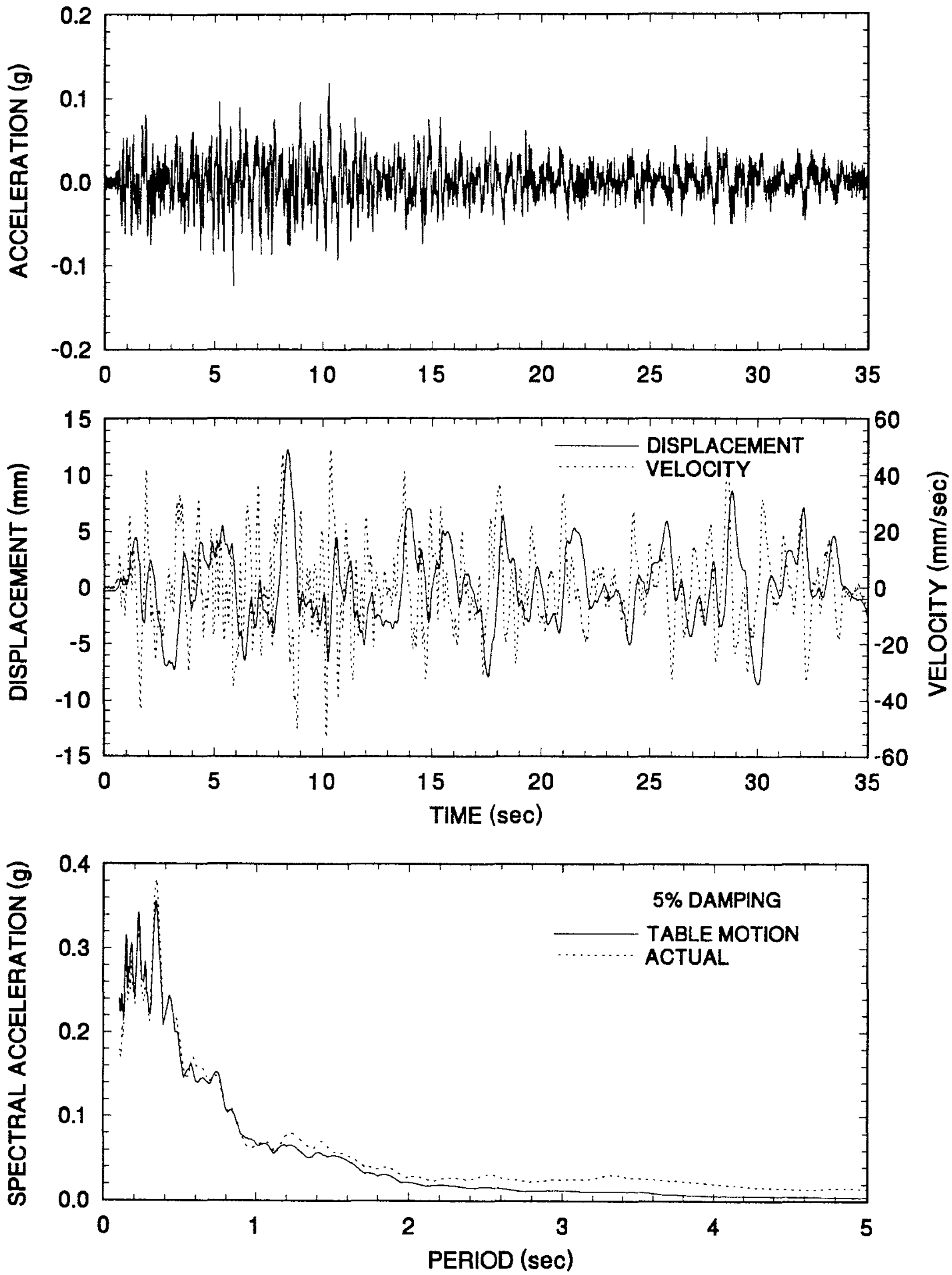


Figure 3-21 Acceleration, Velocity and Displacement Histories and Response Spectrum of Taft (Vertical) - Ground in Prototype Scale

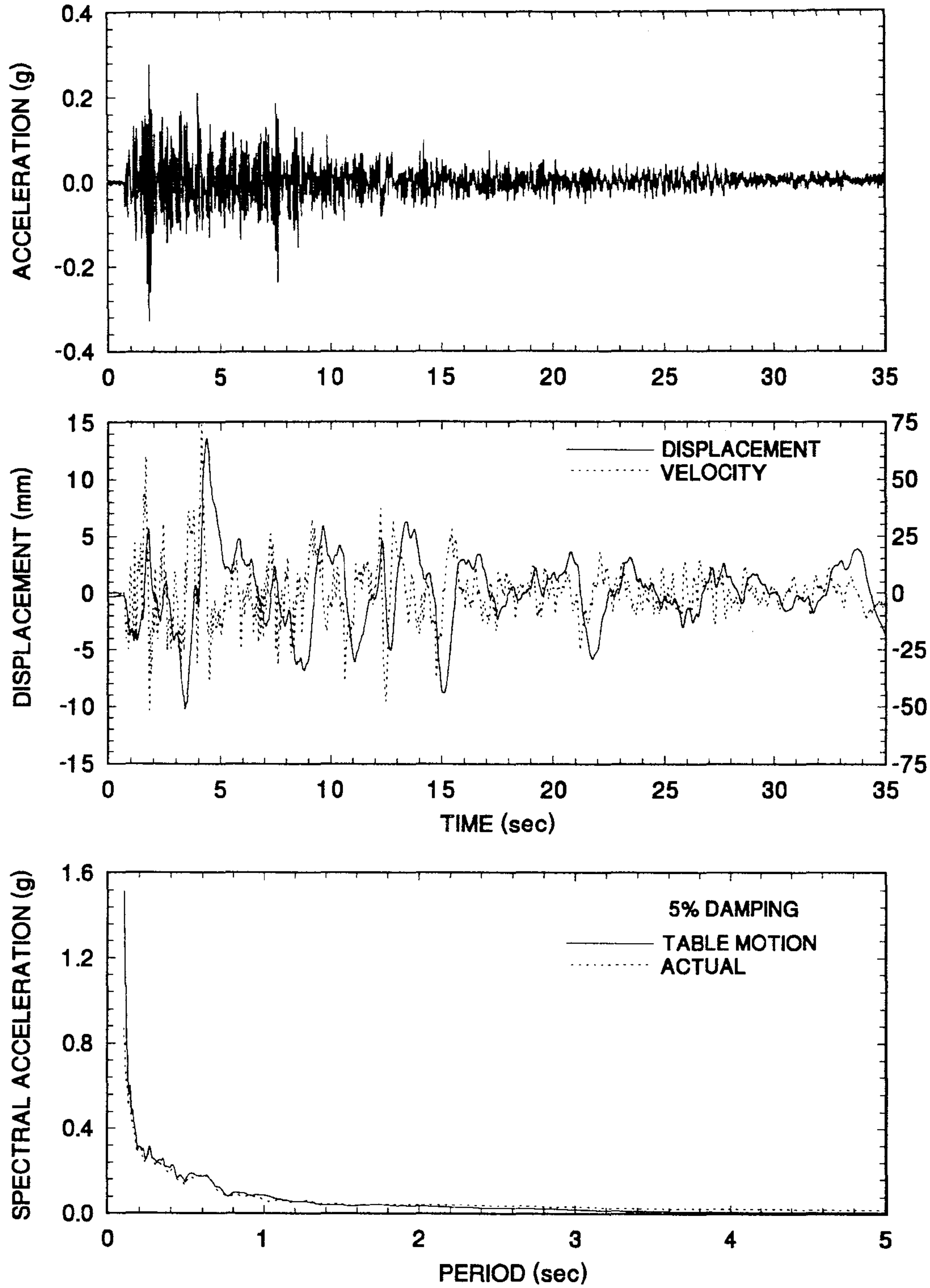


Figure 3-22 Acceleration, Velocity and Displacement Histories and Response Spectrum of El Centro (Vertical) - Ground in Prototype Scale

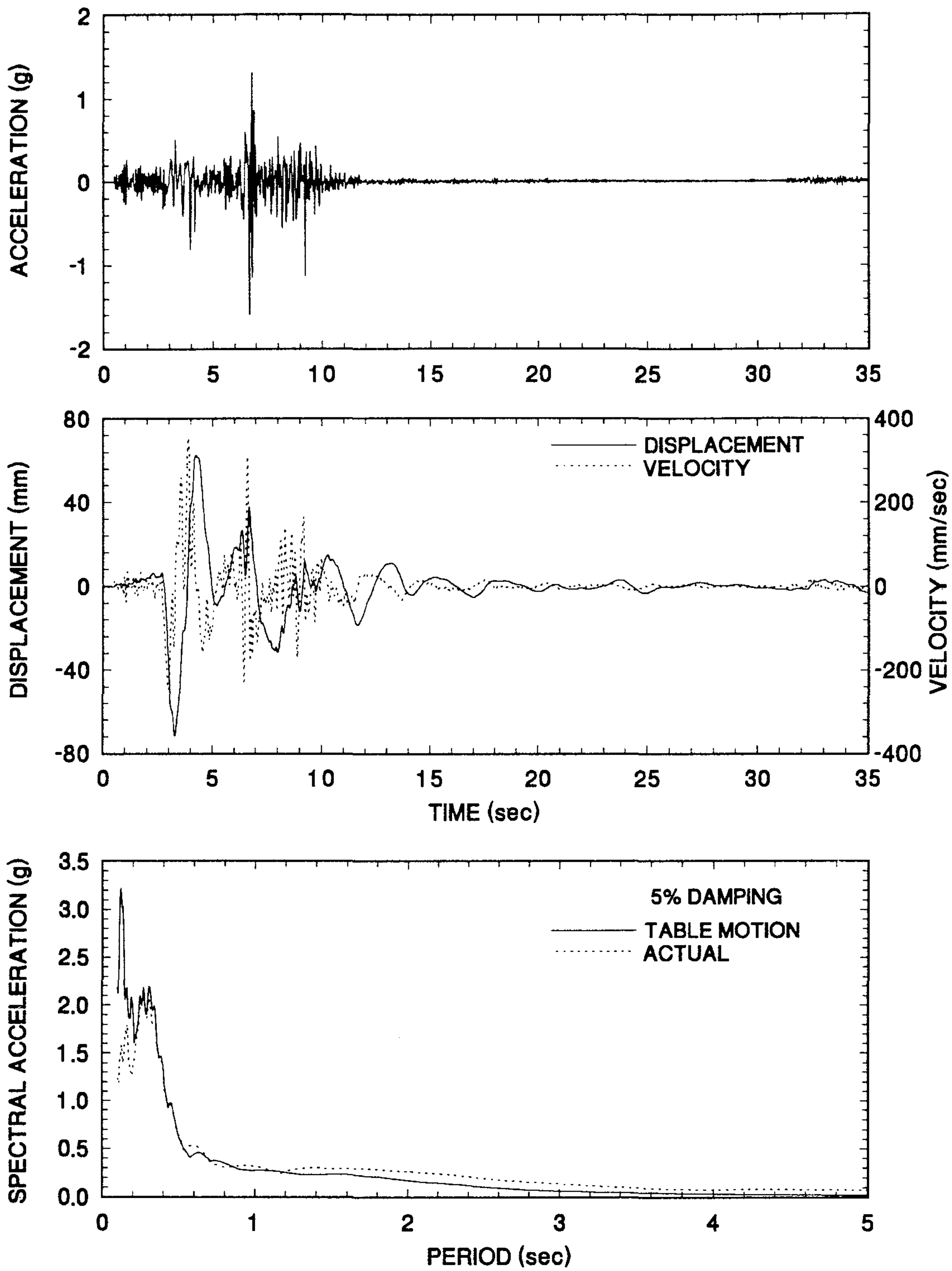


Figure 3-23 Acceleration, Velocity and Displacement Histories and Response Spectrum of Pacoima Dam (Vertical) - Ground in Prototype Scale

3.7 Instrumentation

The behavior of the Floor System and the Cabinet was monitored by load cells, accelerometers and displacement transducers. The instrumentation is shown in Figures 3-24 to 3-27. The 47 monitored channels are listed in Table 3-IV.

Table 3-IV : List of Channels (with reference to Figures 3-24 to 3-27)

CHANNEL	NOTATION	INSTRUMENT	RESPONSE MEASURED
1	ALAT	ACCL	Table Horizontal Accel.
2	AVRT	ACCL	Table Vertical Accel.
3	ABLH	ACCL	Deck Horizontal Accel.- South Side Center
4	ABLV	ACCL	Deck Vertical Accel.- South Side Center
5	AVLS	ACCL	Load Cell Vertical Accel.- South East
6	AVLN	ACCL	Load Cell Vertical Accel.- North East
7	AWFE	ACCL	Base Floor Horizontal Accel.- South East
8	AWFW	ACCL	Base Floor Horizontal Accel.- North East
9	ARFH	ACCL	Raised Floor Horizontal Accel.- South Side Center
10	ARFV	ACCL	Raised Floor Vertical Accel.- South Side Center
11	ACBH	ACCL	Base of Cabinet Horizontal Accel.- North Center
12	ACMH	ACCL	C.M. of Cabinet Horizontal Accel.- North Center
13	AC2H	ACCL	2nd Level of Cabinet Horizontal Accel.- North Center
14	AC3H	ACCL	3rd Level of Cabinet Horizontal Accel.- North Center
15	ACTH	ACCL	Top of Cabinet Horizontal Accel.- North Center
16	ACSV	ACCL	Top of Cabinet Vertical Accel.- South Center
17	ACNV	ACCL	Top of Cabinet Vertical Accel.- North Center
18	ACOP	ACCL	Top of Cabinet out of Plane Hor. Accel.-East Center
19	DLAT	DT	Table Horizontal Displ.
20	DVRT	DT	Table Vertical Displ.
21	DBLC	DT	Deck Total Horizontal Displ.-South Side Center
22	DBSW	DT	Bearing Horizontal Displ.- South West
23	DBSE	DT	Bearing Horizontal Displ.- South East
24	DBNW	DT	Bearing Horizontal Displ.- North West
25	DBNE	DT	Bearing Horizontal Displ.- North East

Table 3-IV : List of Channels (with reference to Figures 3-24 to 3-27)

CHANNEL	NOTATION	INSTRUMENT	RESPONSE MEASURED
26	DWFW	DT	Base Floor Total Horizontal Displ.- South West
27	DRFW	DT	Raised Floor Total Horizontal Displ.- South West
28	DCBW	DT	Base of Cabinet Total Horizontal Displ.- South West
29	DCMW	DT	C.M. of Cabinet Total Horizontal Displ.- South West
30	DCTW	DT	Top of Cabinet Total Horizontal Displ.- South West
31	DCTE	DT	Top of Cabinet Total Horizontal Displ.- South East
32	DTDW	DT	Axial Damper Displ.- West Side
33	DTDE	DT	Axial Damper Displ.- East Side
34	LC1N	LOAD CELL	Axial Bearing Force- North East
35	LC2N	LOAD CELL	Axial Bearing Force- North West
36	LC3N	LOAD CELL	Axial Bearing Force- South West
37	LC4N	LOAD CELL	Axial Bearing Force- South East
38	LC1SX	LOAD CELL	Shear Bearing Force in South-North Dir.- North East
39	LC2SX	LOAD CELL	Shear Bearing Force in South-North Dir.- North West
40	LC3SX	LOAD CELL	Shear Bearing Force in South-North Dir.- South West
41	LC4SX	LOAD CELL	Shear Bearing Force in South-North Dir.- South East
42	LC1SY	LOAD CELL	Shear Bearing Force in West-East Dir.- North East
43	LC2SY	LOAD CELL	Shear Bearing Force in West-East Dir.- North West
44	LC3SY	LOAD CELL	Shear Bearing Force in West-East Dir.- South West
45	LC4SY	LOAD CELL	Shear Bearing Force in West-East Dir.- South East
46	LCDW	LOAD CELL	Axial Force in Damper- West Side
47	LCDE	LOAD CELL	Axial Force in Damper- East Side

ACCEL= Accelerometer, DT= Displacement Transducer

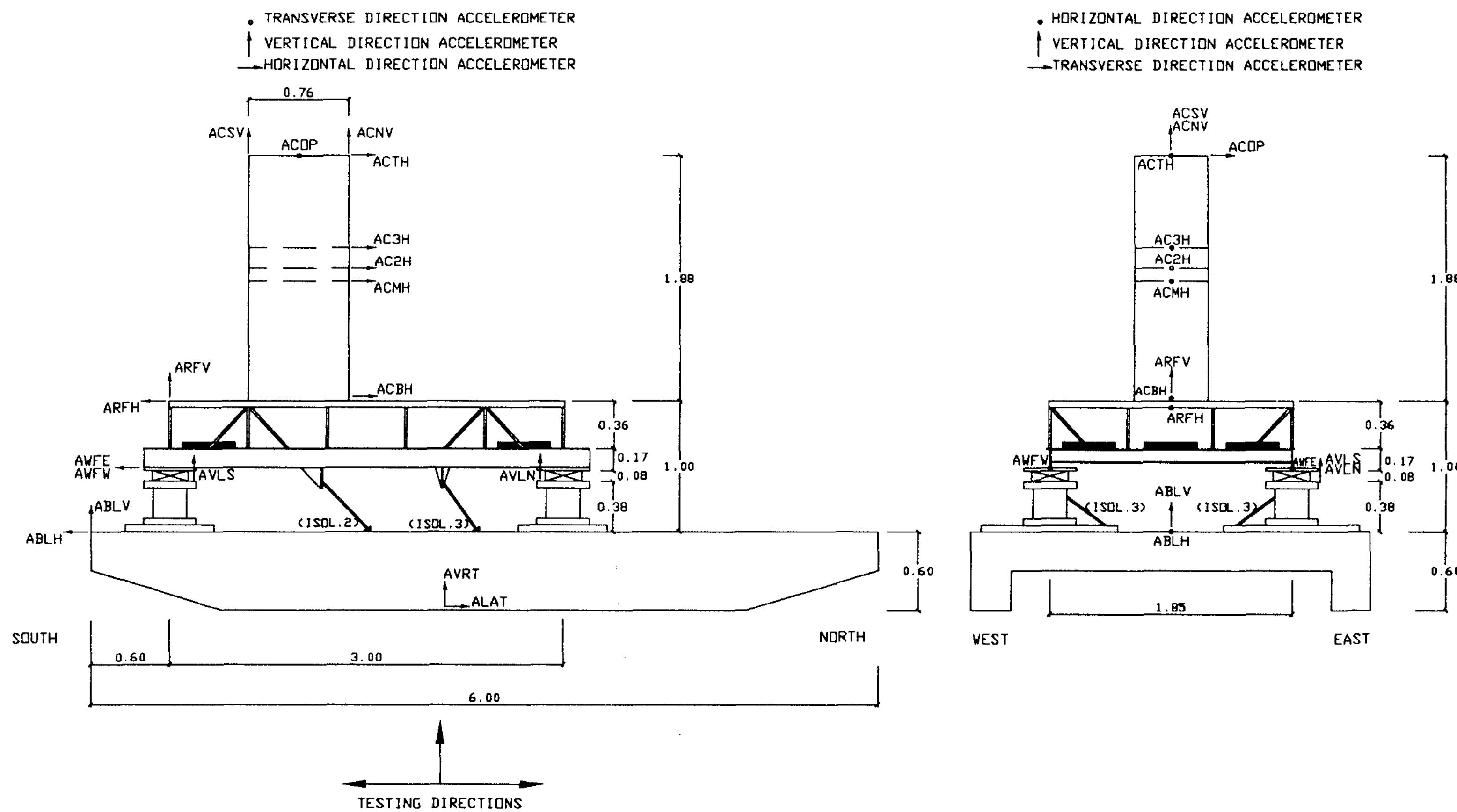


Figure 3-24 Location of Accelerometers (Units: m)

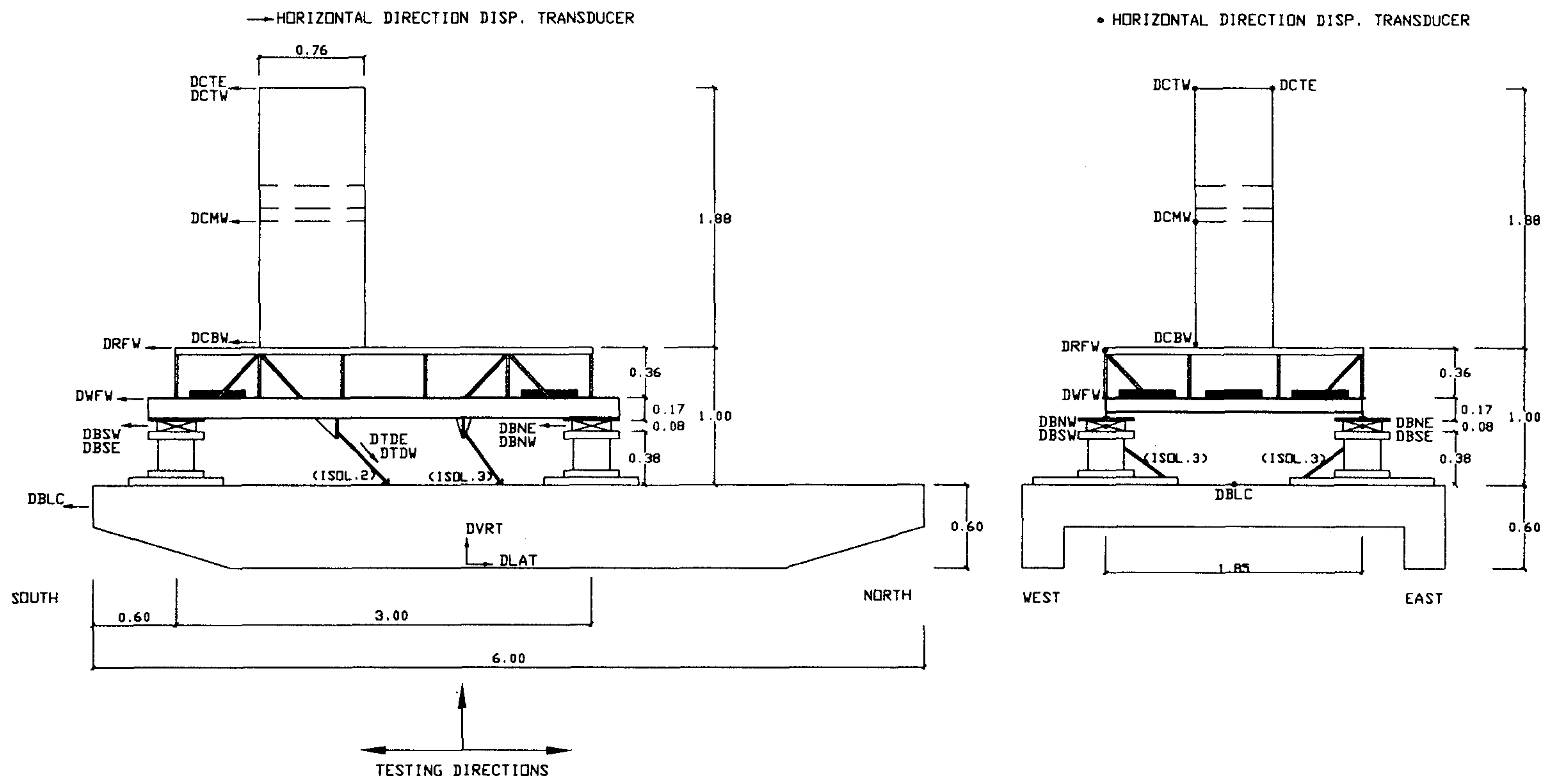


Figure 3-25 Location of Displacement Transducers (Units: m)

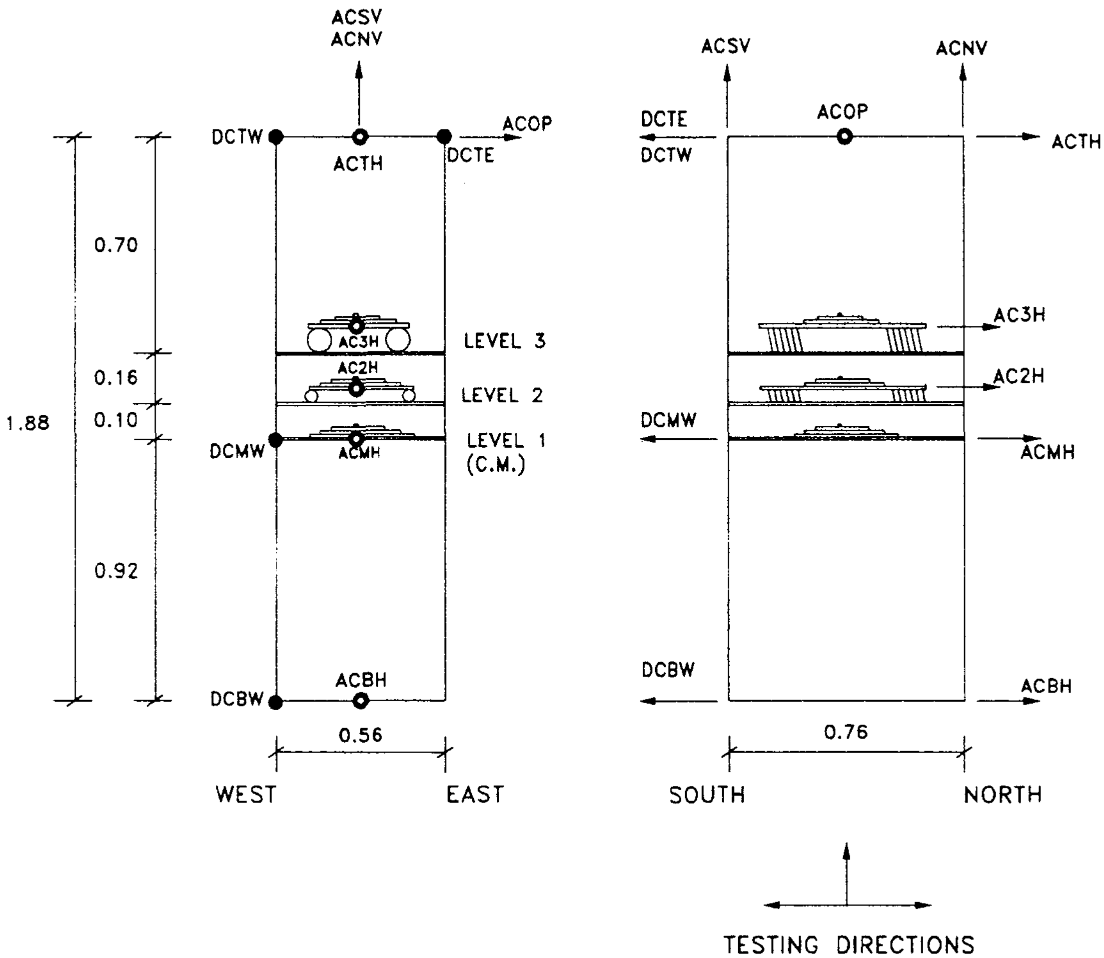


Figure 3-26 Instrumentation on Cabinet (Units: m)

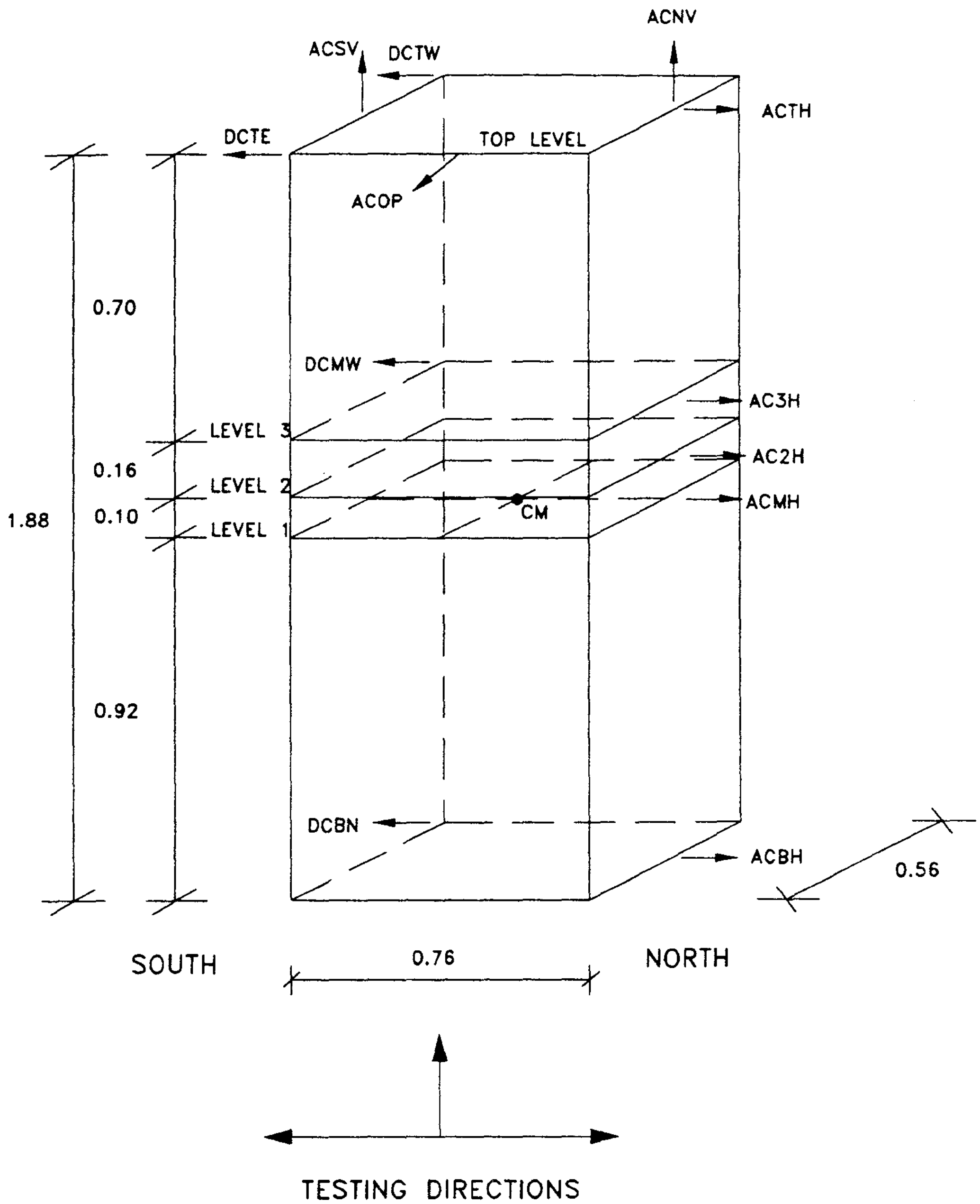


Figure 3-27 Three Dimensional View of Instrumentation on Cabinet (Units: m)

SECTION 4

TEST RESULTS AND INTERPRETATION

4.1 Test Results

The recorded peak response in each test is presented in Appendix A. This appendix contains tables, each one of which corresponds to a specific input motion and length scale of experiment. Each table compares the response of the system with the three isolation systems and without isolation. The tables contain the recorded peak table motion and the following recorded peak values of response:

(1) Horizontal and vertical acceleration of Raised Floor.

(2) Horizontal acceleration of center of mass (level 1) of Cabinet.

(3) Horizontal acceleration of flexible internal components at levels 2 and 3 (see Figure 3-26)

(4) Horizontal and vertical acceleration of top of Cabinet.

(5) FPS bearing horizontal displacement.

(6) Total horizontal displacement of Raised Floor (that is, displacement of Raised Floor with respect to a stationary frame).

(7) Horizontal displacement of Raised Floor and top of Cabinet with respect to the Raised Floor.

4.2 Comparison of Behavior of Isolated and Non-isolated Computer Floor

The results of Appendix A demonstrate that seismic isolation offers significant benefits. In all cases of strong excitation (Taft 7th floor, El Centro 7th floor, Pacoima, Bellcore and IBM inputs) the non-isolated Cabinet underwent rocking motion, resulting in large accelerations. These accelerations were of the order of 2 to 4 g, thus sufficiently strong to cause interruption of operation in computers and damage to equipment.

Rocking of the Cabinet was also observed in tests of the isolated floor system in the Bellcore input at length scale of 1. This case corresponds to an isolation system period in prototype scale of 1.5 secs which is apparently not long enough to provide effective isolation in long period motions. For example, an inspection of the response spectra of Figures 3-17 to 3-19 reveals large spectral values at period of about 1 sec. Furthermore, uplift and rocking of the Cabinet on the isolated Raised Floor was observed in the Pacoima input with vertical component. This has been the result of the vertical table motion, which exceeded 1 g in peak value (see Appendix A). The actual earthquake had vertical acceleration of 0.71 g (see Table 3-II), however the shake table could not accurately simulate this component. This was clearly evident during testing when the Cabinet and Base Floor could be seen to momentarily separate from the Raised Floor and isolation bearings, respectively.

We proceed to present a comprehensive comparison of isolated and non-isolated Cabinet response at length scales of 2, 3 and 4 and excluding the unsuccessfully run tests with the vertical component of Pacoima input. Figures 4-1 to 4-10 present profiles of recorded peak acceleration of the Cabinet for all tested isolation systems. The profiles show the recorded acceleration at the shake table, Raised Floor, center of mass (level 1) of Cabinet and top of Cabinet. It should be noted that the three length scales correspond, in prototype scale, to three different isolation system periods (see Table 3-III). The profiles clearly demonstrate that the isolation systems achieve substantial reductions of acceleration in comparison to the non-isolated floor system.

Figures 4-1 to 4-10 provide also information to compare the behavior of the three isolation systems. The peak acceleration response of the Cabinet with isolation system 3 (that is the system with friction coefficient $f_{max} = 0.13$ and damping ratio of 0.35) appears to be the least among the three isolation systems, although the differences are relatively small.

A more enlightening comparison of the behavior of the three isolation systems is presented in Figures 4-11 to 4-30 , where "floor spectra" for the recorded motions at the center of mass and top of Cabinet are shown. The spectra show the peak acceleration response of a small weight (so that interaction with the Cabinet is negligible), lightly damped oscillator (damping ratio = 2 %) with frequency up to 100 Hz if it were attached to various parts of the Cabinet. Thus, the spectra present information on the response of small internal components of the Cabinet, as for example in electronic components of a computer. The figures included also, for comparison, the floor spectra of the non-isolated Cabinet and of shake table.

All floor spectra contain peaks at the frequency of 10 Hz. The origin of this frequency could not be determined. Concentrating first on the results for length scale of 2 (isolation system period in prototype scale equal to 2.12 secs) we observe:

(1) In weak seismic excitation (such as Taft input and El Centro - ground input) the high friction in isolation system 1 generates higher spectral accelerations than the lower friction, viscously damped isolation systems 2 and 3.

(2) In strong seismic excitation the three isolation systems exhibit similar behavior and general conclusions are difficult to arrive at. However, it is clear that in the artificial Bellcore and IBM inputs the floor spectra for the isolated Cabinet are substantially lower than those of the non-isolated Cabinet and that isolation system 3 exhibits best performance.

For length scale of 4 (isolation system period in prototype scale equal to 3 secs) we observe:

(1) In weak seismic excitation (Taft input and El Centro - ground input) the three isolation systems have comparable performance.

(2) In strong seismic excitation all isolation systems show a substantial reduction of spectral response in comparison with the non-isolated system. Particularly, the lower friction, viscously damped isolation system 3 shows a better performance than the higher friction isolation system 1.

This behavior of the long period (3 secs in prototype scale) isolation systems is easily interpreted. The isolation system period is sufficiently long to avoid the long period strong components of the simulated floor motions (see spectra of Figures 3-16 to 3-20). All tested isolation systems have very large energy dissipation capability, so that they appear ineffective in weak excitation. Under these conditions, the presence of high damping (either frictional or viscous) is detrimental to the isolation mechanism. However, in strong excitation the isolation systems undergo larger displacements and isolation becomes effective. As expected, isolation system 3 shows better performance than isolation system 1 because high frictional damping has been exchanged for a combination of lower frictional damping and viscous damping. At zero velocity, where the frictional force abruptly changes direction, high frequency motion is generated in the structure above the isolation system. System 3 has friction force at zero velocity (f_{min}W , where W=weight) equal to about one half of that of system 1 (see Figure 3-5). Thus, less high frequency response is generated, leading to lower floor spectral values.

The better performance of isolation system 3 is further illustrated in Figure 4-31 which presents the recorded peak acceleration of the flexible internal component at level 3 (see Section 3.2 , Figure 3-2) for various earthquakes. The results for length scales of 2 and 4 are presented. Had been possible to test with lower friction than achieved in isolation systems 2 and 3 , even better performance could be achieved. This is analytically demonstrated in Section 5 .

4.3 Displacement Demand in Isolation System

Having determined that effective isolation requires isolation system period, in prototype scale, of the order of 3 secs, it is important to establish the displacement demand in the isolation bearings. It might be expected to be large because of the long isolation system period.

An inspection of the results of Appendix A reveals that the peak bearing displacement, in prototype scale occurs for the El Centro 7th floor input for length scale of 4 and isolation system 3. It is only 134 mm. This is small and, apparently, the result of the high energy dissipation capacity of the tested systems. FPS bearings to accommodate this displacement demand would be approximately 400 mm by 400 mm in plan dimension.

A more detailed presentation of bearing displacement demand is given in Figures 4-32 to 4-34. Here the recorded bearing displacement in all tests has been extrapolated to prototype scale and plotted as function of length scale. It should be noted that length scale corresponds to isolation system period as noted in the figure captions. Clearly, increases in isolation system period are not accompanied by corresponding increases in bearing displacement. Rather, bearing displacements appear only marginally affected by the isolation system period. This is the result of high energy dissipation capability of the tested isolation systems.

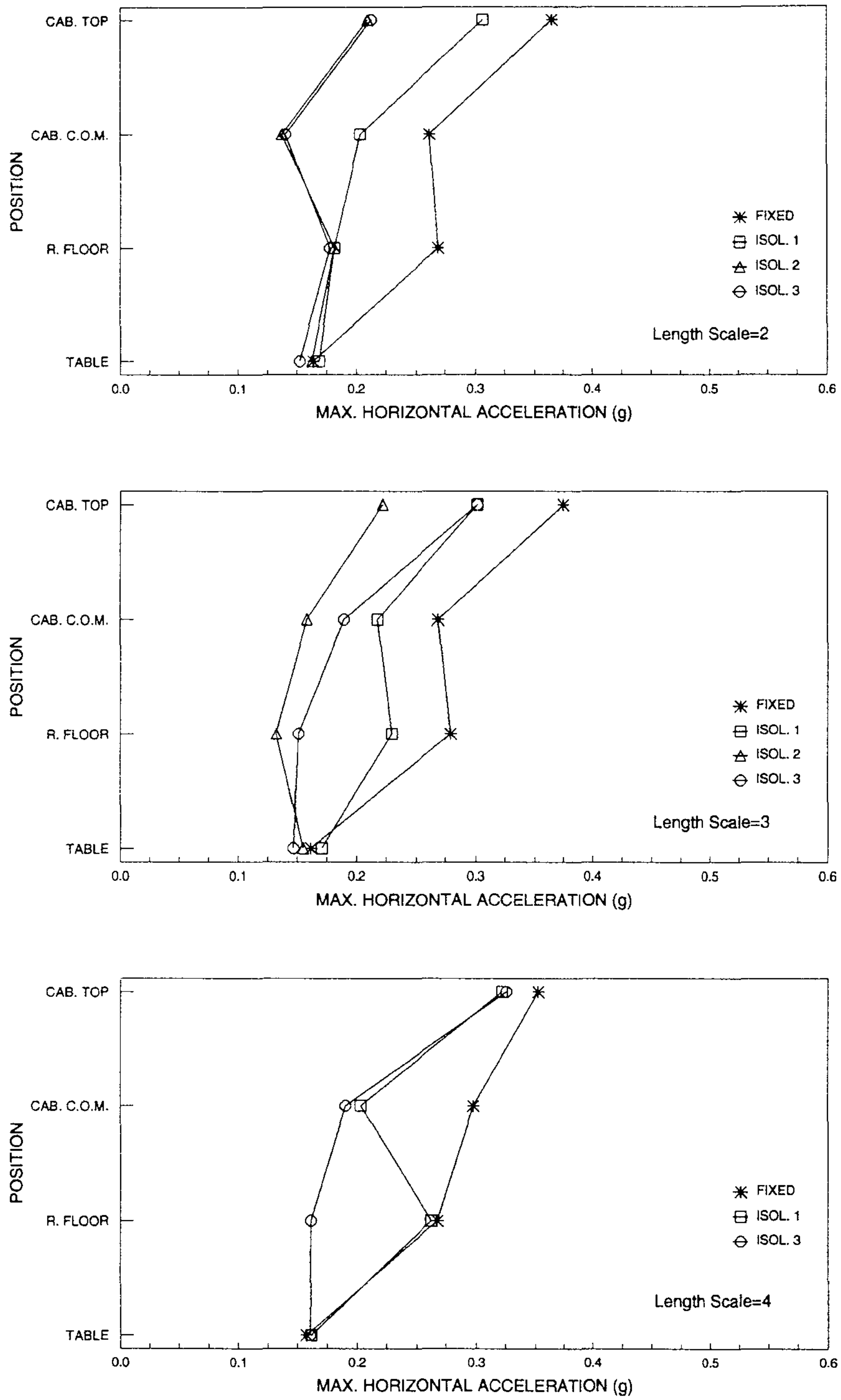


Figure 4-1 Profiles of Peak Acceleration Along Height of Cabinet in Taft N21E Ground Horizontal -Vertical Input

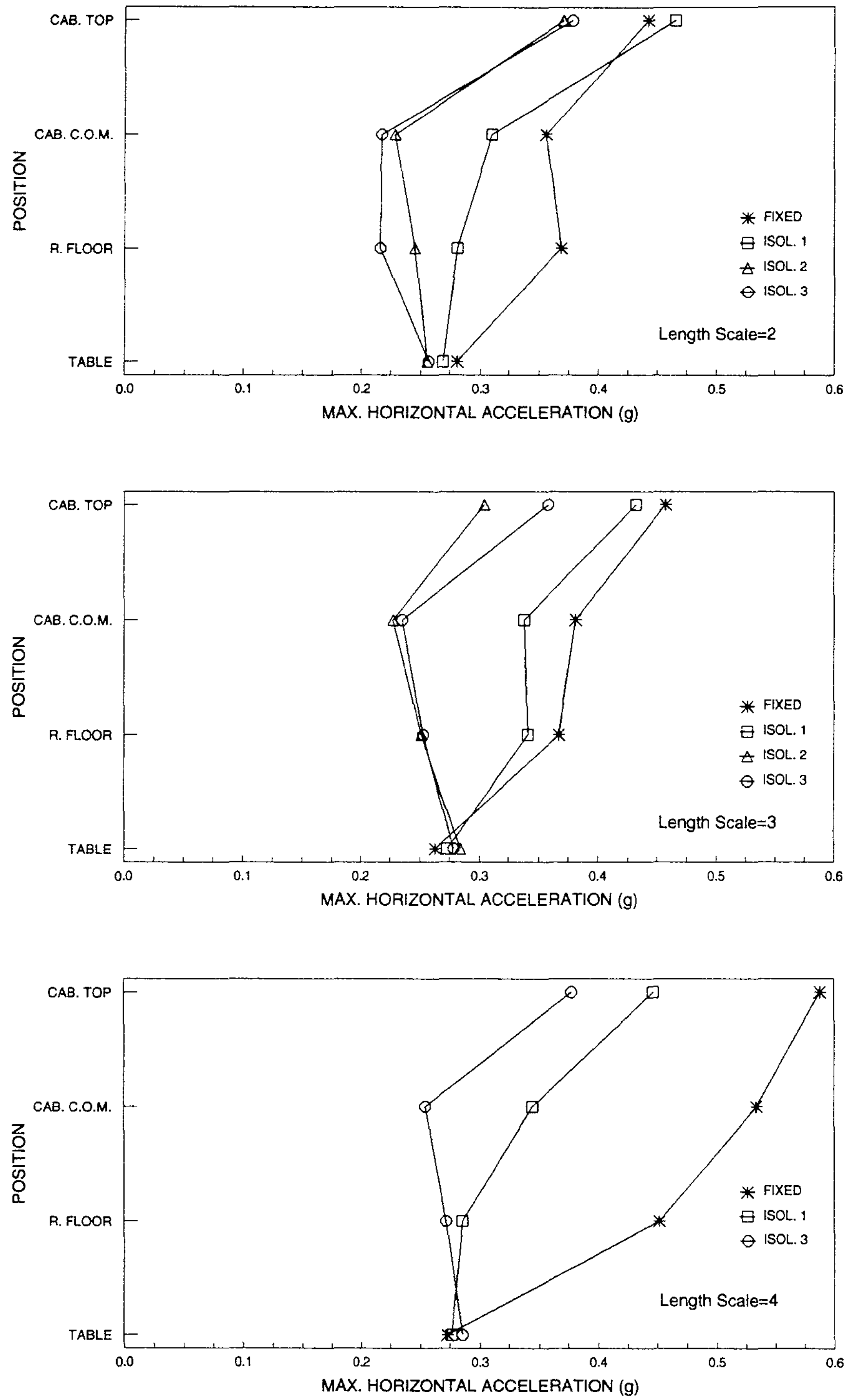
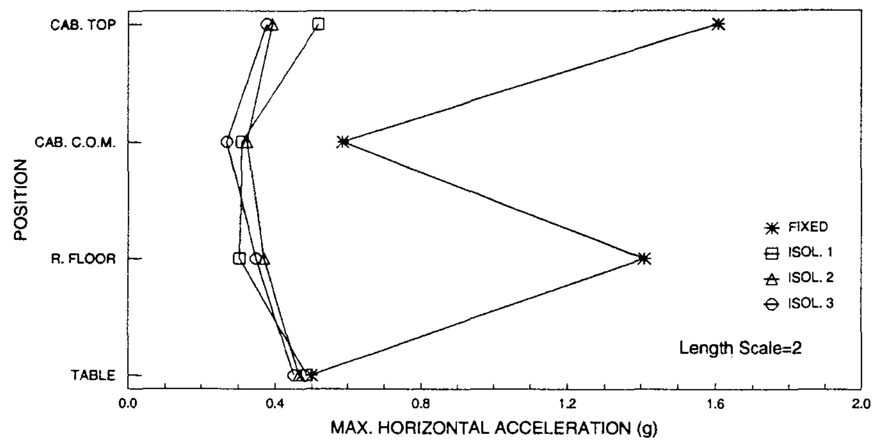
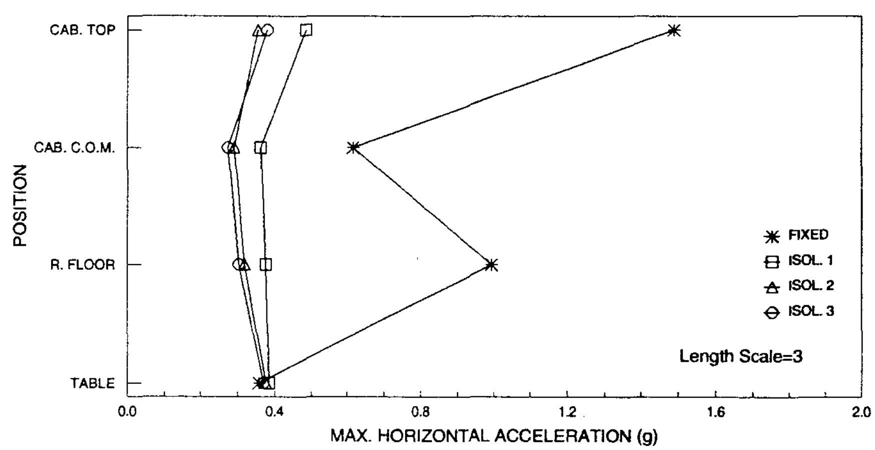


Figure 4-2 Profiles of Peak Acceleration Along Height of Cabinet in Taft N21E 5th Floor Horizontal -Vertical Input





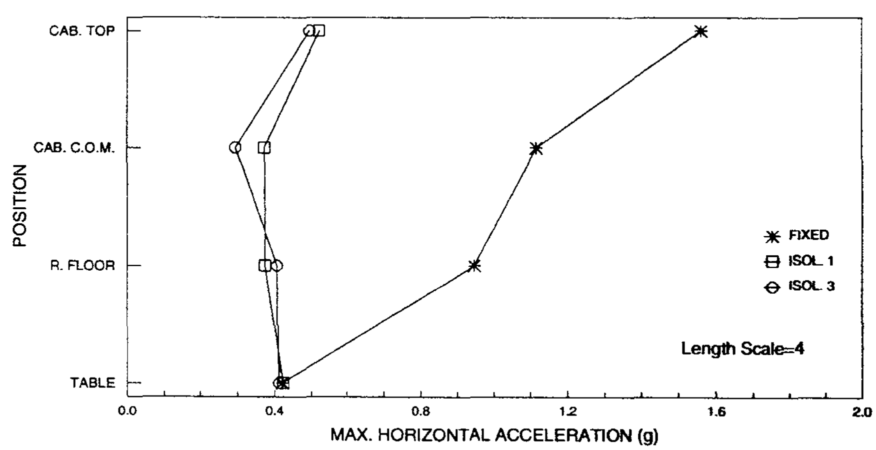


Figure 4-3 Profiles of Peak Acceleration Along Height of Cabinet in Taft N21E 7th Floor Horizontal -Vertical Input

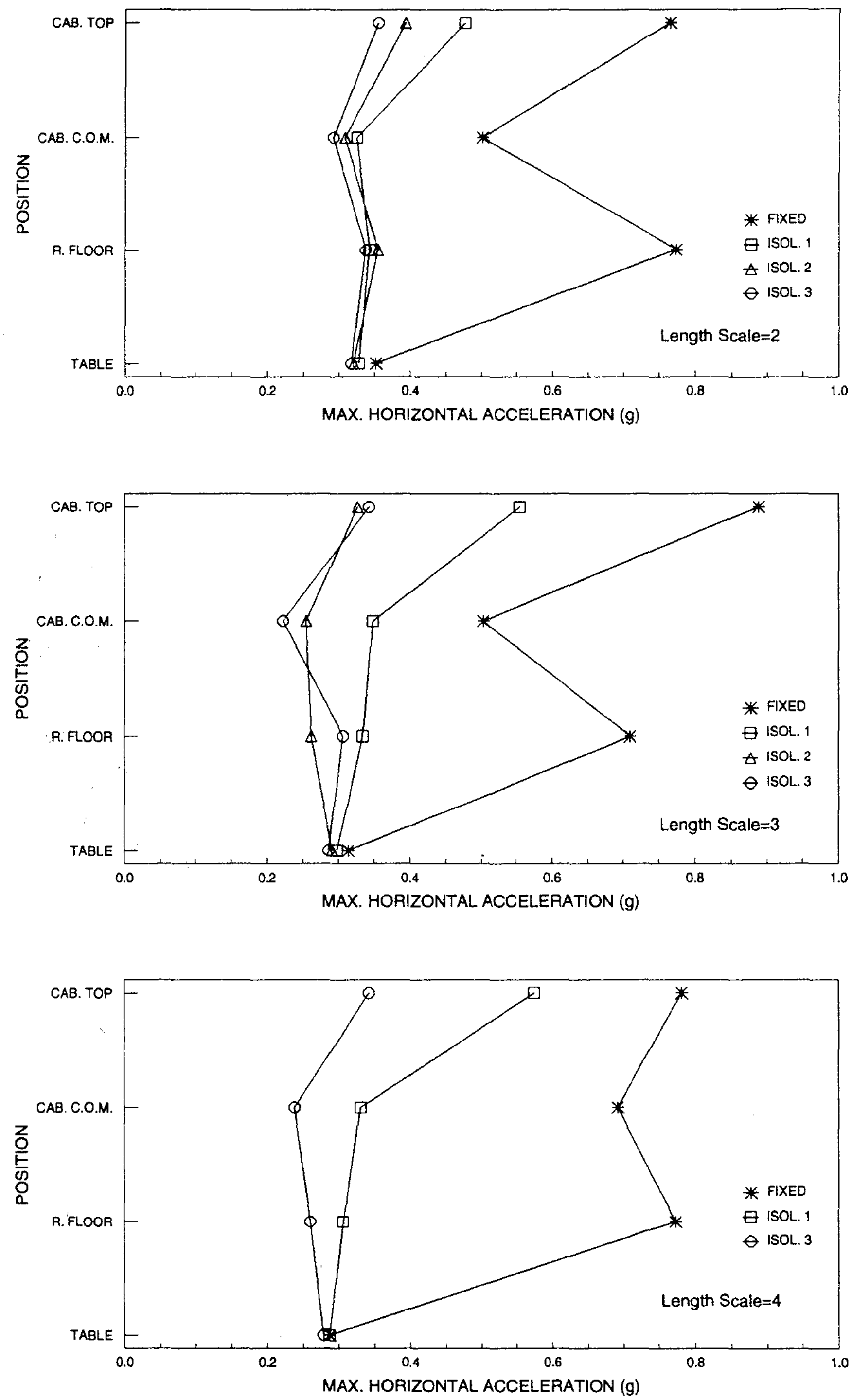


Figure 4-4 Profiles of Peak Acceleration Along Height of Cabinet in El Centro S00E Ground Horizontal -Vertical Input

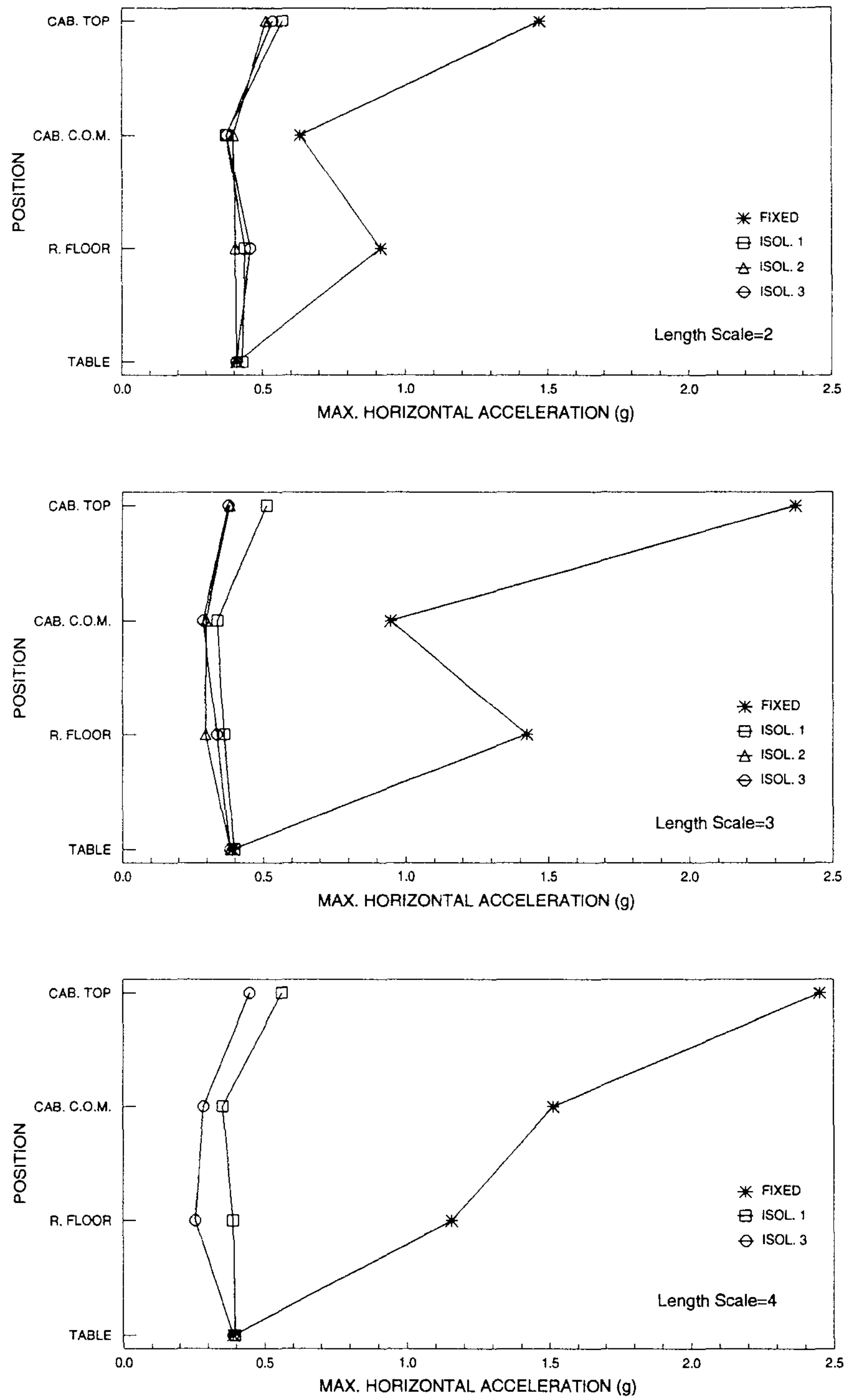


Figure 4-5 Profiles of Peak Acceleration Along Height of Cabinet in El Centro S00E 5th Floor Horizontal -Vertical Input

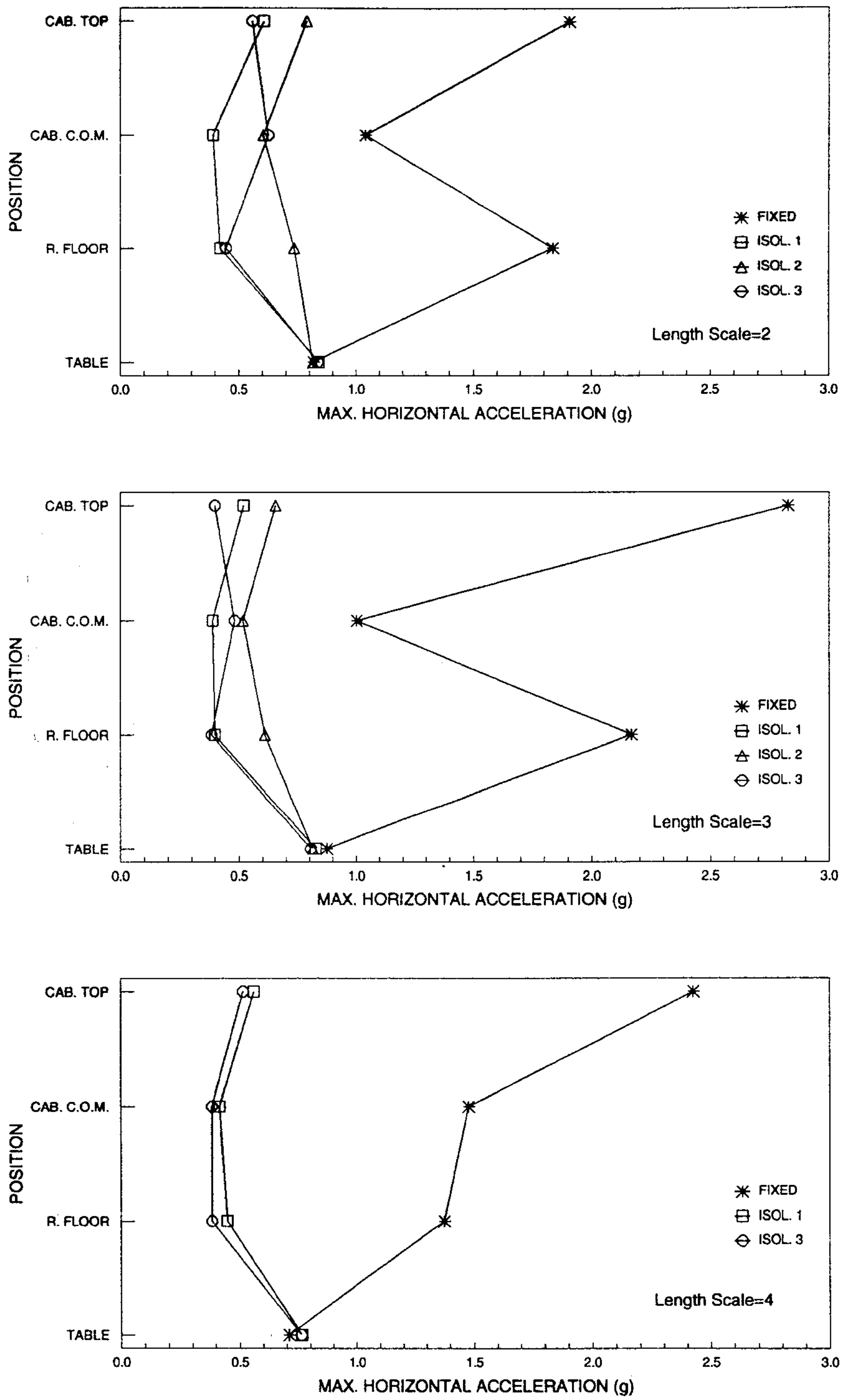


Figure 4-6 Profiles of Peak Acceleration Along Height of Cabinet in El Centro S00E 7th Floor Horizontal -Vertical Input

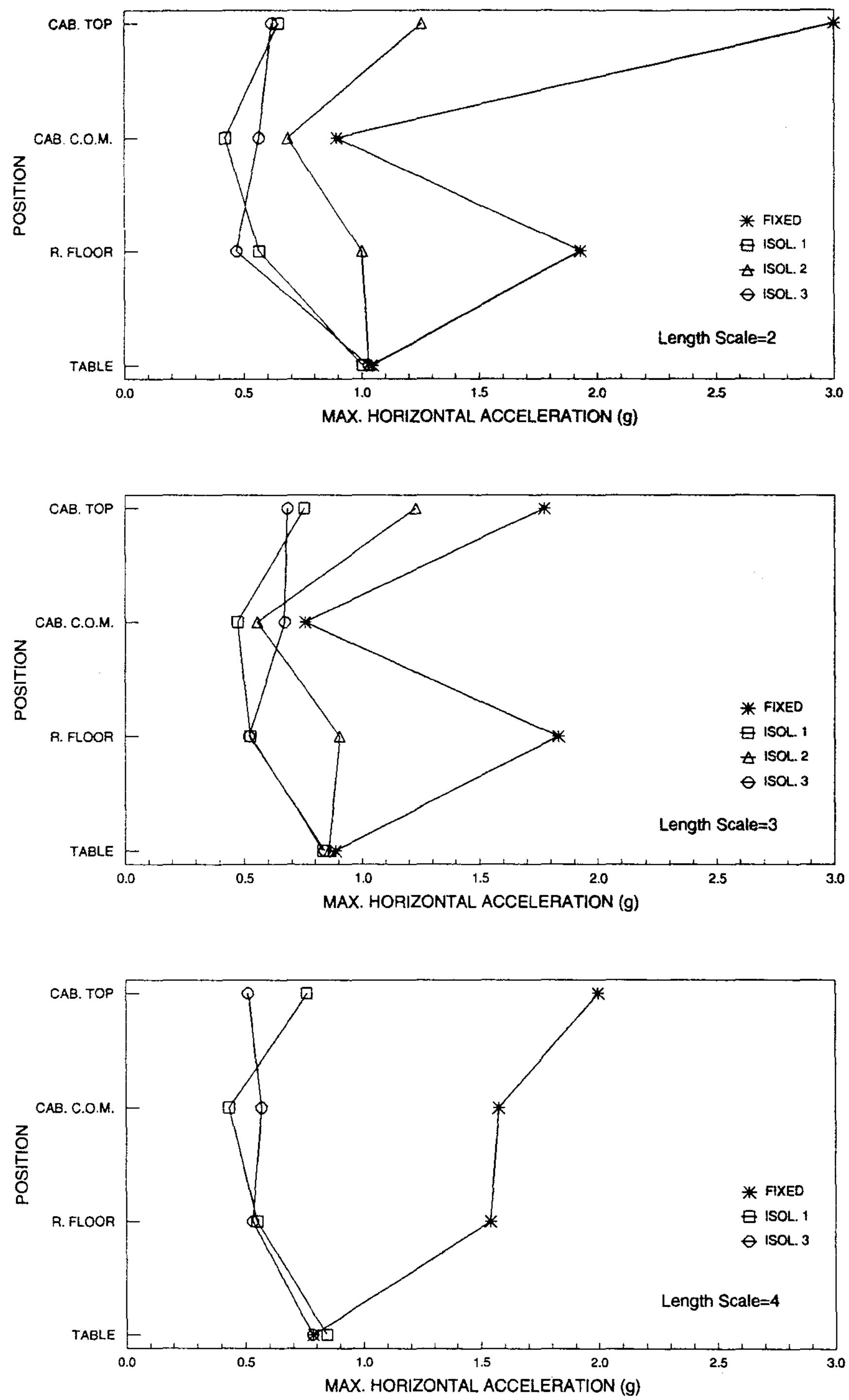


Figure 4-7 Profiles of Peak Acceleration Along Height of Cabinet in Pacoima Dam S74W Ground Horizontal Input

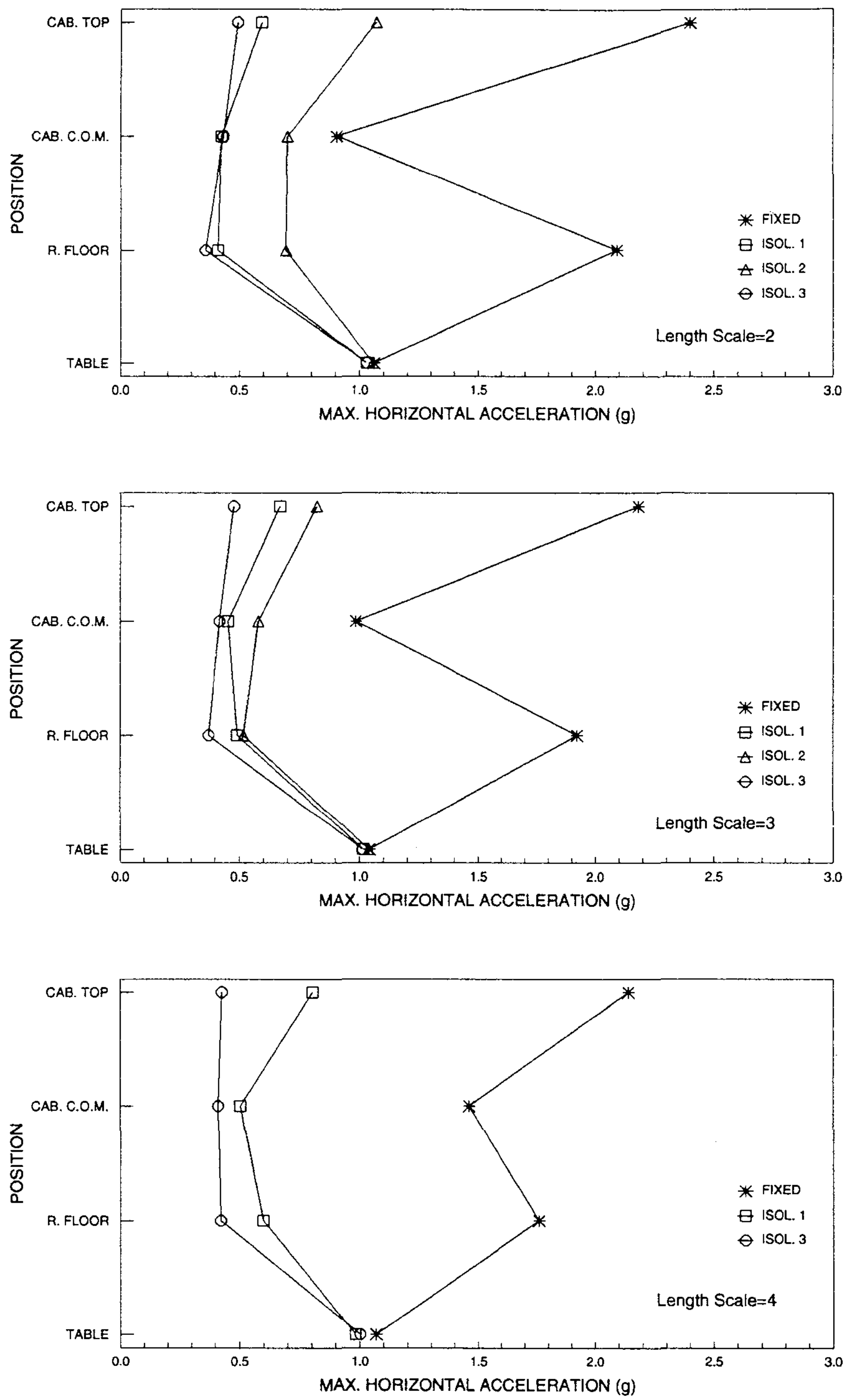


Figure 4-8 Profiles of Peak Acceleration Along Height of Cabinet in Bellcore Horizontal -Vertical Input

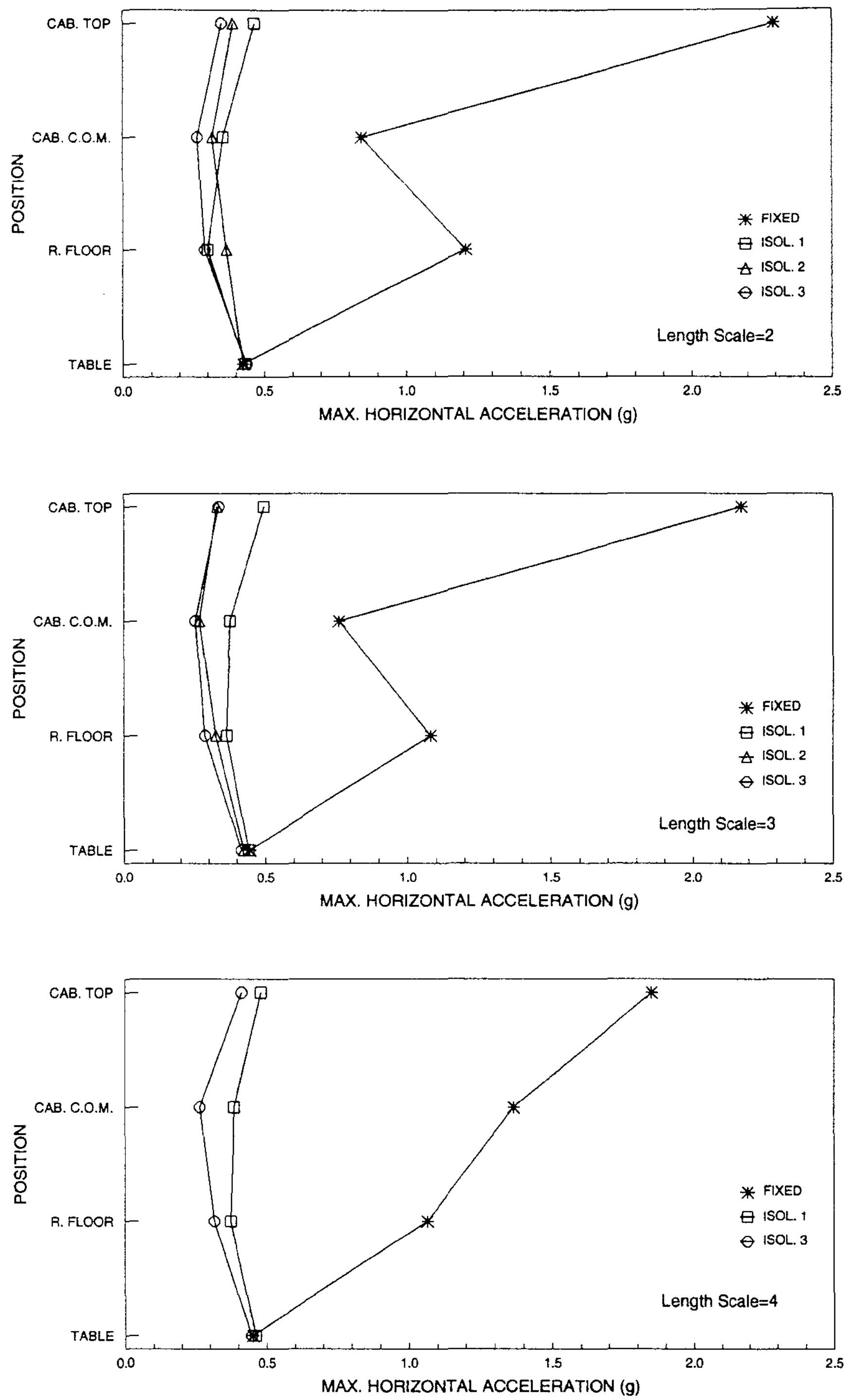


Figure 4-9 Profiles of Peak Acceleration Along Height of Cabinet in IBM Level-1 Horizontal -Vertical Input

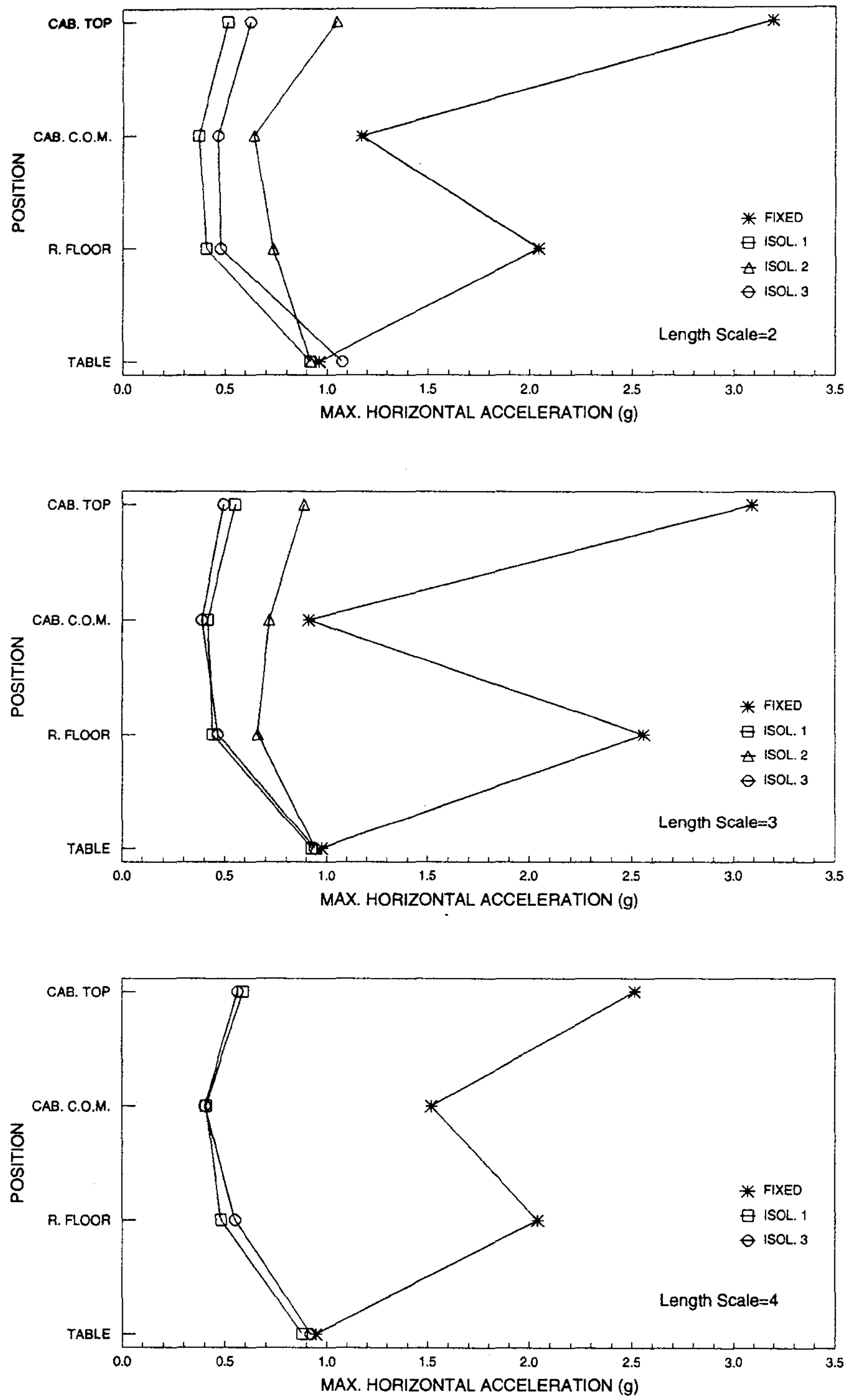


Figure 4-10 Profiles of Peak Acceleration Along Height of Cabinet in IBM Level-2 Horizontal -Vertical Input

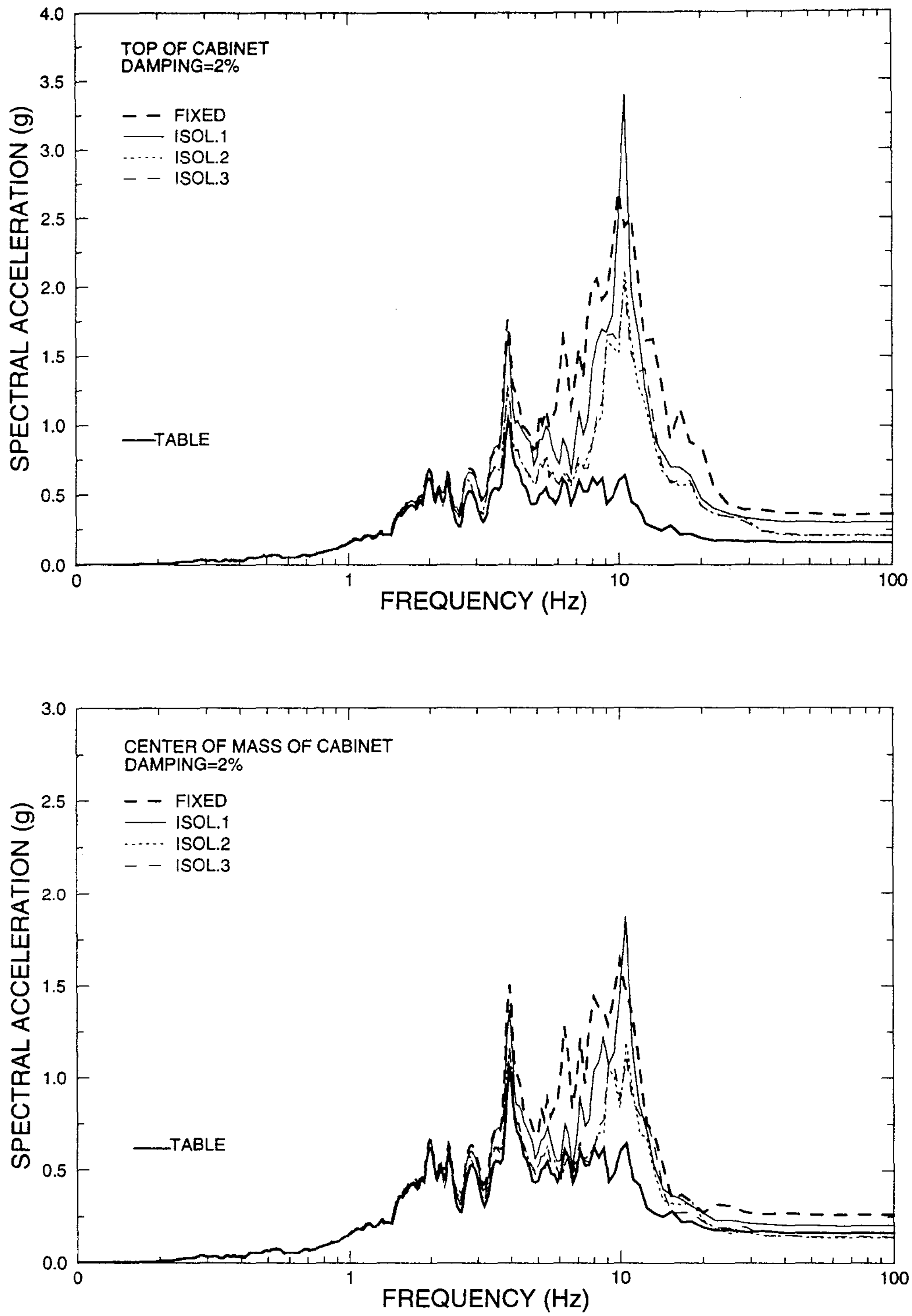
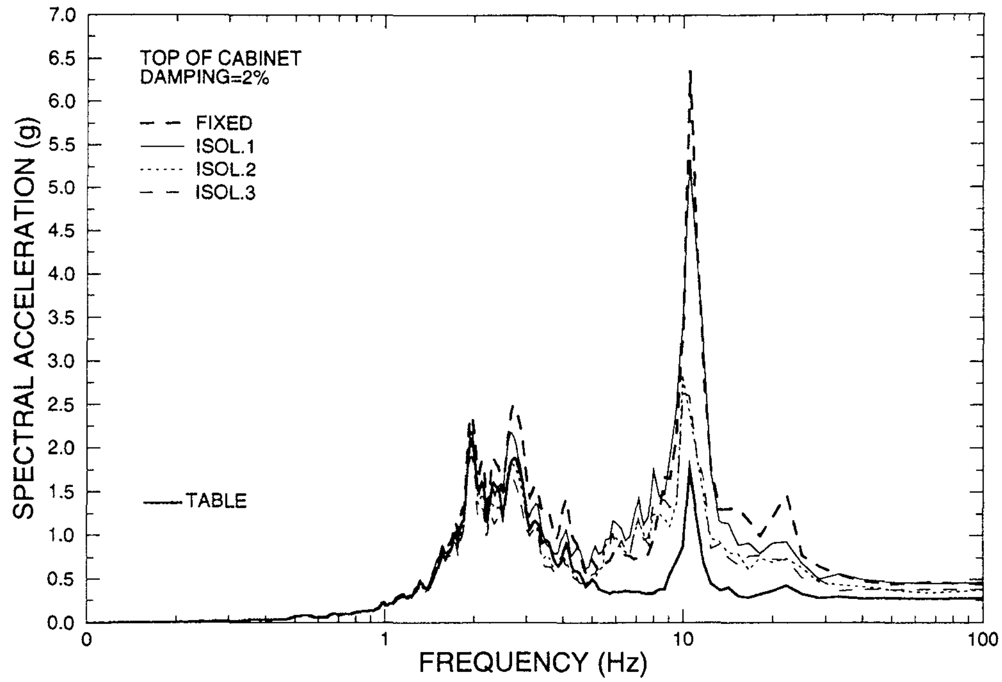


Figure 4-11 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E Ground Horizontal-Vertical Input and Length Scale of 2



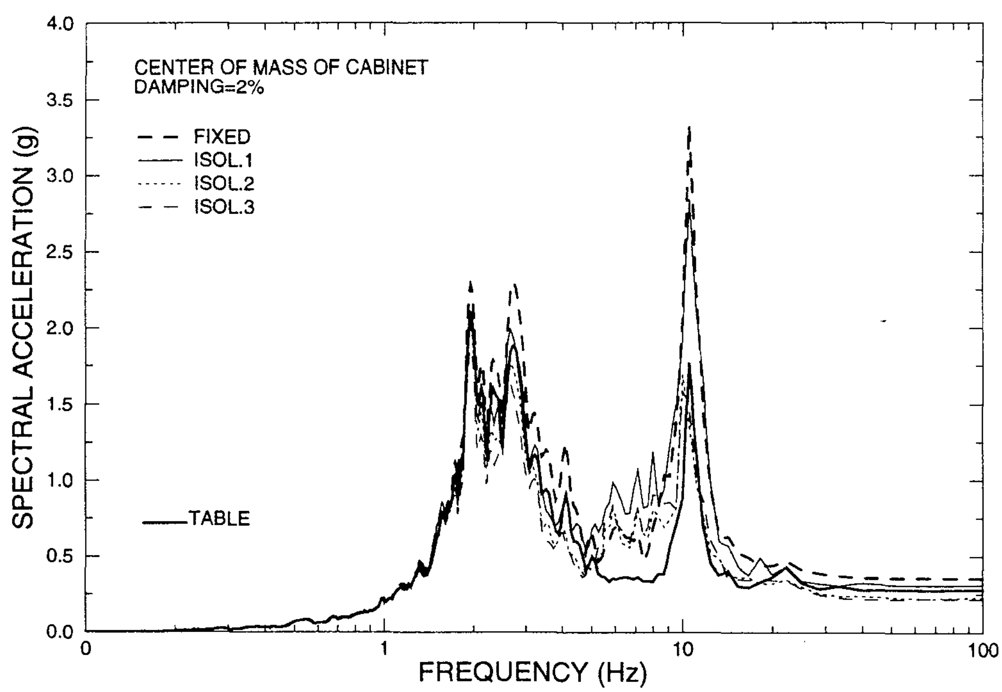
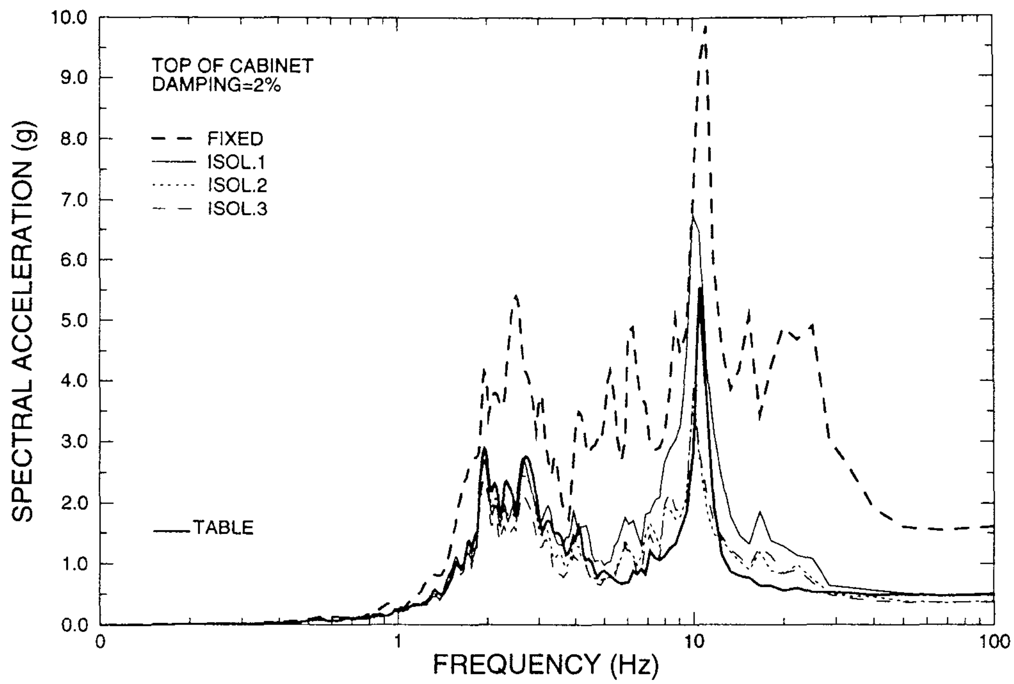


Figure 4-12 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E 5th Floor Horizontal-Vertical Input and Length Scale of 2



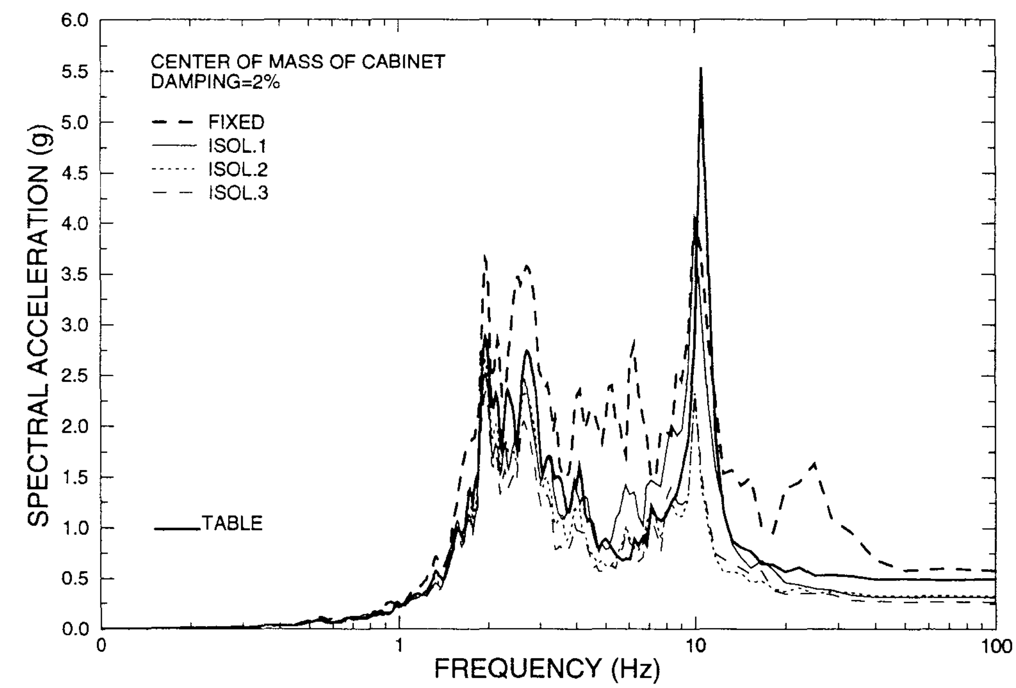
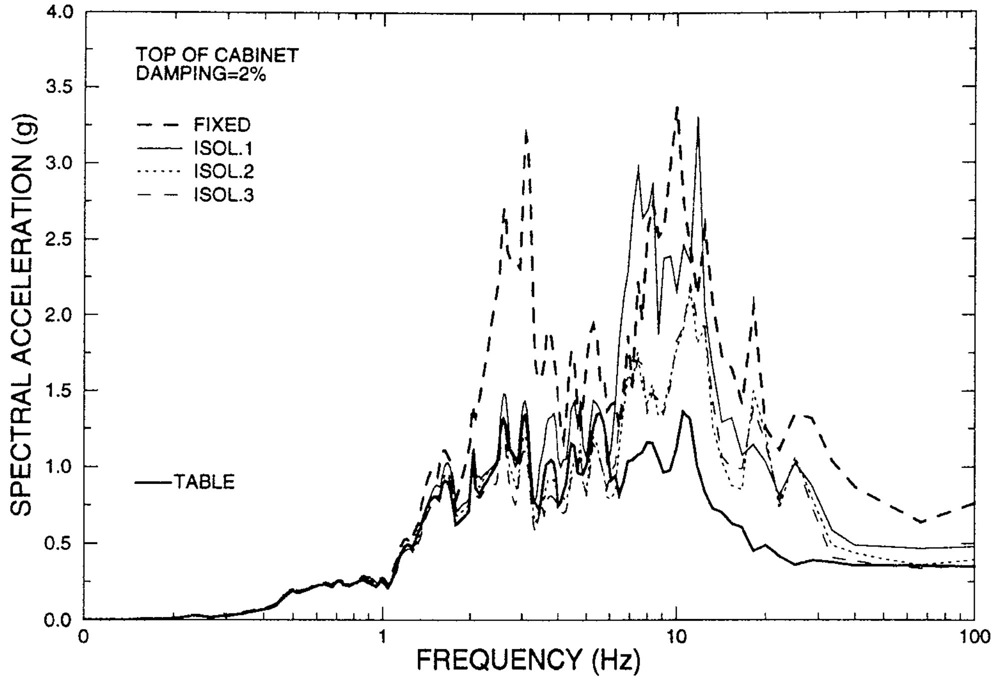


Figure 4-13 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E 7th Floor Horizontal-Vertical Input and Length Scale of 2



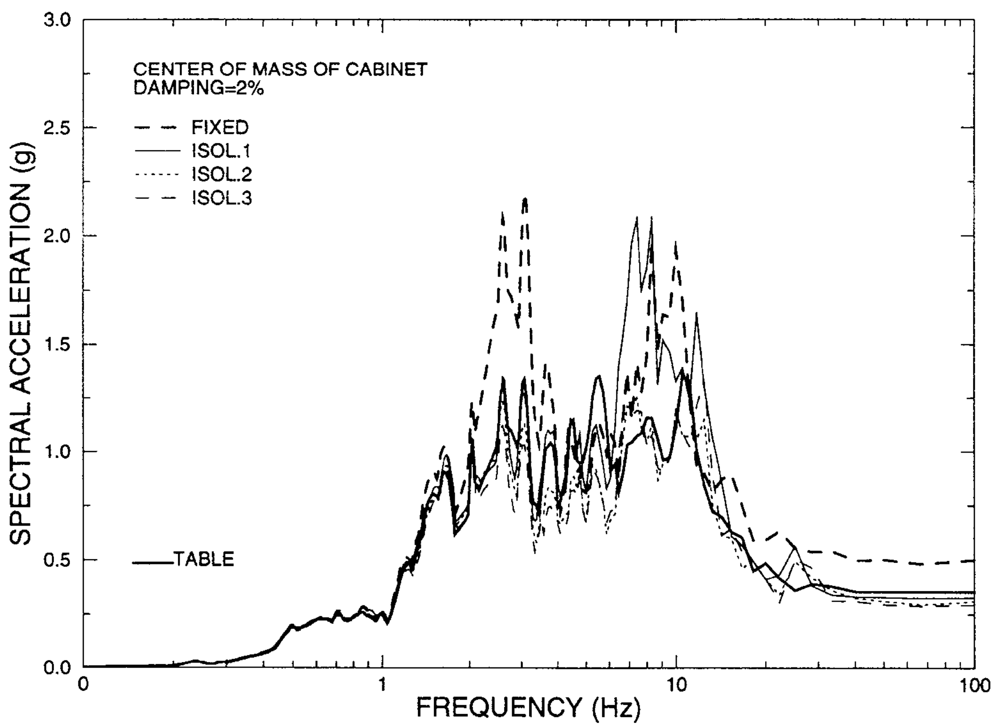
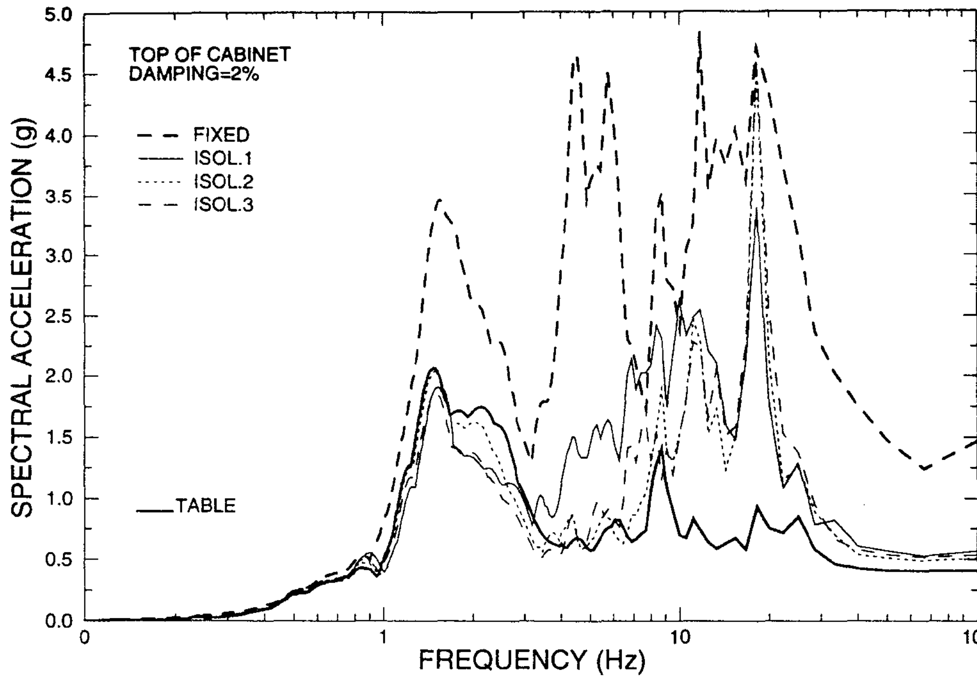


Figure 4-14 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E Ground Horizontal-Vertical Input and Length Scale of 2



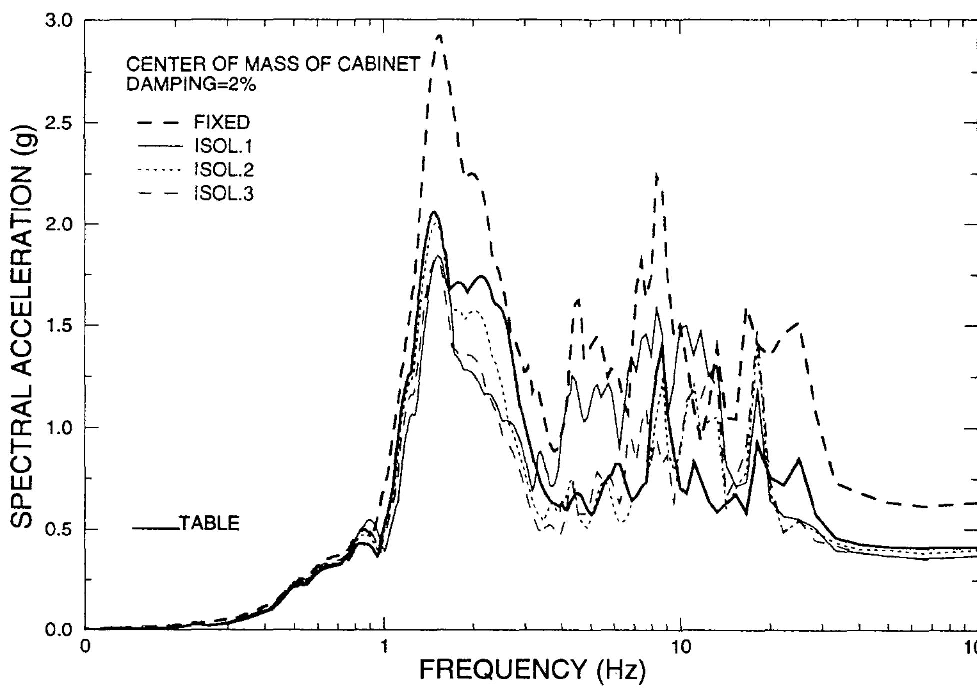
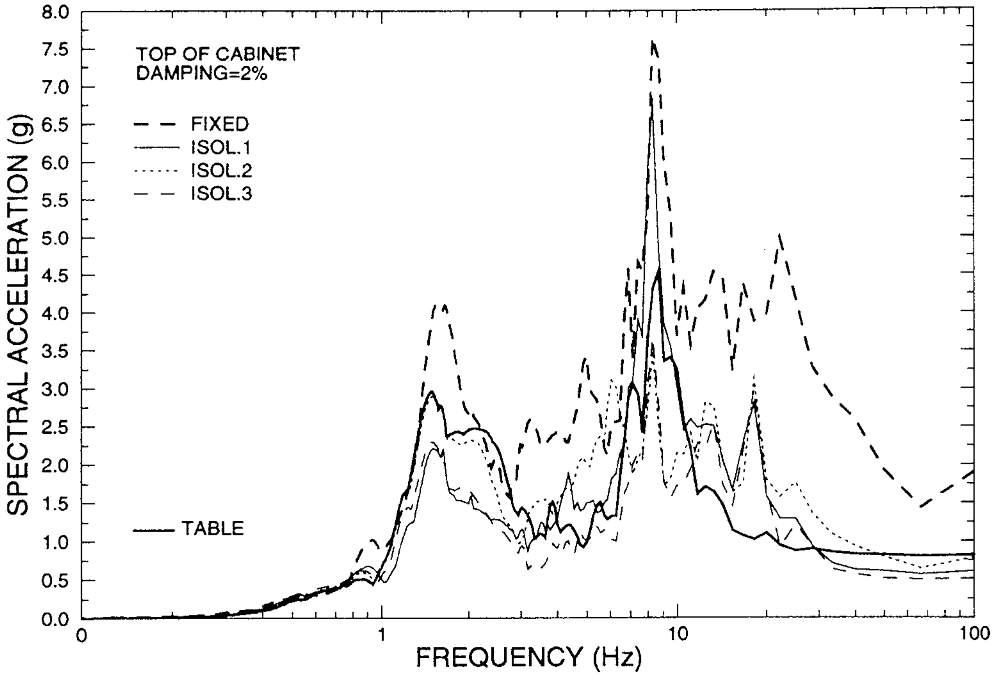


Figure 4-15 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E 5th Floor Horizontal-Vertical Input and Length Scale of 2



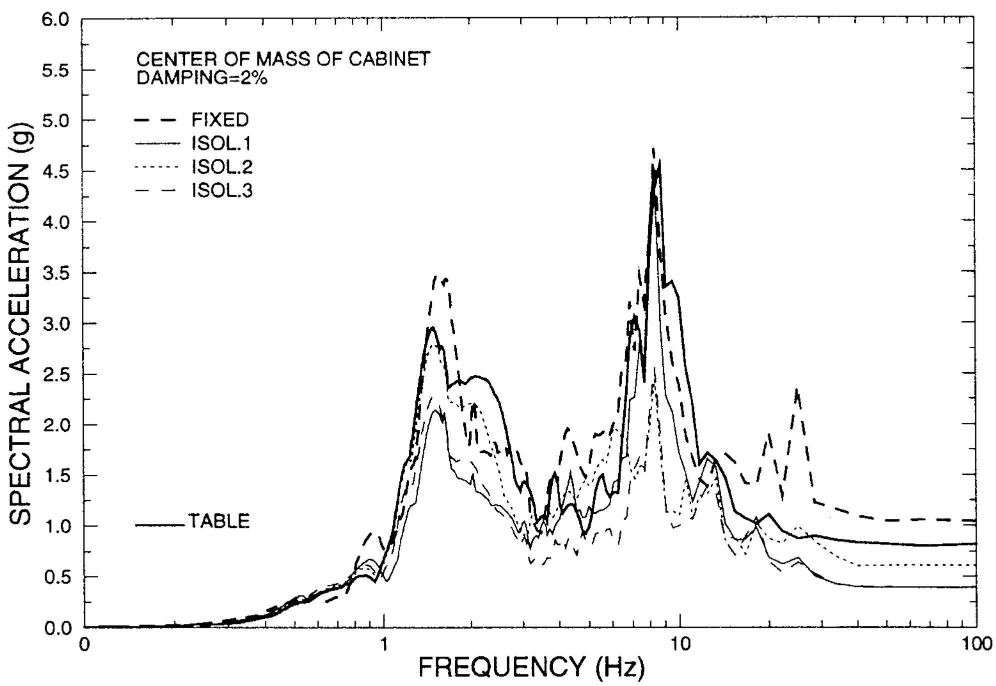


Figure 4-16 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E 7th Floor Horizontal-Vertical Input and Length Scale of 2

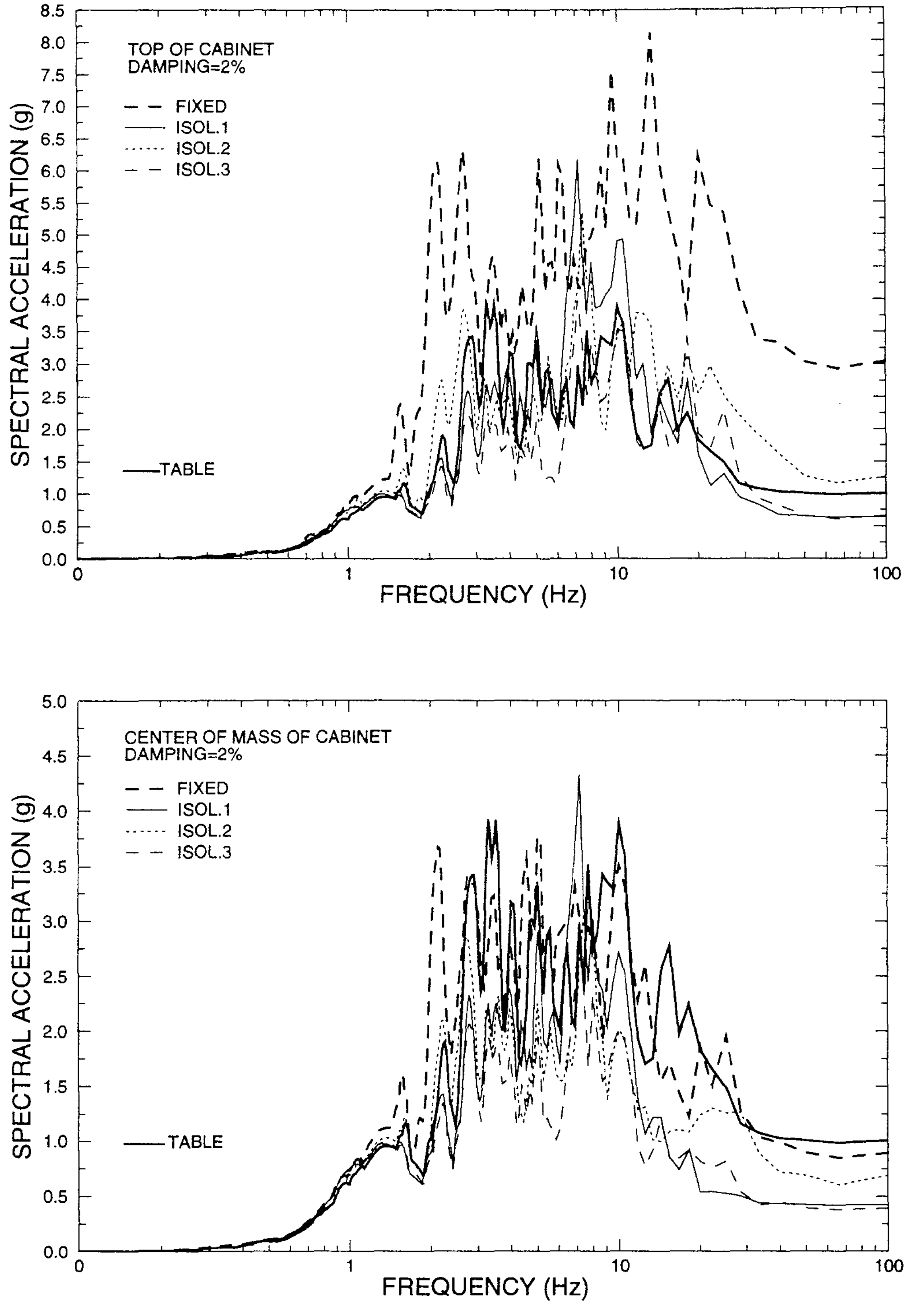
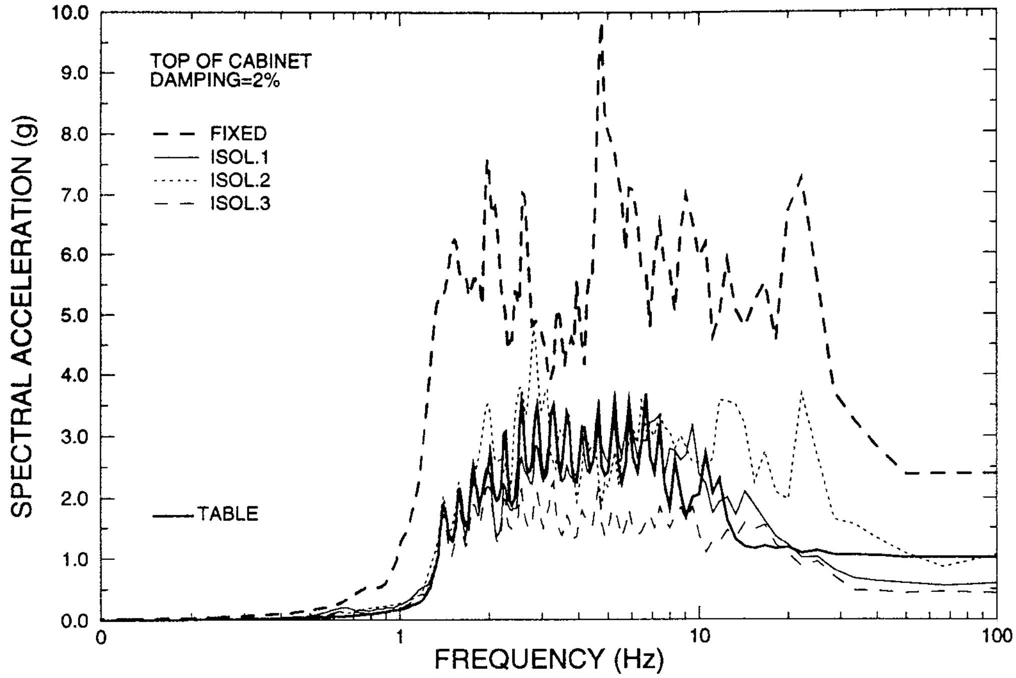


Figure 4-17 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Pacoima Dam S74W Ground Horizontal Input and Length Scale of 2



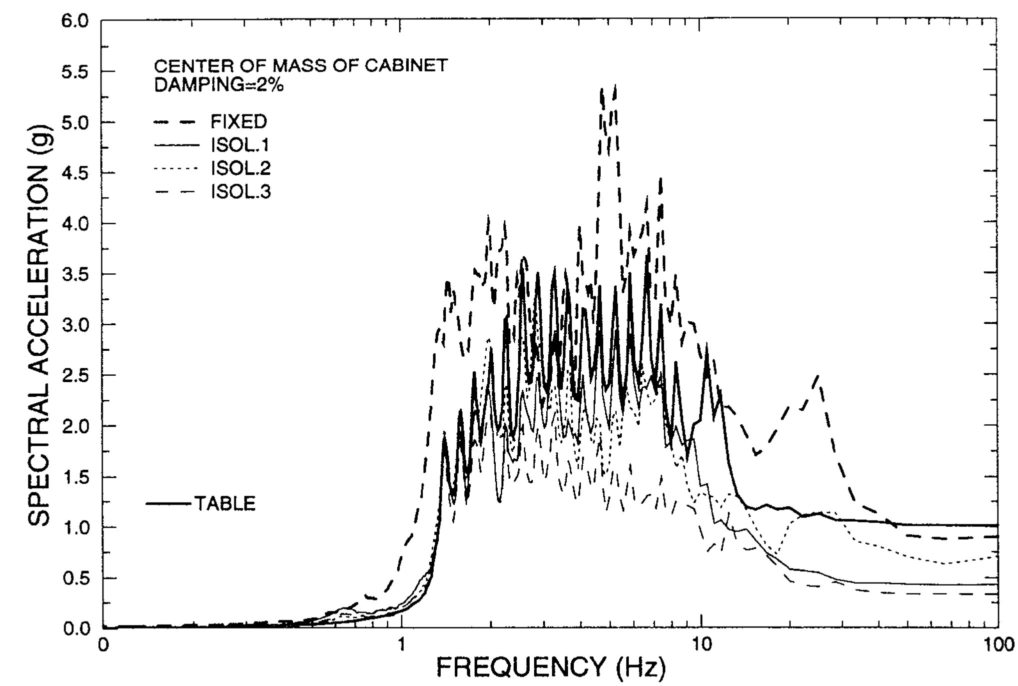


Figure 4-18 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Bellcore Horizontal-Vertical Input and Length Scale of 2

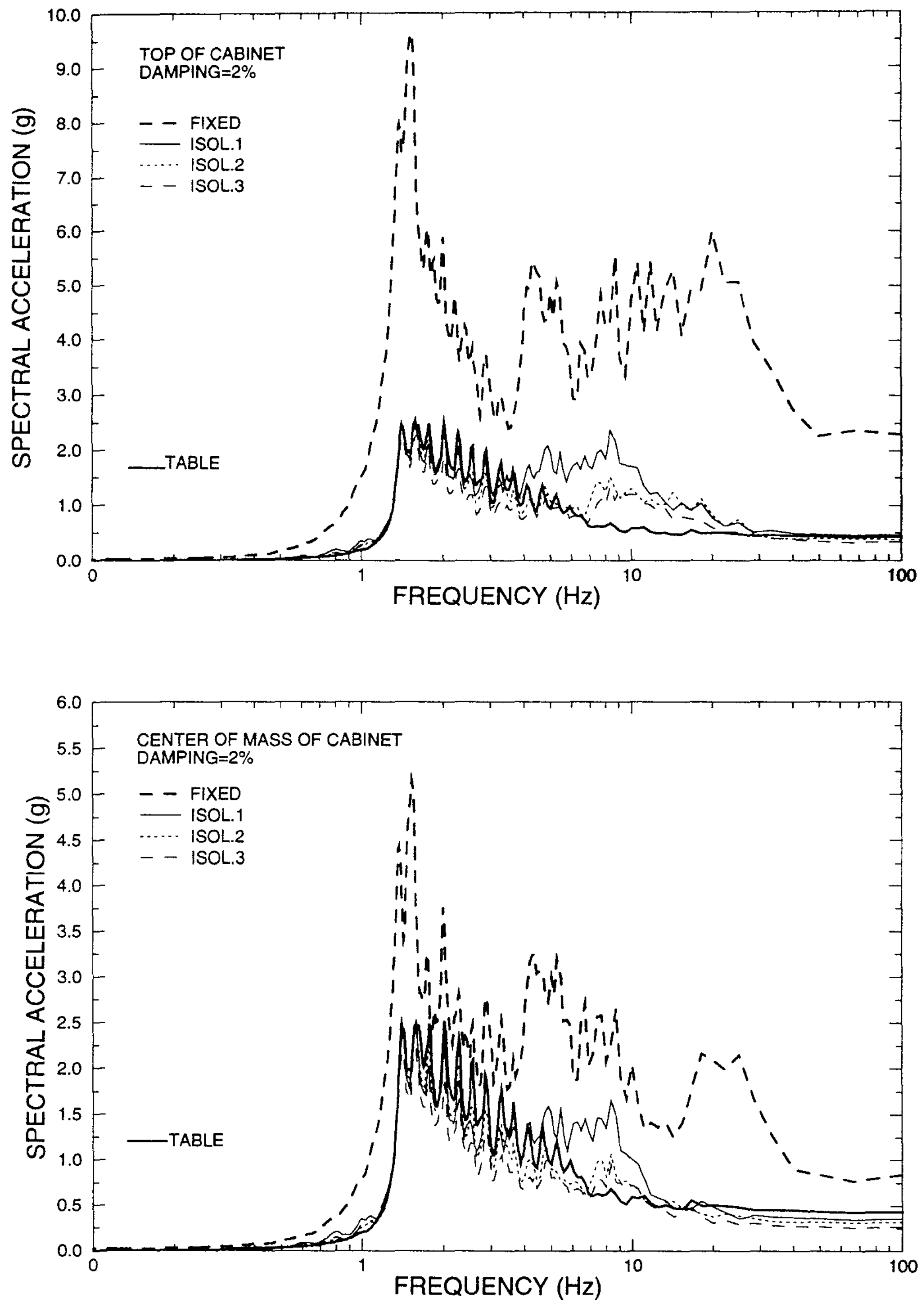
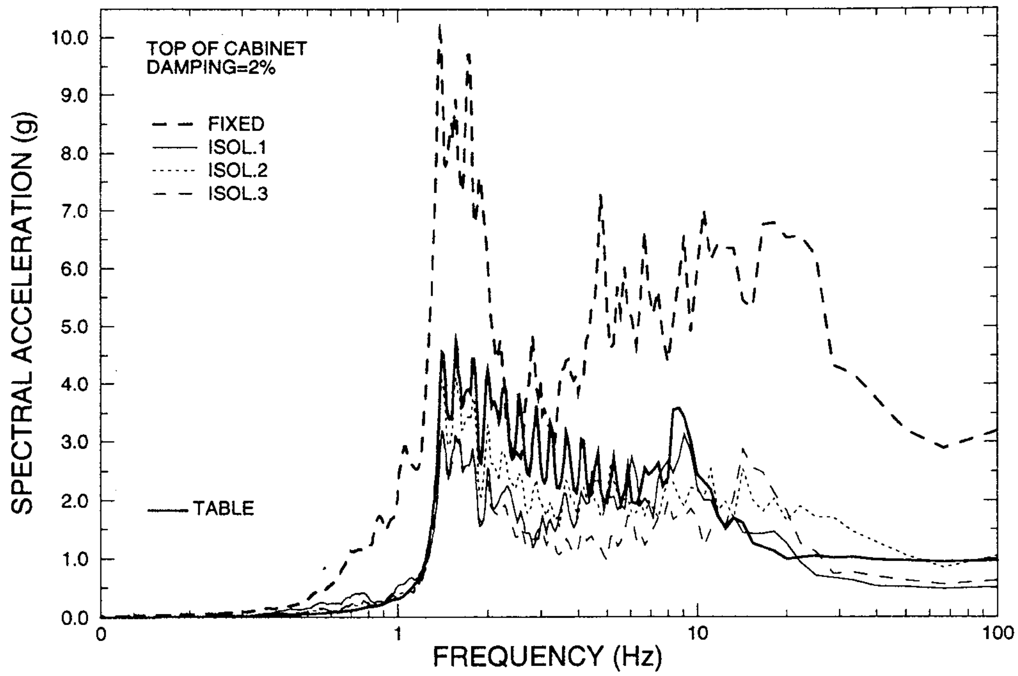


Figure 4-19 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in IBM Level-1 Horizontal-Vertical Input and Length Scale of 2



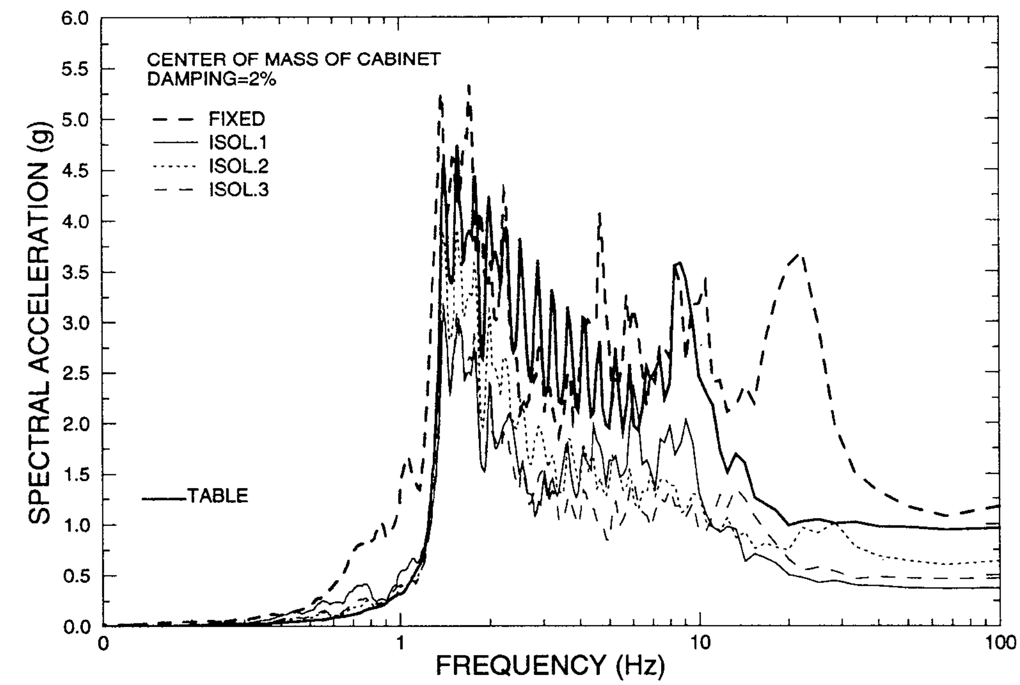
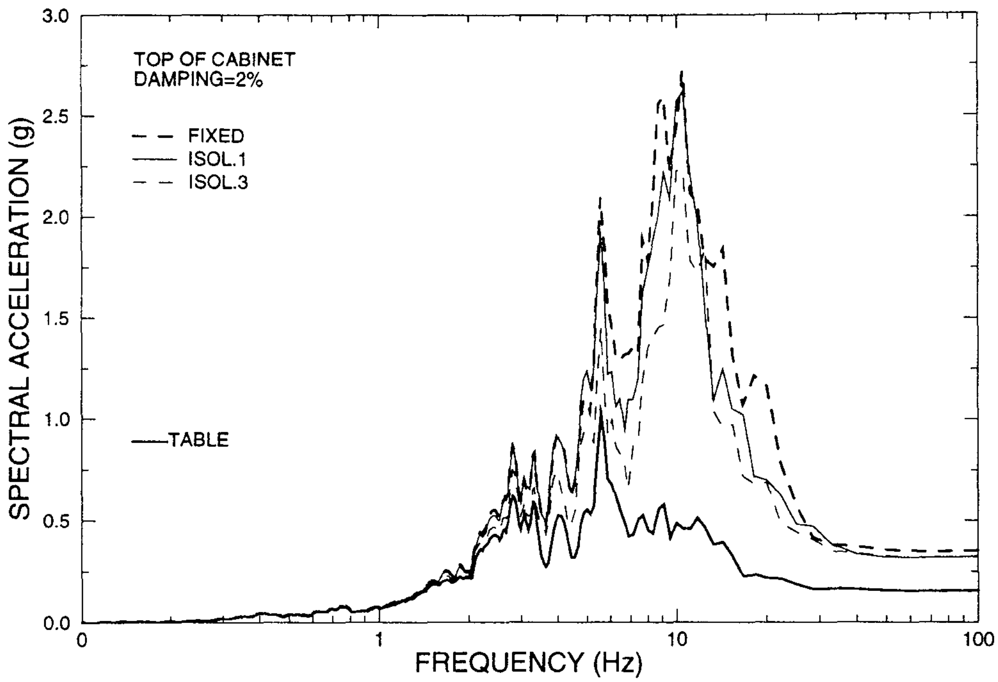


Figure 4-20 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in IBM Level-2 Horizontal-Vertical Input and Length Scale of 2



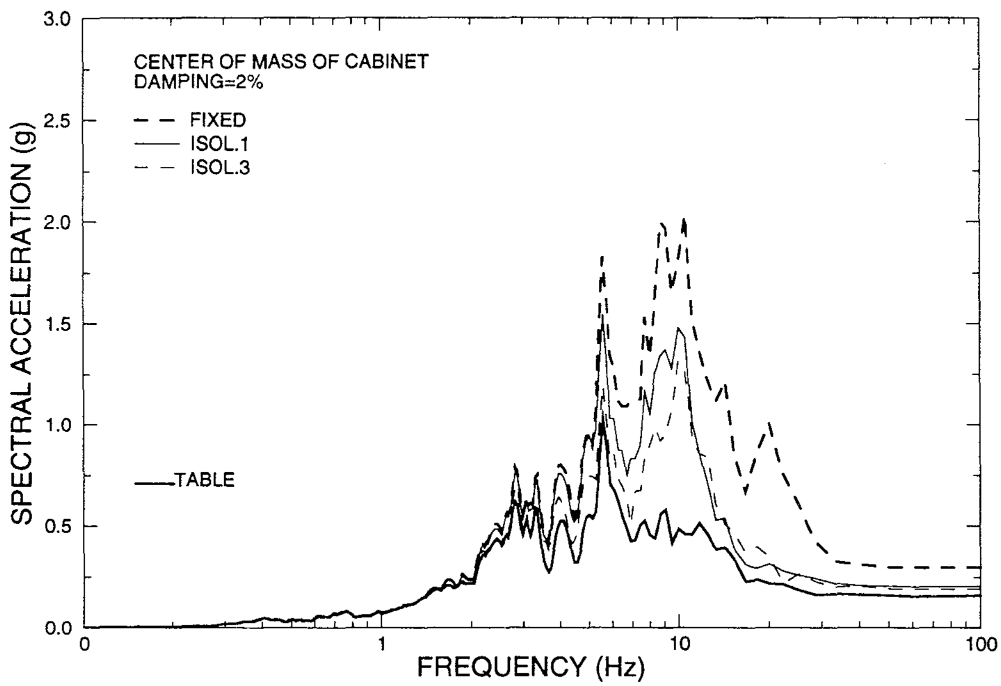
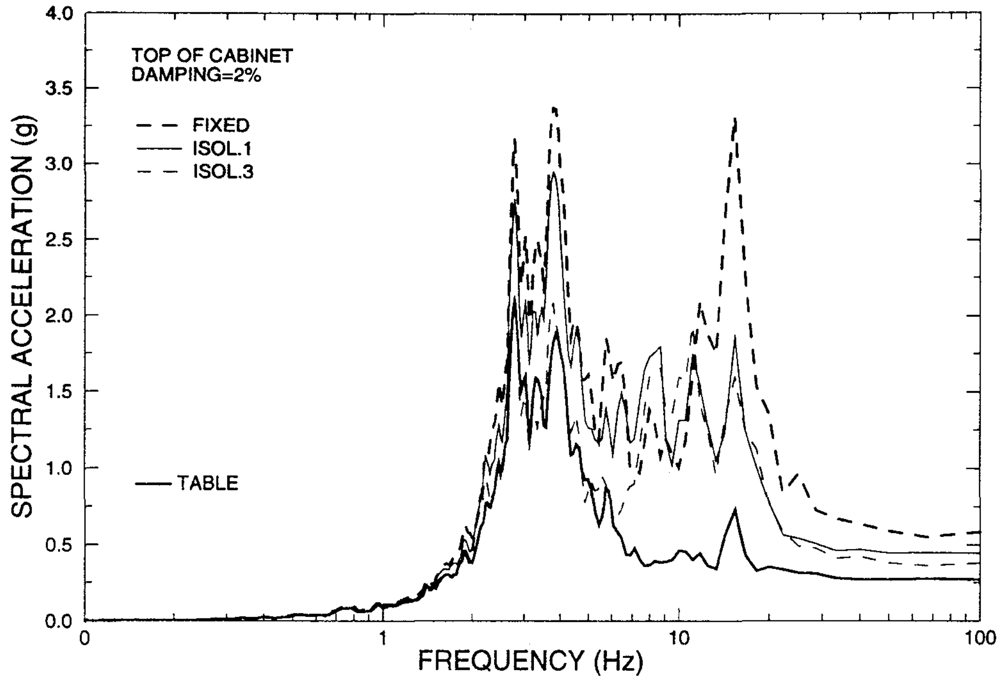


Figure 4-21 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E Ground Horizontal-Vertical Input and Length Scale of 4



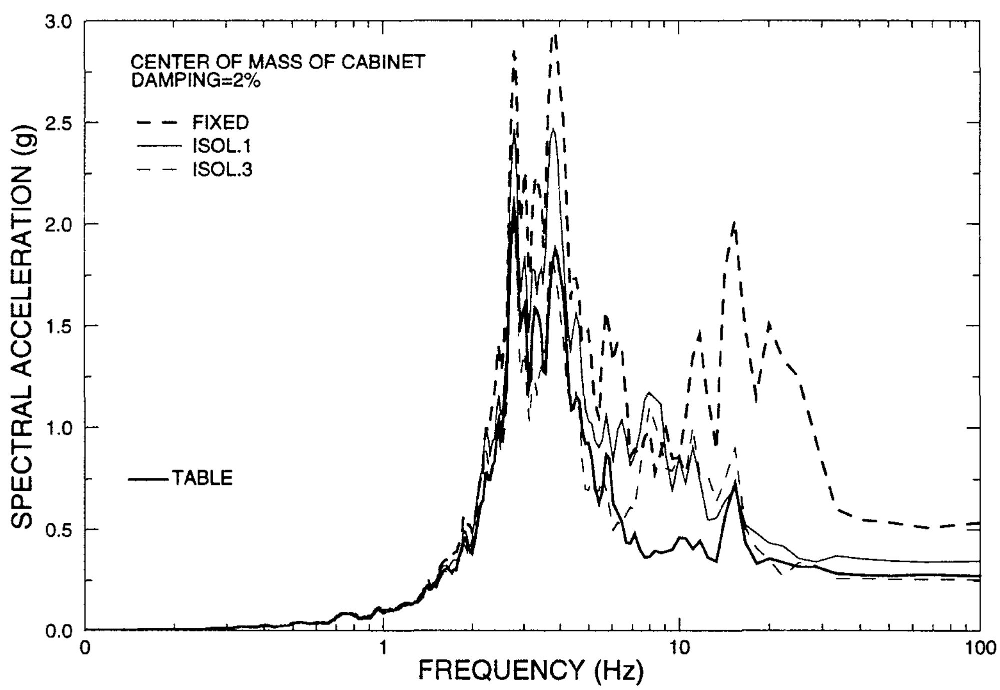
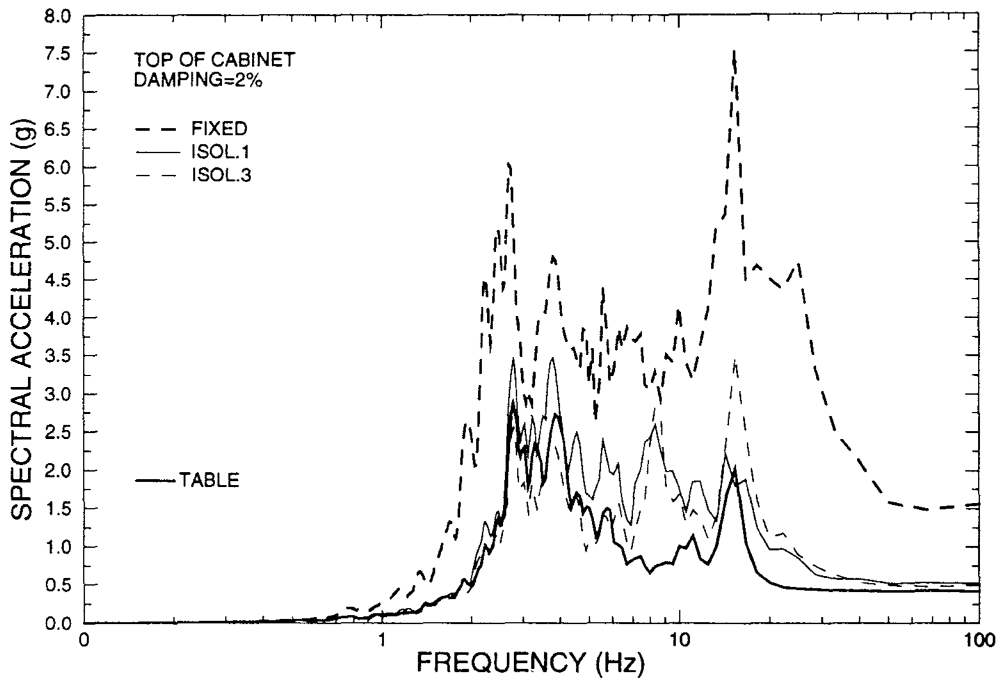


Figure 4-22 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E 5th Floor Horizontal-Vertical Input and Length Scale of 4



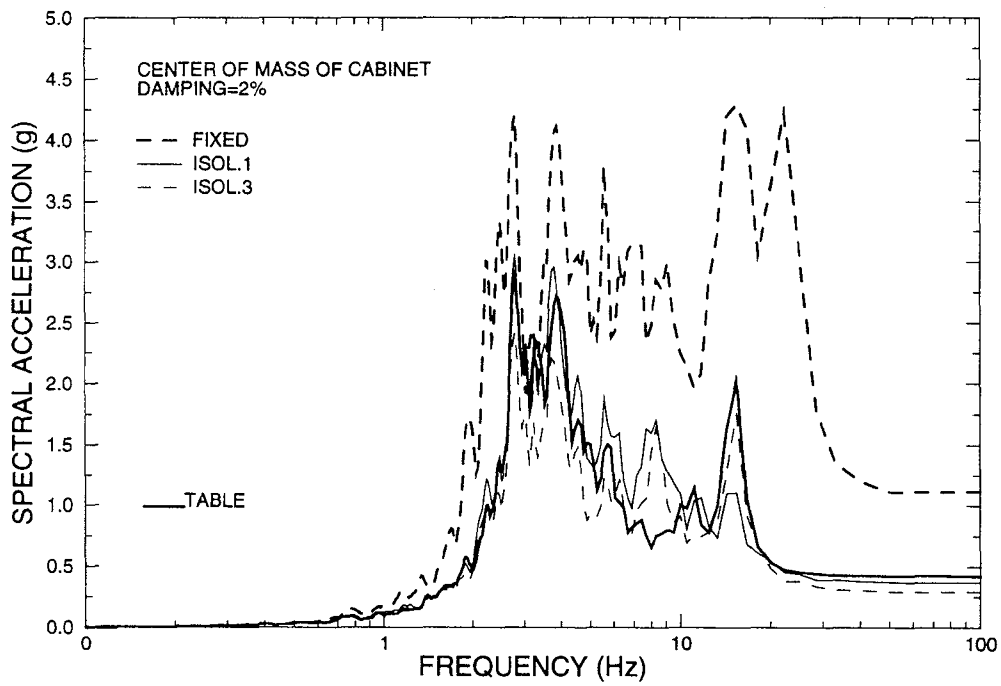
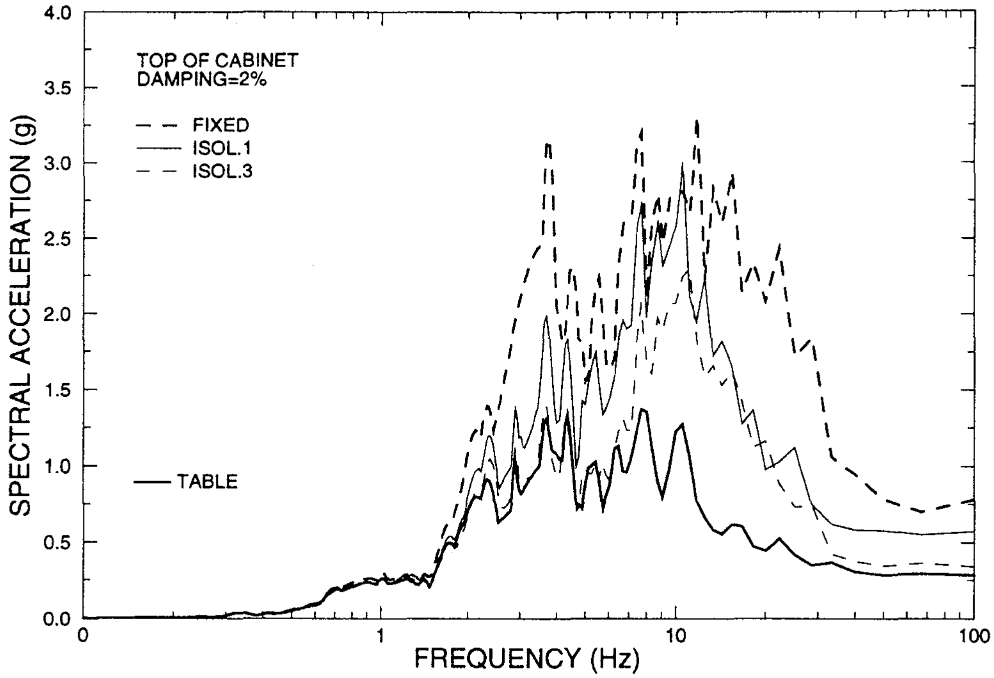


Figure 4-23 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Taft N21E 7th Floor Horizontal-Vertical Input and Length Scale of 4



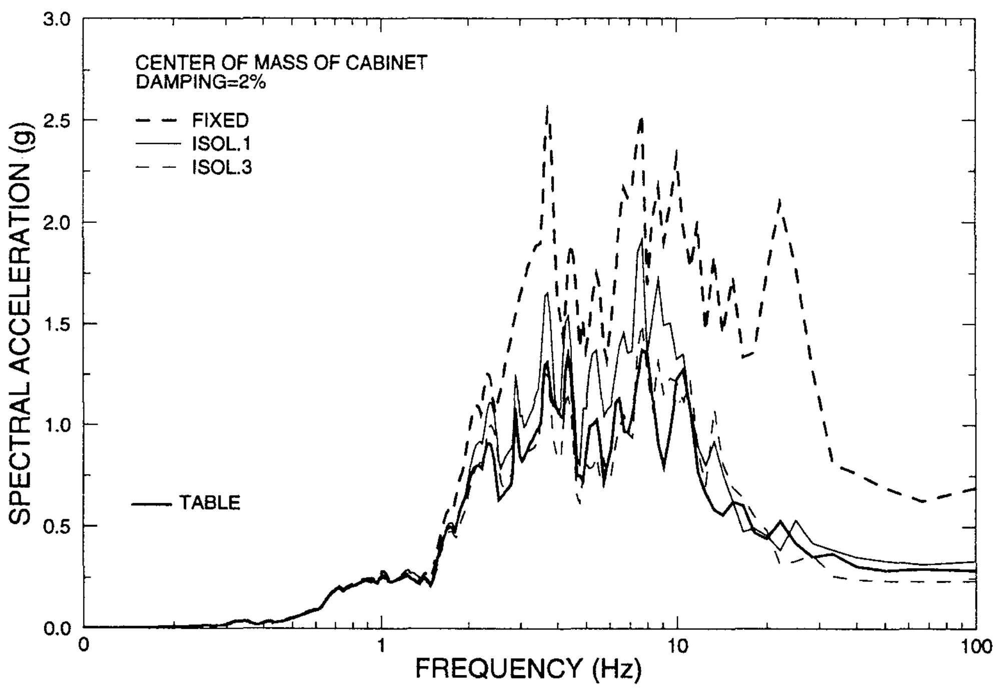


Figure 4-24 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E Ground Horizontal-Vertical Input and Length Scale of 4

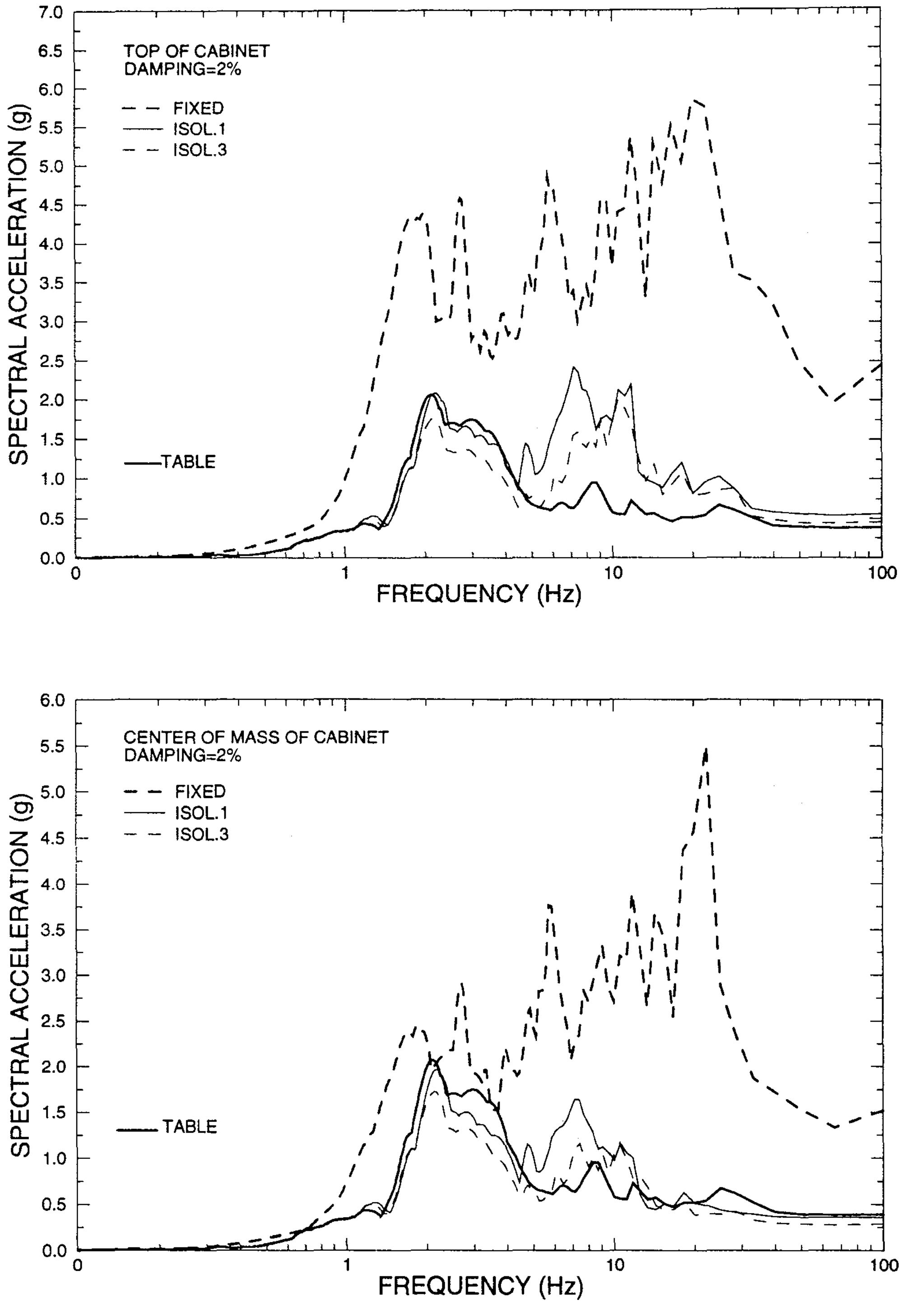
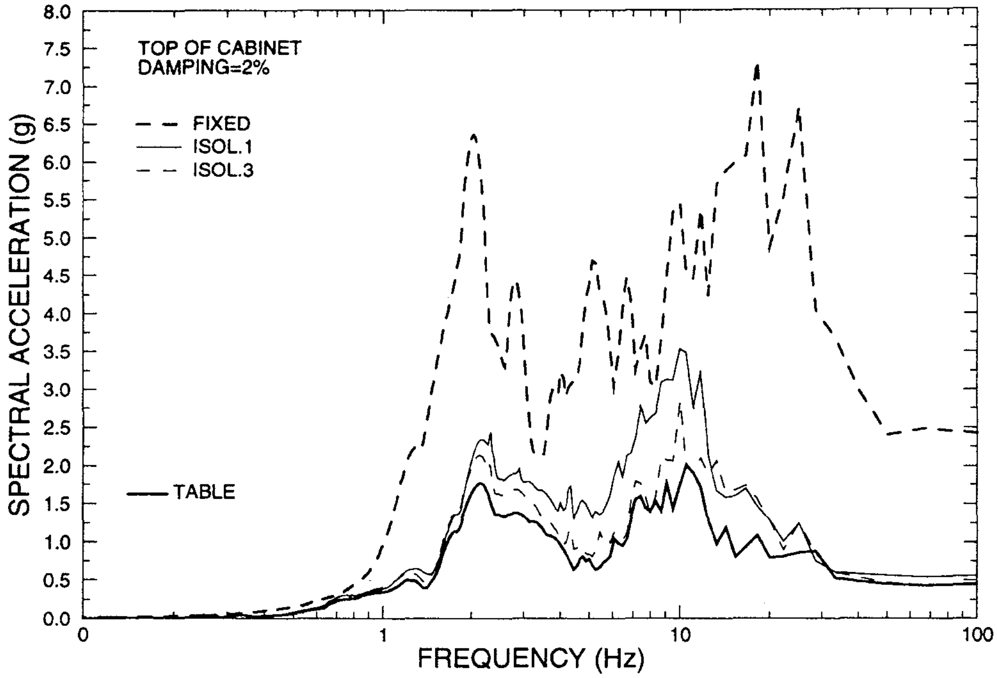


Figure 4-25 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E 5th Floor Horizontal-Vertical Input and Length Scale of 4



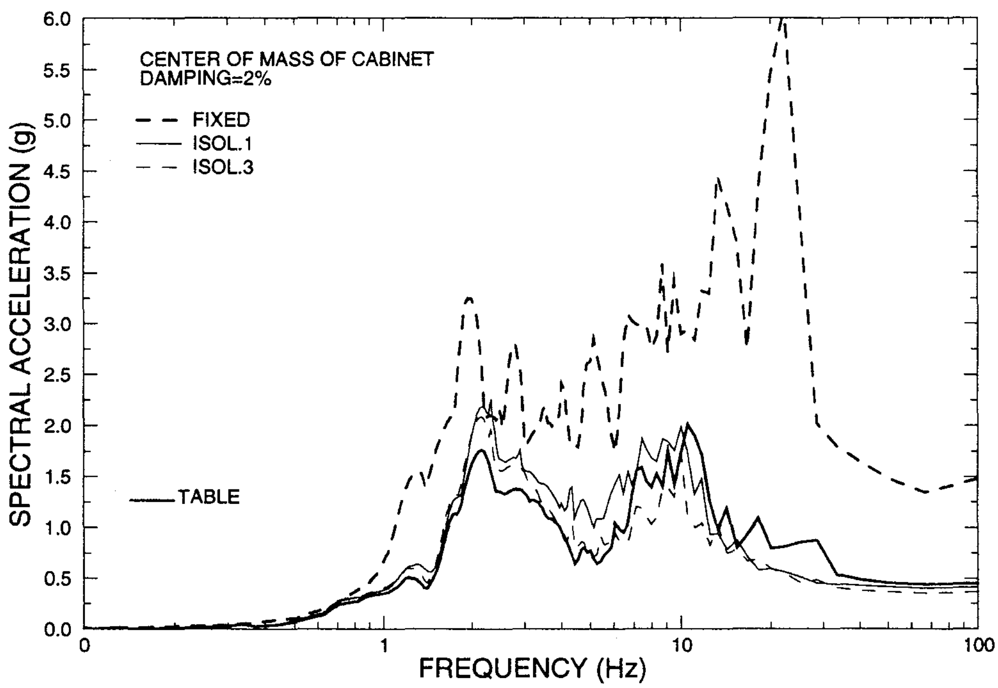
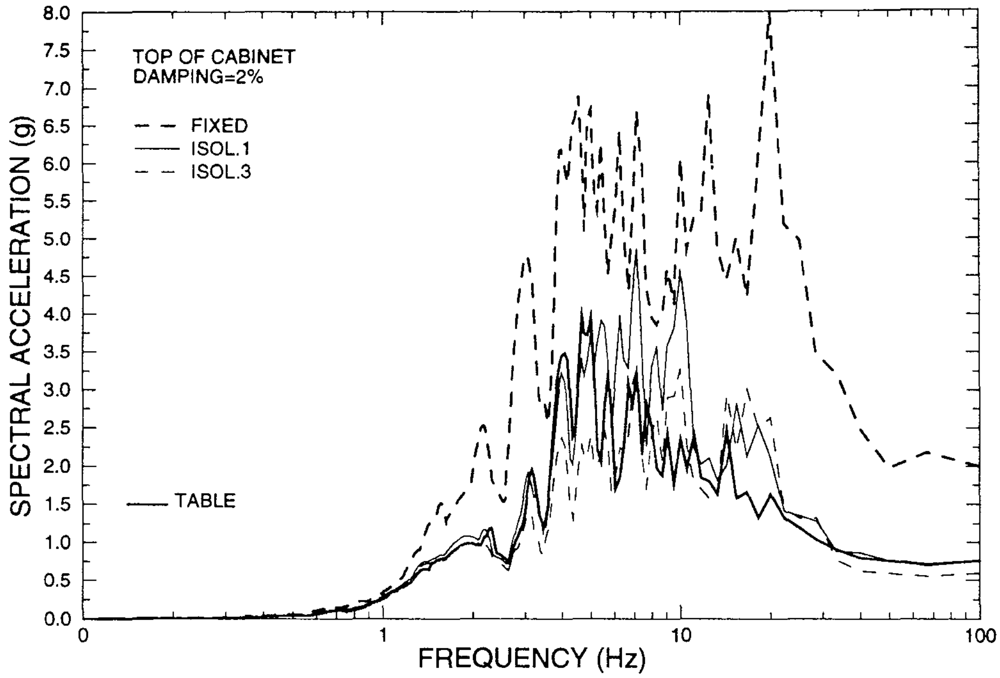


Figure 4-26 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in El Centro S00E 7th Floor Horizontal-Vertical Input and Length Scale of 4



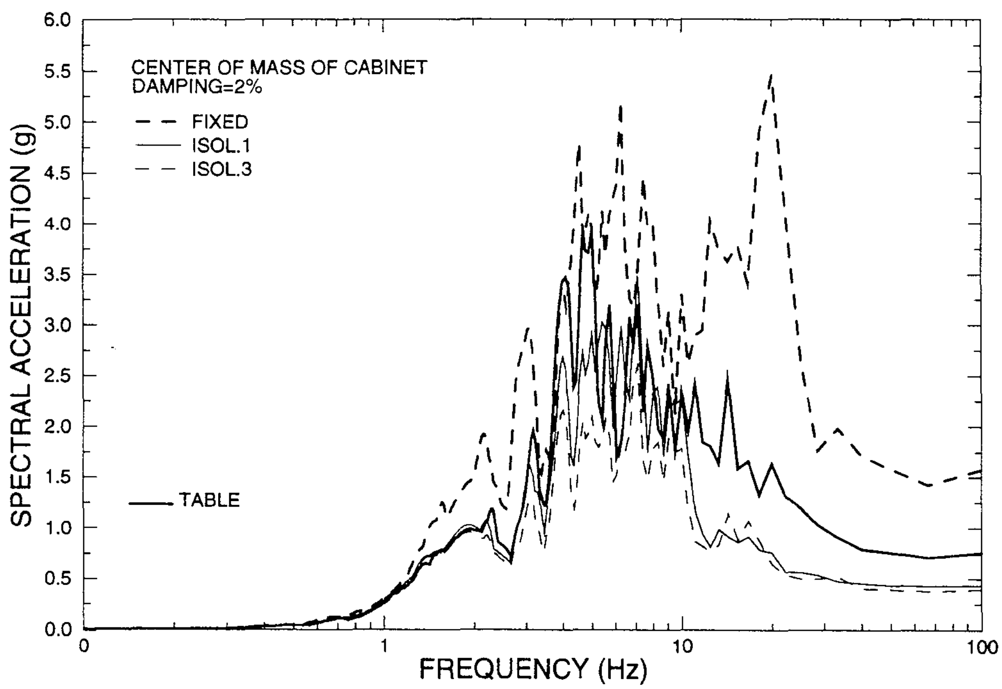


Figure 4-27 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Pacoima Dam S74W Ground Horizontal Input and Length Scale of 4

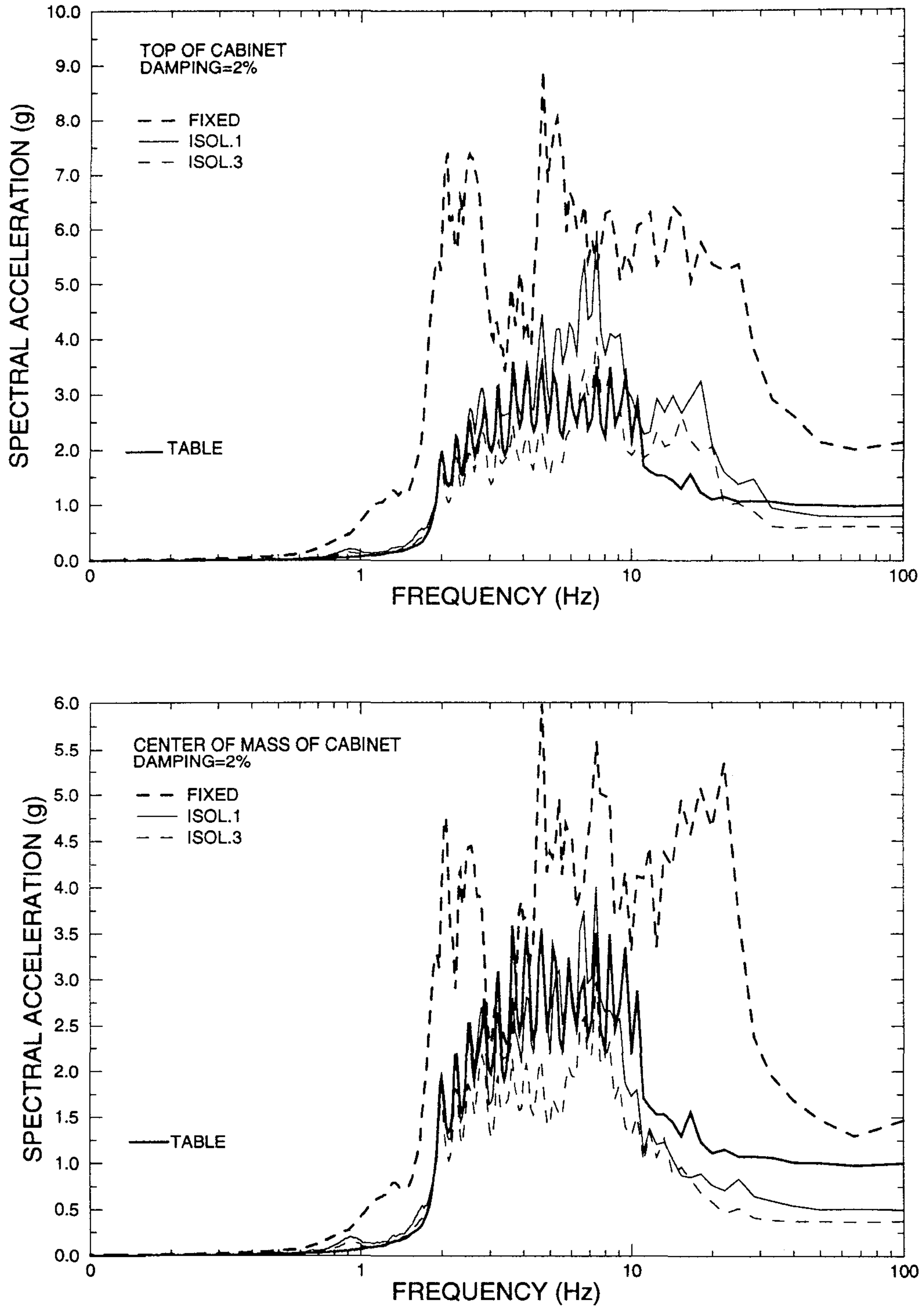
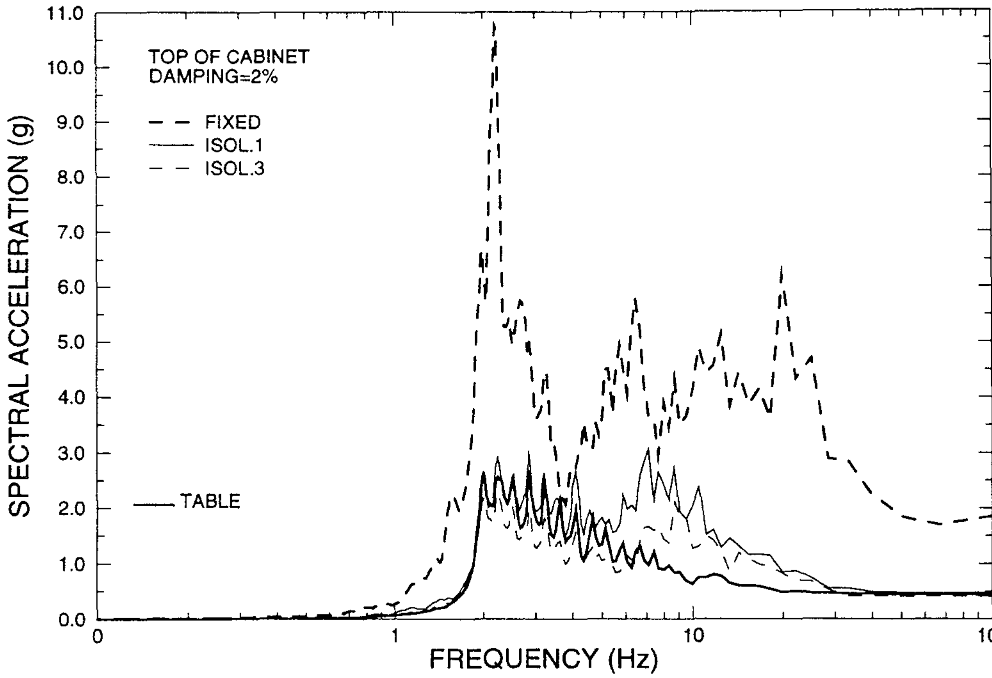


Figure 4-28 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in Bellcore Horizontal-Vertical Input and Length Scale of 4



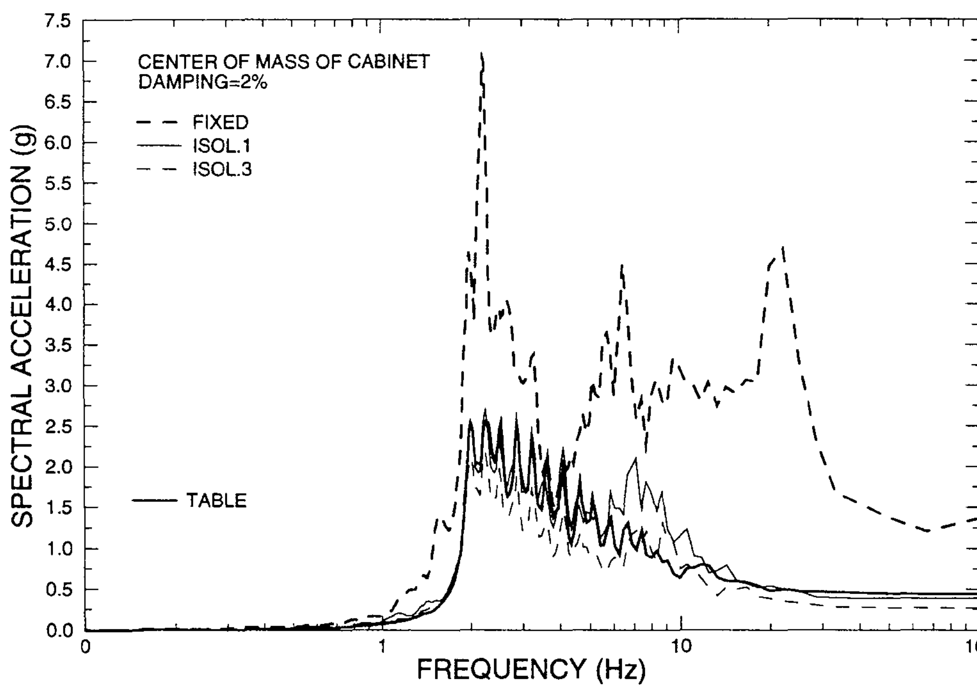
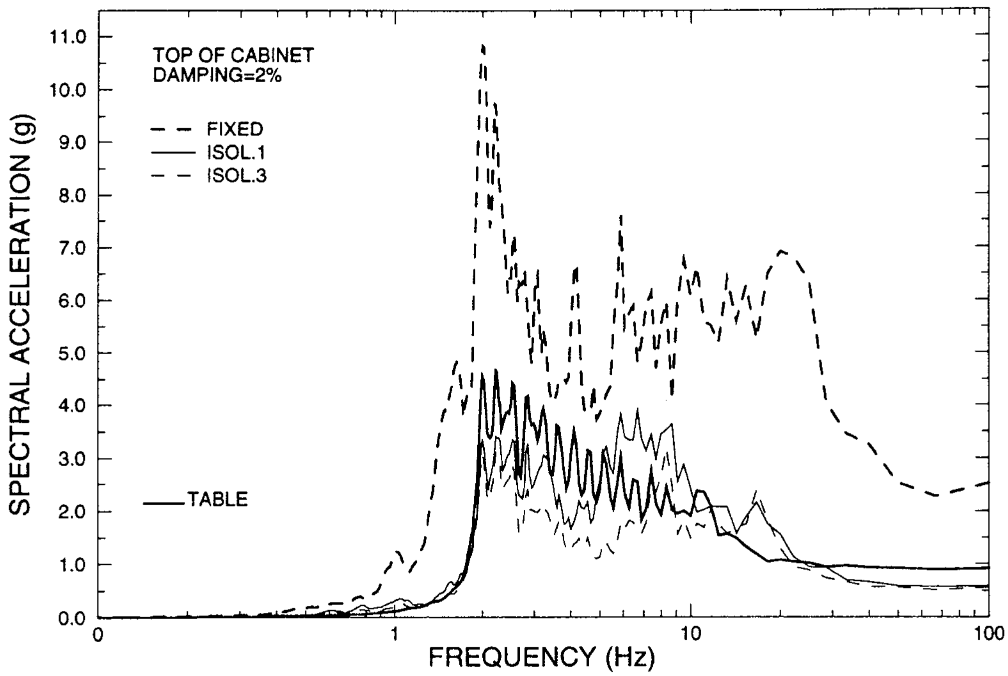


Figure 4-29 Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in IBM Level-1 Horizontal-Vertical Input and Length Scale of 4



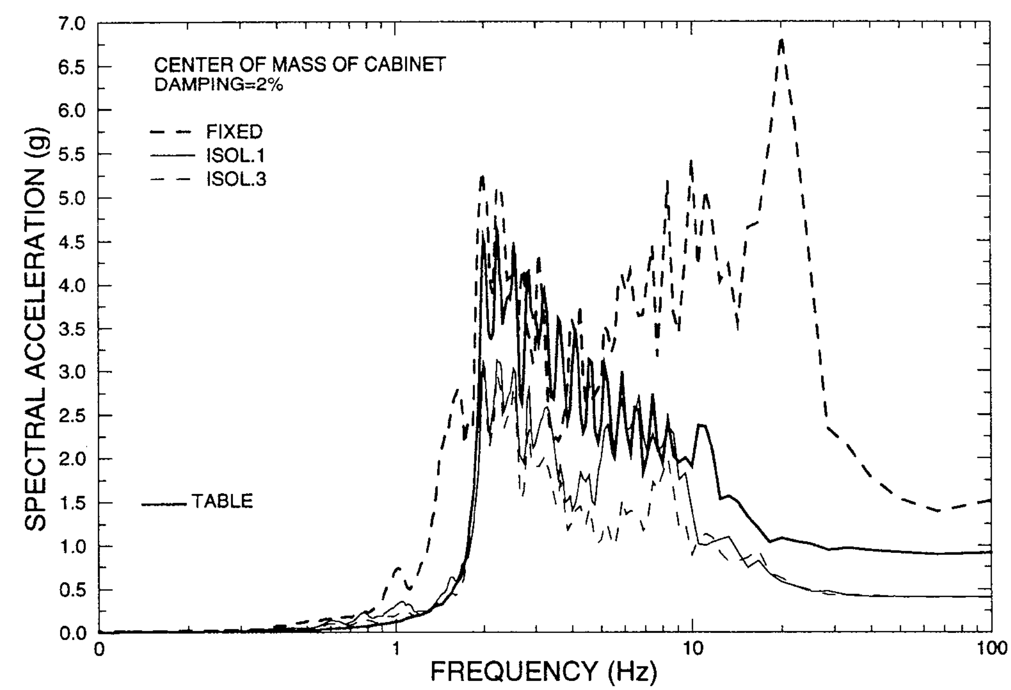
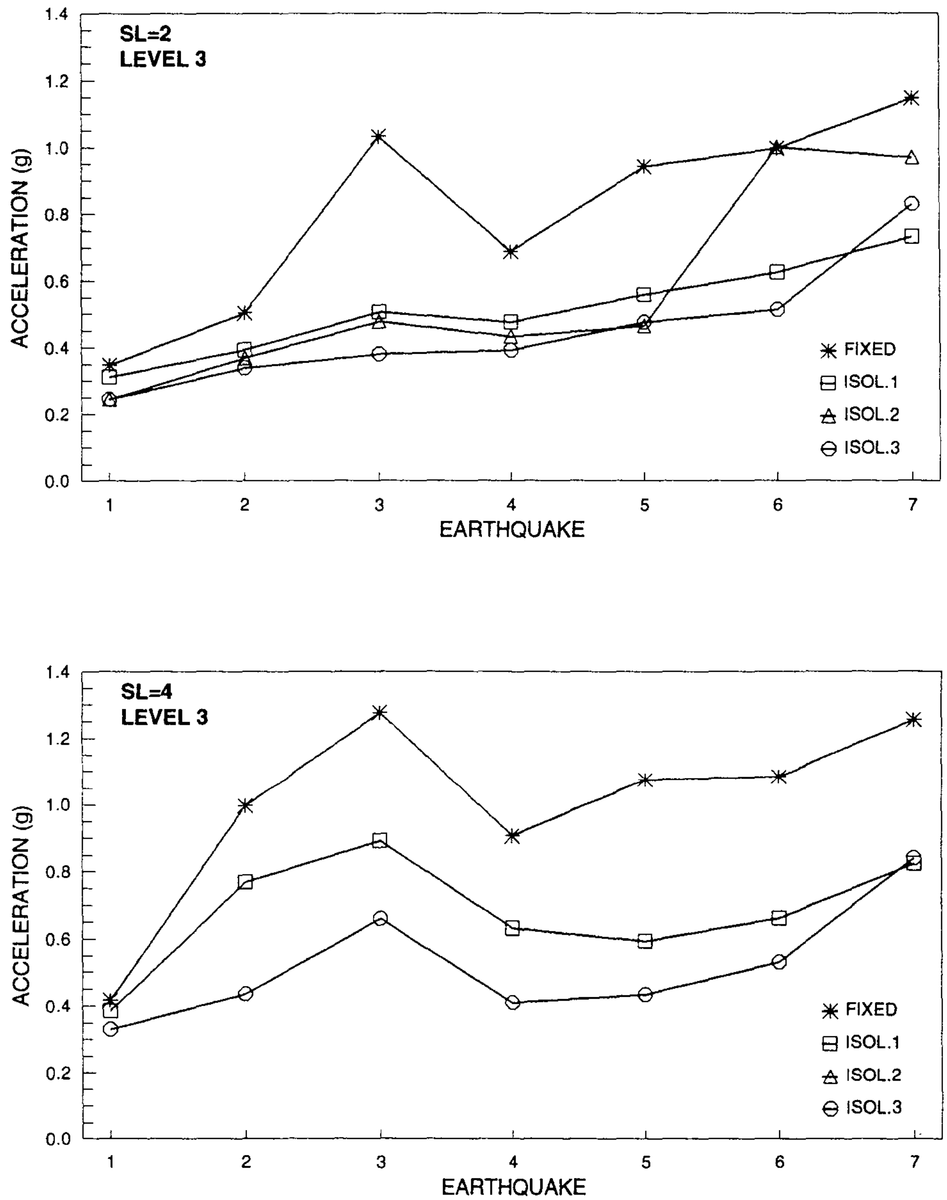


Figure 4-30 **Floor Spectra for Recorded Motions at Center of Mass and Top of Cabinet in IBM Level-2 Horizontal-Vertical Input and Length Scale of 4**



1: Taft Ground+Vert. 2: Taft 5th+Vert. 3: Taft 7th+Vert.
4: El Centro Ground+Vert. 5: El Centro 5th+Vert.
6: El Centro 7th+Vert. 7: Pacoima Ground

Figure 4-31 Comparison of Response of Internal Flexible Component (Level 3) for Various Excitations.

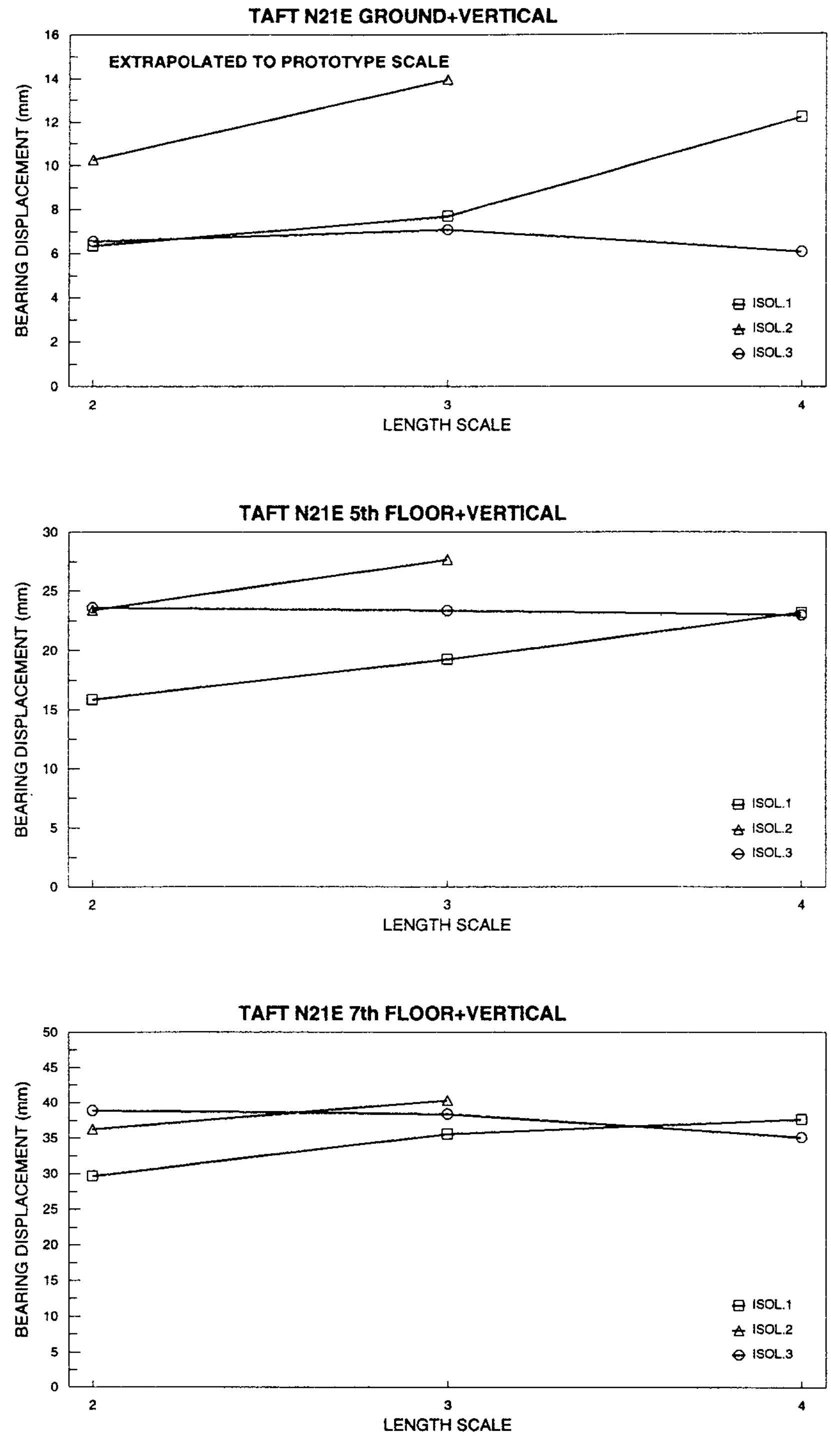


Figure 4-32 Peak Bearing Displacement in Prototype Scale for the Taft Input.Length Scale of 2 Corresponds to Isolation Period of 2.12 secs, Length Scale of 3 Corresponds to 2.60 secs, and Length Scale of 4 Corresponds to 3.00 secs

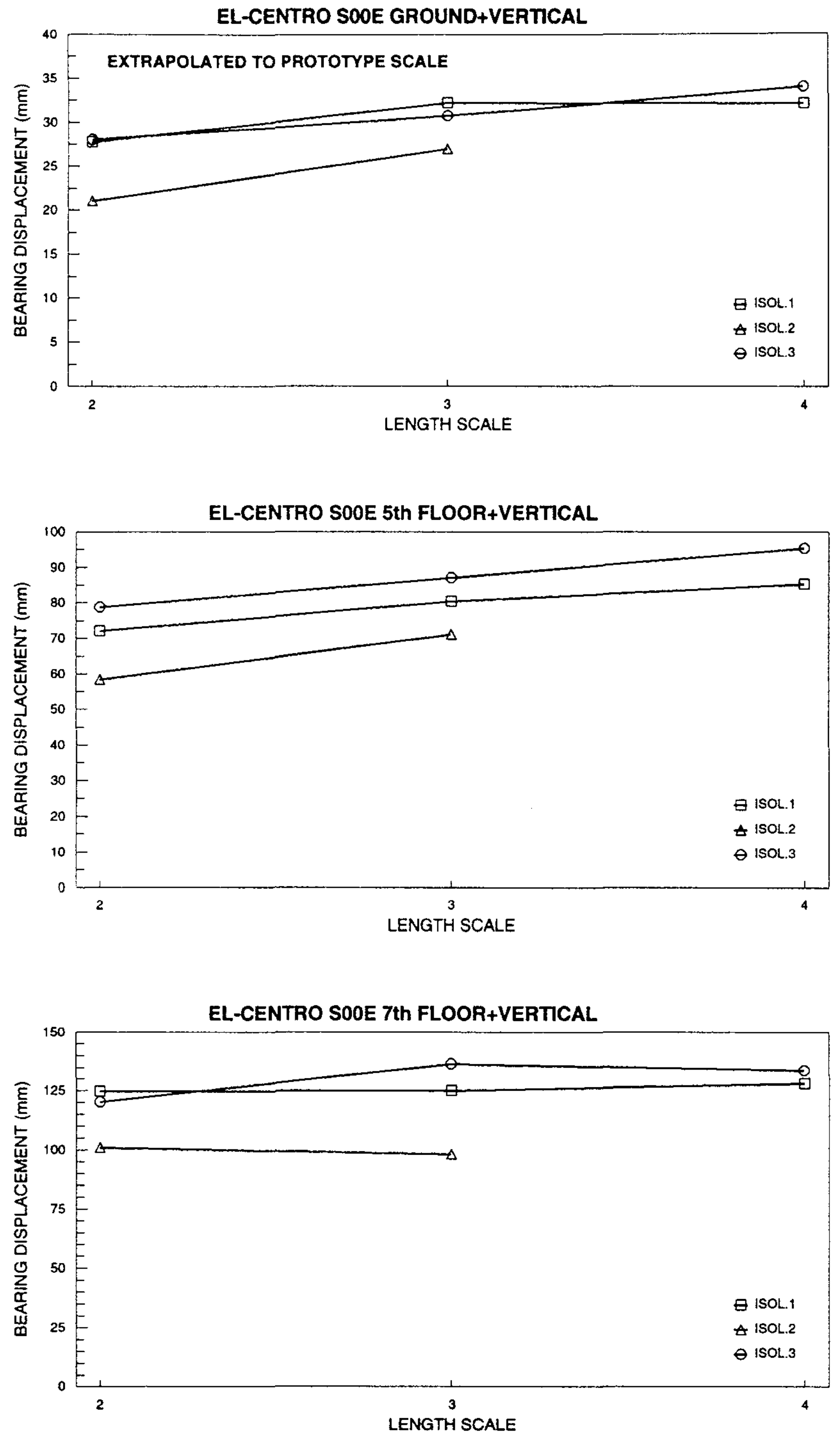


Figure 4-33 Peak Bearing Displacement in Prototype Scale for the El Centro Input.Length Scale of 2 Corresponds to Isolation Period of 2.12 secs, Length Scale of 3 Corresponds to 2.60 secs, and Length Scale of 4 Corresponds to 3.00 secs

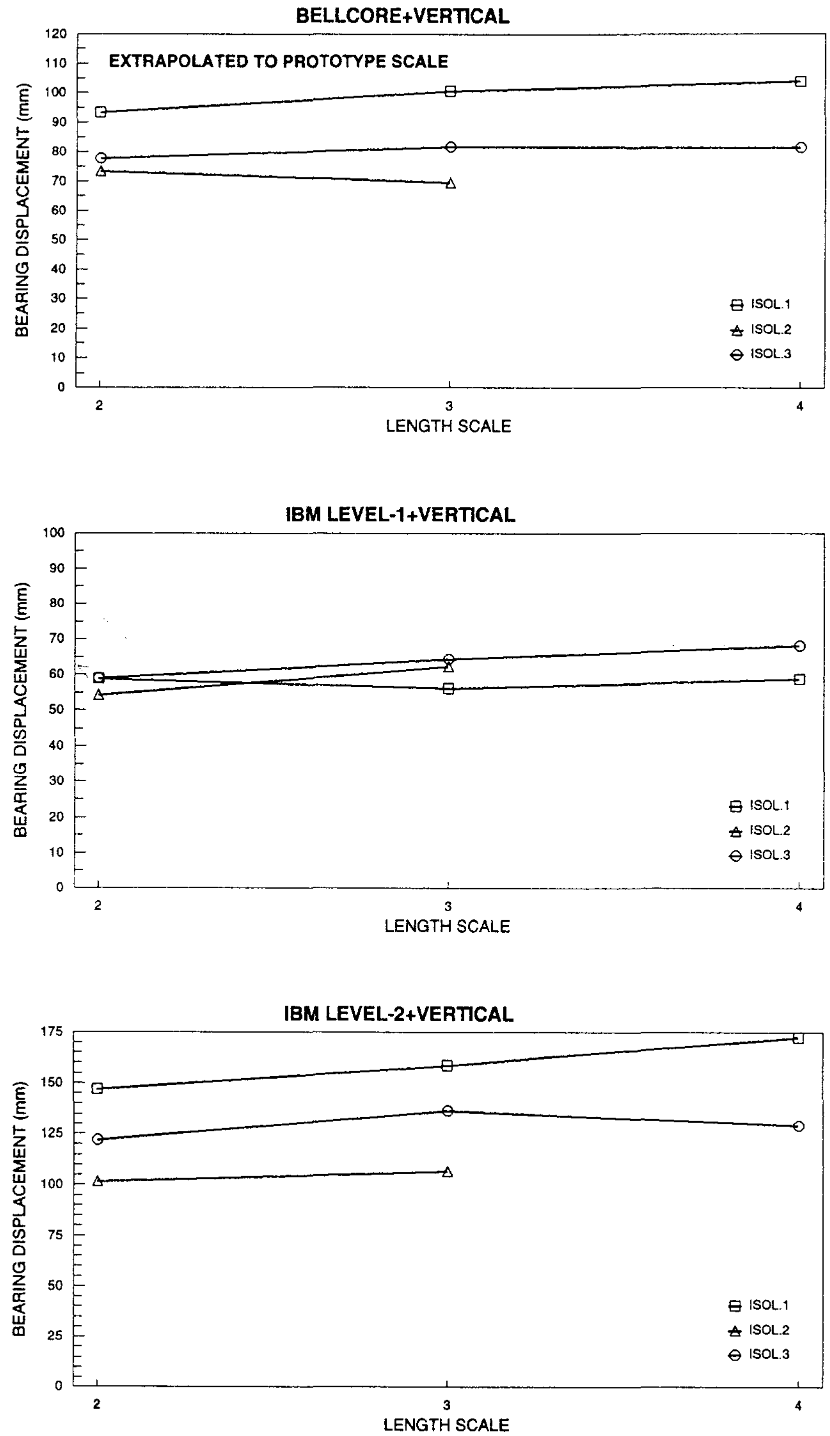


Figure 4-34 **Peak Bearing Displacement in Prototype Scale for the Artificial Inputs.Length Scale of 2 Corresponds to Isolation Period of 2.12 secs, Length Scale of 3 Corresponds to 2.60 secs, and Length Scale of 4 Corresponds to 3.00 secs**

SECTION 5

ANALYTICAL PREDICTION OF RESPONSE

5.1 Introduction

A simple analytical model of the isolated floor system is developed and calibrated. The model is used for the analytical prediction of the response of the tested system. The model is subsequently used to extend the results of the experimental study over a range of isolation system parameters which could not be experimentally evaluated.

5.2 Analytical Model

The analytical model, as shown in Figure 5-1, is a three degree of freedom representation of the floor system and Cabinet. The selected degrees of freedom were: The displacement at the center of mass of the Cabinet with respect to the Raised Floor, U_C, the Raised Floor displacement with respect to the Base Floor, U_R , and the Base Floor displacement with respect to the shake table, U_B.

The Cabinet was assumed to be fixed on the Raised Floor, a condition which is valid only when sliding or rocking of the Cabinet does not occur.

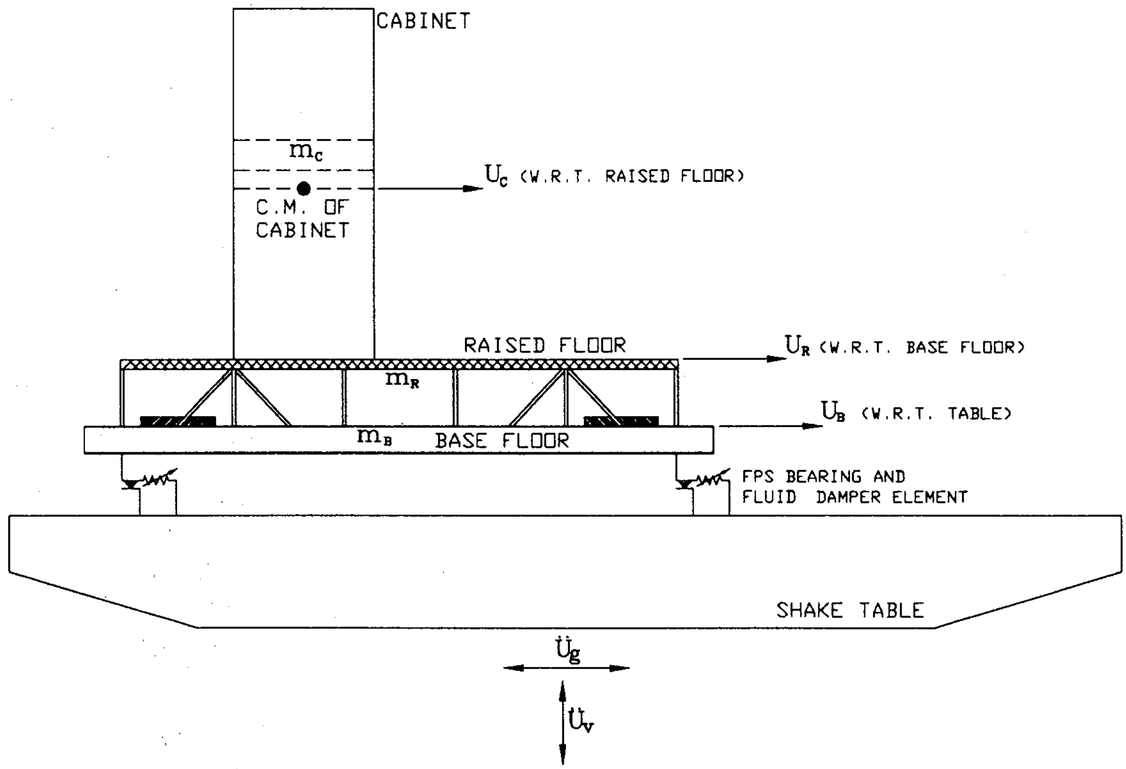


Figure 5-1 Longitudinal Direction Model of Isolated Floor System

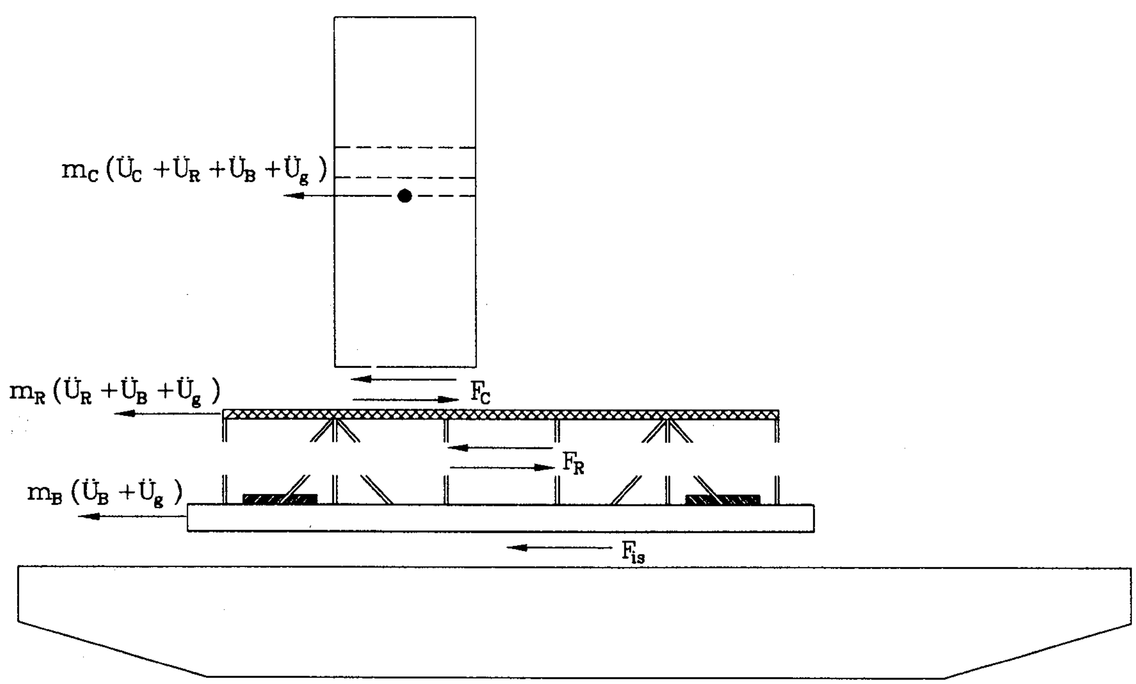


Figure 5-2 Free Body Diagram of Floor System Model

A free body diagram of the model is shown in Figure 5-2. The equations of motion were derived by consideration of dynamic equilibrium of the Cabinet, Raised Floor and Base Floor in the horizontal direction:

$$m_C(\ddot{U}_B + \ddot{U}_R + \ddot{U}_C + \ddot{U}_g) + F_C = 0 \quad (5\text{-}1)$$

$$m_R(\ddot{U}_B + \ddot{U}_R + \ddot{U}_g) + F_R - F_C = 0 \quad (5\text{-}2)$$

$$m_B(\ddot{U}_B + \ddot{U}_g) + F_{is} - F_R = 0 \quad (5\text{-}3)$$

where F_C and F_R are, respectively, the restoring and damping (assumed viscous) forces of the Cabinet and Raised Floor. Furthermore, F_{is} is the isolation system force, which consists of a component contributed by the FPS bearings and another contributed by the fluid dampers. That is,

$$F_C = K_C U_C + C_C \dot{U}_C \quad (5\text{-}4)$$

$$F_R = K_R U_R + C_R \dot{U}_R \quad (5\text{-}5)$$

$$F_{is} = \frac{W^*}{R} + \mu W^* Z + C_0 \dot{U}_B \quad (5\text{-}6)$$

where μ= coefficient of friction, R= radius of curvature of FPS bearings, W^*= instantaneous normal load on FPS bearings and C_0= effective damping constant (in horizontal direction) of fluid dampers.

The instantaneous load on the bearings was obtained as

$$W^* = W(1 + \frac{\ddot{U}_v}{g}) \quad (5\text{-}7)$$

where W= gravity load on bearings (27595 N) and $\ddot{U}_v$= vertical table acceleration. Equation (5-7) should actually include a modified vertical acceleration to account for the vertical flexibility of the floor system and distribution of mass. This modified vertical acceleration has the general form

$$\ddot{U}_{vm}(t) = \frac{g}{W}\int_0^L \bar{m}(x)\ddot{U}_{Rv}(x,t)dx \tag{5-8}$$

where L= distance between bearings, $\bar{m}$= mass distribution over distance L and $\ddot{U}_{Rv}$= vertical acceleration of Raised Floor. Noting that in the tested system most of the mass was located in the vicinity of the bearings, for which $\ddot{U}_{Rv} = \ddot{U}_v$ (FPS bearings are vertically rigid), it is concluded that $\ddot{U}_{vm} \approx \ddot{U}_v$. Thus, Equation (5-7) is valid .

The coefficient of friction in the FPS bearings was described by

$$\mu = f_{\max} - (f_{\max} - f_{\min})\exp(-a\left|\dot{U}_B\right|) \tag{5-9}$$

where f_{min} and a were assumed independent of instantaneous bearing pressure, whereas f_{max} was assumed to depend on the instantaneous bearing pressure, p :

$$f_{\max} = f_{\max o} - Dfp \tag{5-10}$$

$$p = p_w(1 + \frac{\ddot{U}_v}{g}) \tag{5-11}$$

where p_w= bearing pressure due to gravity load. Equation (5-10) is not generally valid (see Soong and Constantinou, 1994 for details), but rather it is valid for low pressures in the range of 0 to about 10 MPa.

Furthermore, variable Z in Equation (5-6) was used to describe rigid plastic behavior. It is governed by the following equation (Constantinou 1990):

$$Y\dot{Z}+\gamma\left|\dot{U}_B\right|Z|Z|+\beta\dot{U}_B Z^2-\dot{U}_B=0 \qquad (5\text{-}12)$$

where Y= "yield" displacement and β and γ = parameters satisfying the condition $\beta+\gamma=1$.

Table 5-I lists values of the parameters in the analytical model of Equations (5-1) to (5-12). Solution of these equations was obtained by reducing the equations to first order form and integrating using a predictor-corrector adaptive integration scheme (IMSL, 1987).

Table 5-I : Parameters in Analytical Model of Tested Isolated Floor System

Quantity	Isolation System 1	Isolation System 2	Isolation System 3
$W_C = m_C g$ (N)	1780	1780	1780
$W_R = m_R g$ (N)	1875	1875	1875
$W_B = m_B g$ (N)	23940	23940	23940
$\omega_C = \sqrt{\frac{K_C}{m_C}}$ (r/s)	251.3	251.3	251.3
$\omega_R = \sqrt{\frac{K_R}{m_R}}$ (r/s)	196.0	196.0	196.0
$\beta_C = \frac{C_C}{2 m_C \omega_C}$	0.020	0.020	0.020
$\beta_R = \frac{C_R}{2 m_R \omega_R}$	0.036	0.036	0.036
R (mm)	558.8	558.8	558.8
f_{maxo}	0.24	0.24	0.24
f_{min}	0.07	0.03	0.03
Df $(\text{MPa})^{-1}$	0.0143	0.0143	0.0143
Y (mm)	0.25	0.25	0.25
a (sec/mm)	0.015	0.015	0.015
C_0 (Ns/mm)	0.0	14.0	8.1
p_w (MPa)	3.5	7.7	7.7

5.3 Comparison of Analytical and Experimental Results

Figures 5-3 to 5-10 compare analytical and experimental results for the isolated floor system in the El Centro 7th floor plus vertical input. Results are compared for the three isolation systems and for the three length scales: 2 , 3 and 4 . The compared results include:

(a) Time histories of FPS bearing displacement.

(b) Time histories of horizontal acceleration of the Raised Floor and center of mass of Cabinet.

(c) Loops of horizontal isolation system force (force from bearings and viscous dampers) versus bearing displacement.

Evidently, the analytically calculated bearing displacements and accelerations are in good agreement with the experimental results. However, it may be noted that the recorded acceleration histories contain spikes which are not captured by the analytical model. These spikes are more pronounced in the acceleration histories of the Raised Floor. They may have been caused by movement and impact (rattling) of the tiles of Raised Floor in the vicinity of the instruments.

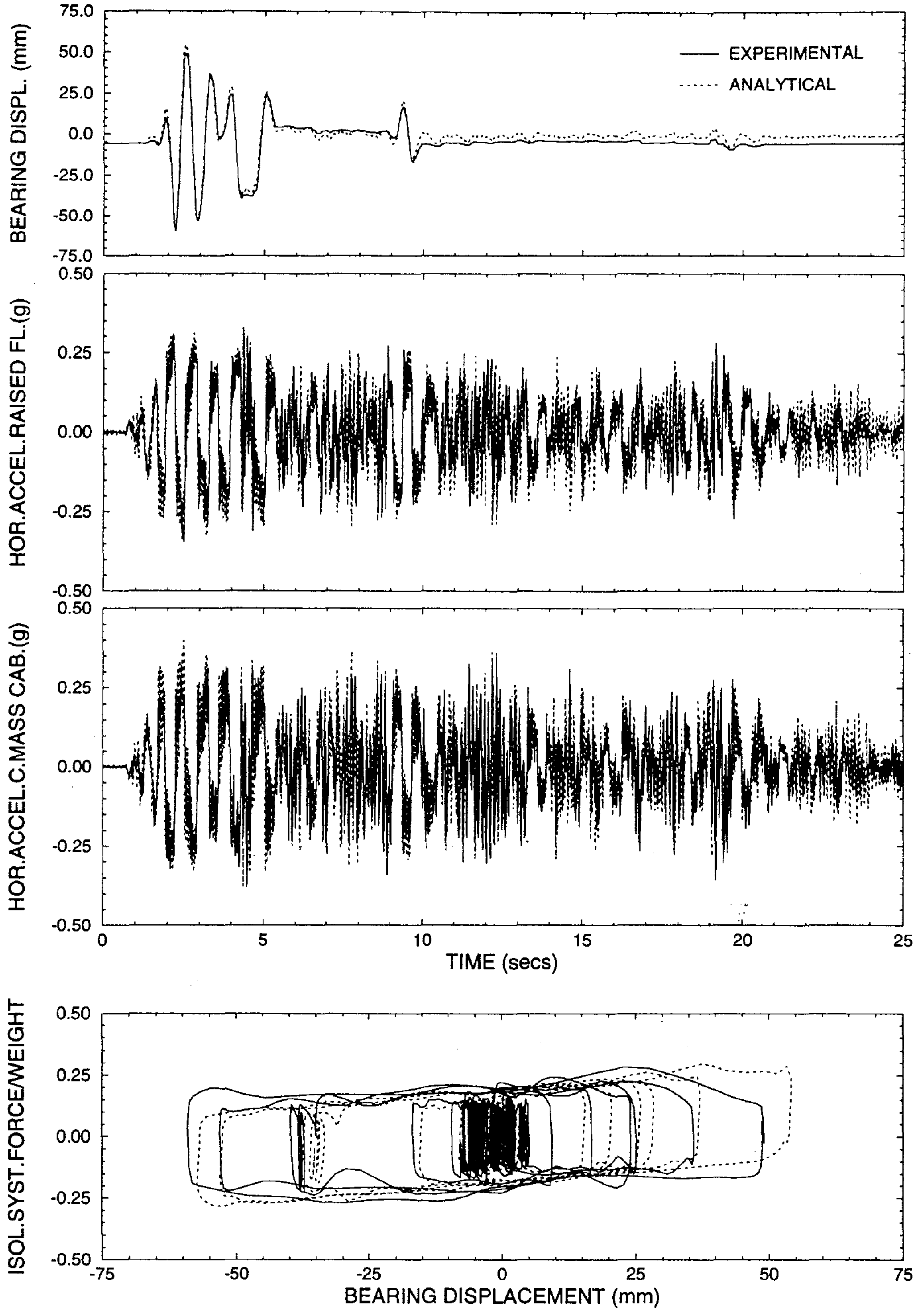


Figure 5-3 Comparison of Analytical and Experimental Results of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale of 2.

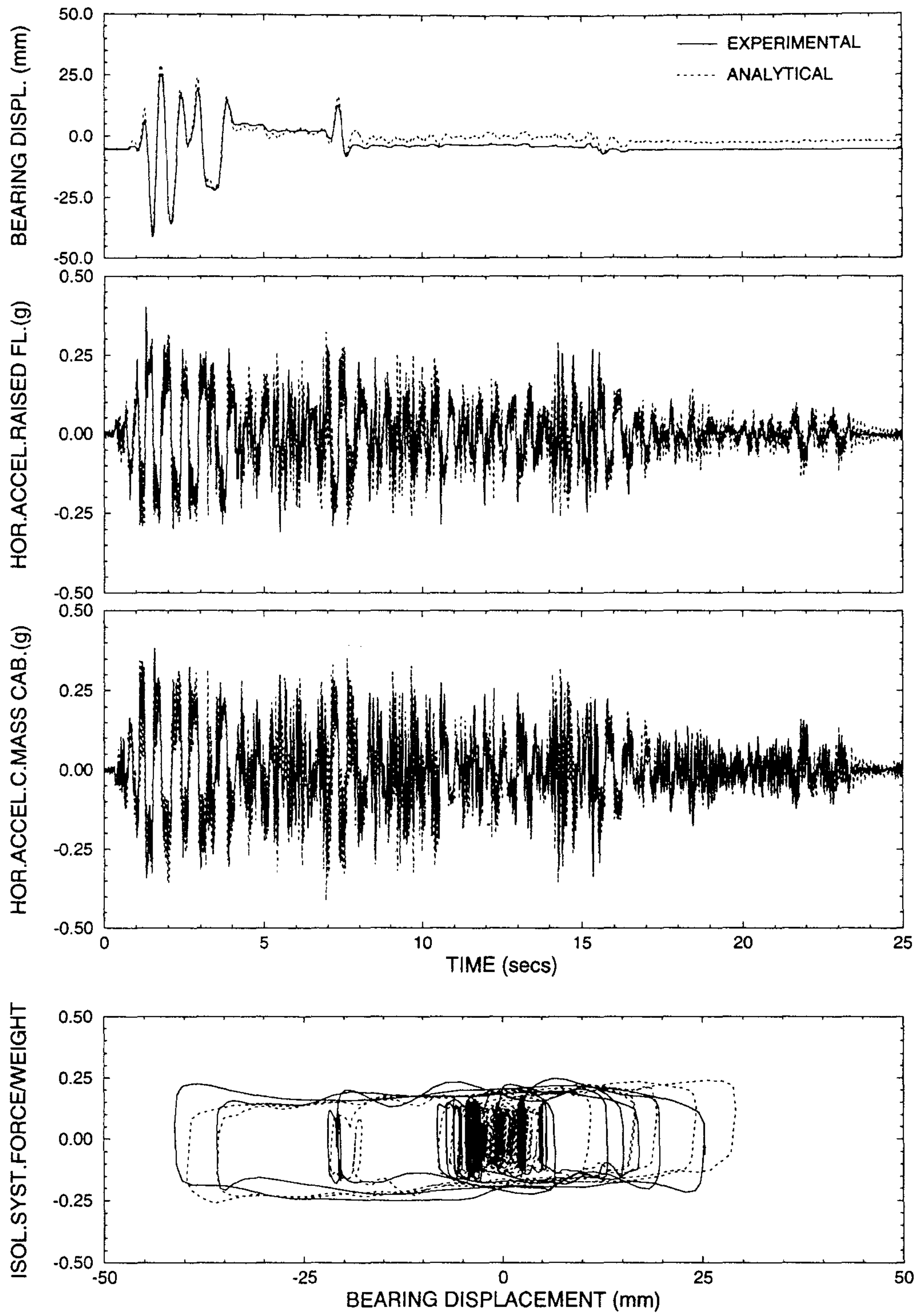


Figure 5-4 Comparison of Analytical and Experimental Results of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale of 3.

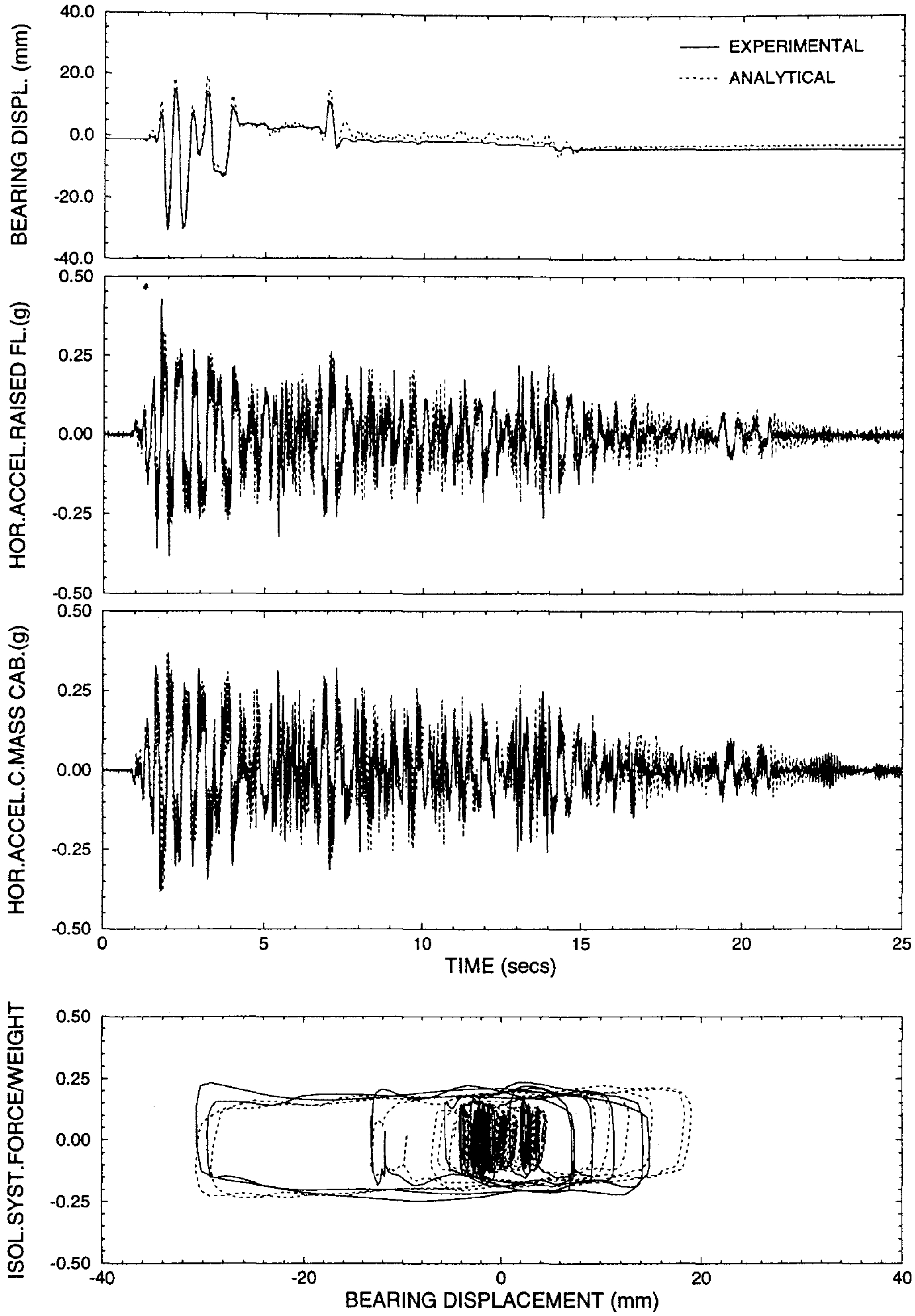


Figure 5-5 Comparison of Analytical and Experimental Results of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale of 4.

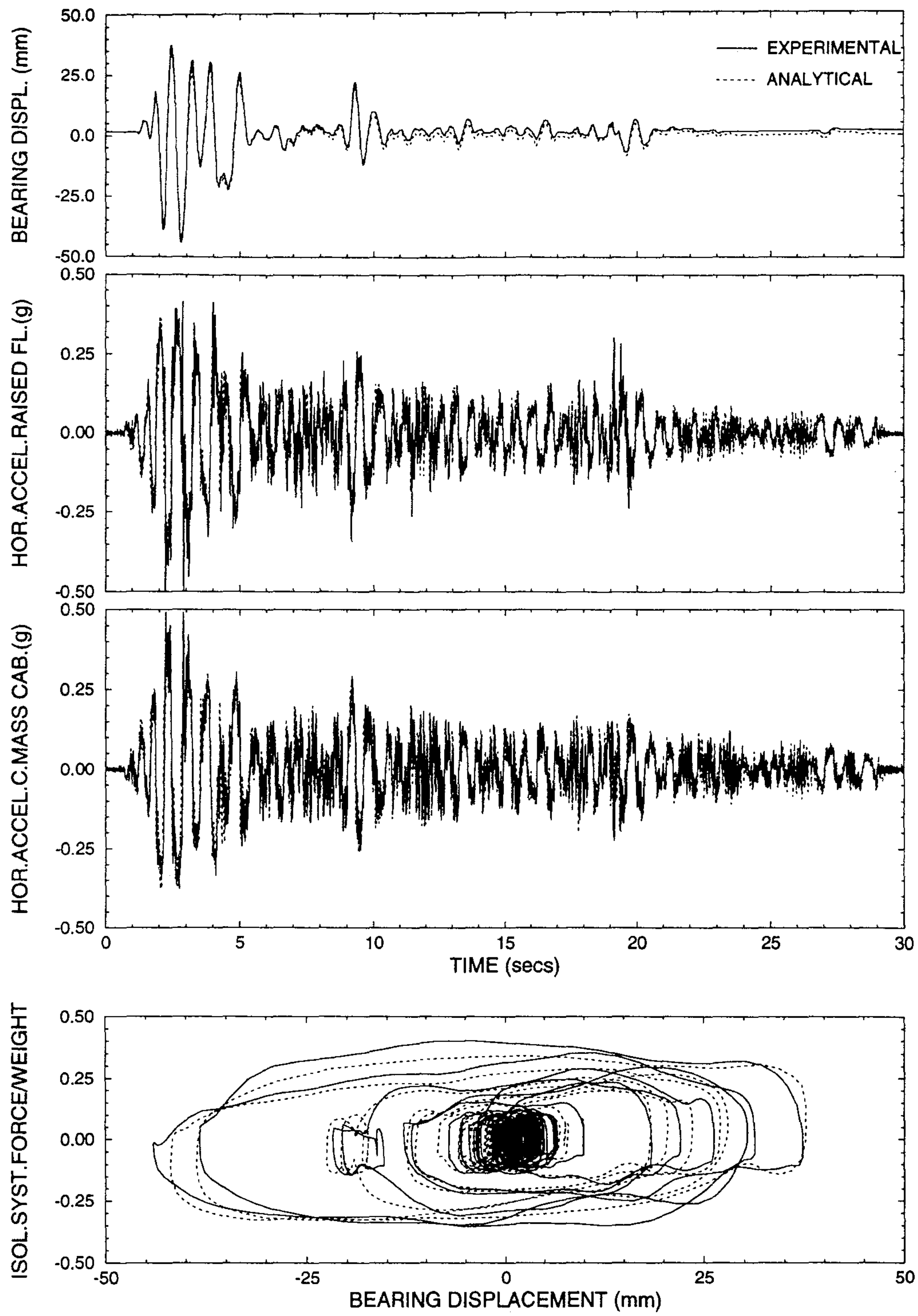


Figure 5-6 Comparison of Analytical and Experimental Results of Floor System with Isolation System 2 in El Centro 7th Floor plus Vertical Input at Length Scale of 2.

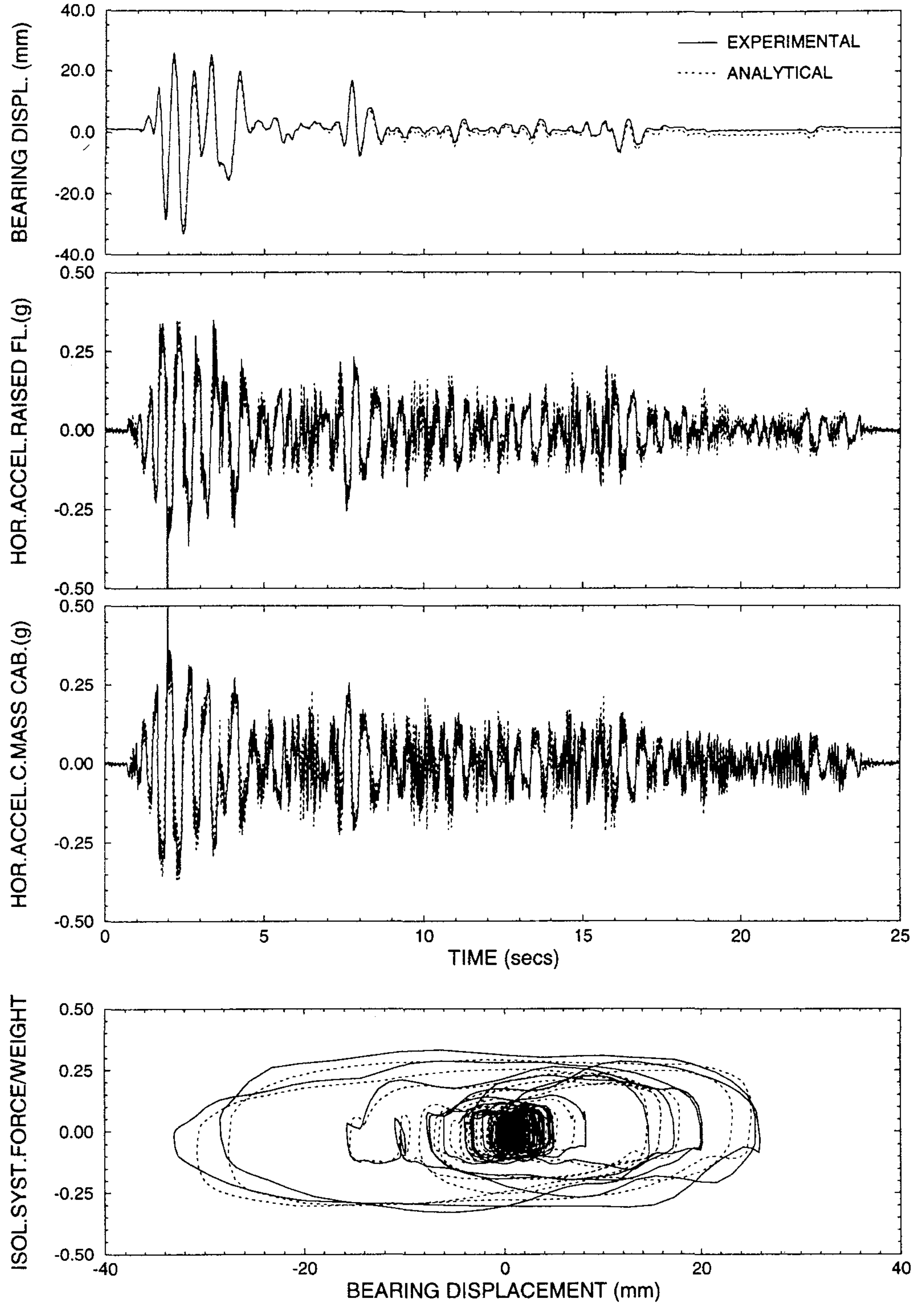


Figure 5-7 Comparison of Analytical and Experimental Results of Floor System with Isolation System 2 in El Centro 7th Floor plus Vertical Input at Length Scale of 3.

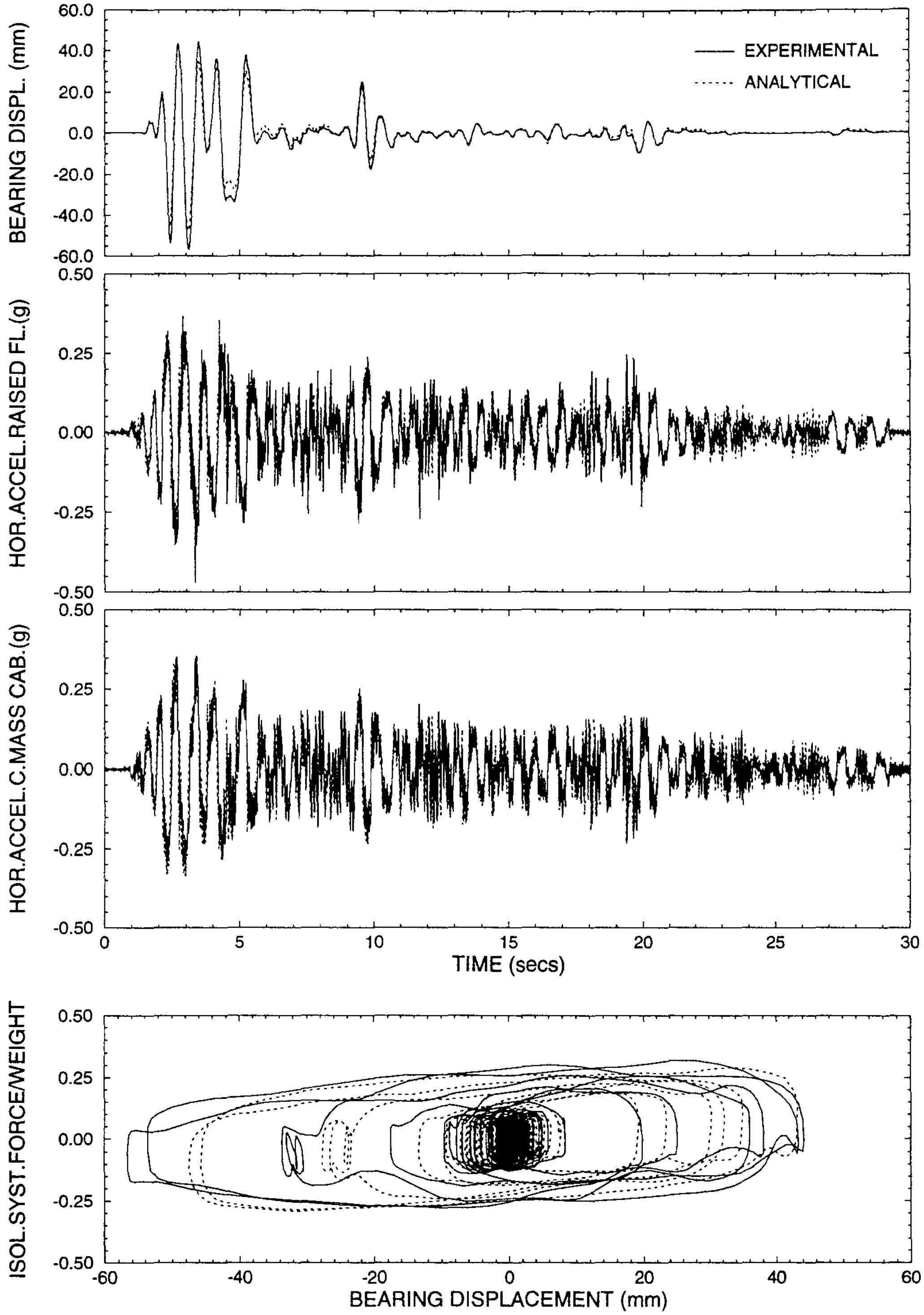


Figure 5-8 **Comparison of Analytical and Experimental Results of Floor System with Isolation System 3 in El Centro 7th Floor plus Vertical Input at Length Scale of 2.**

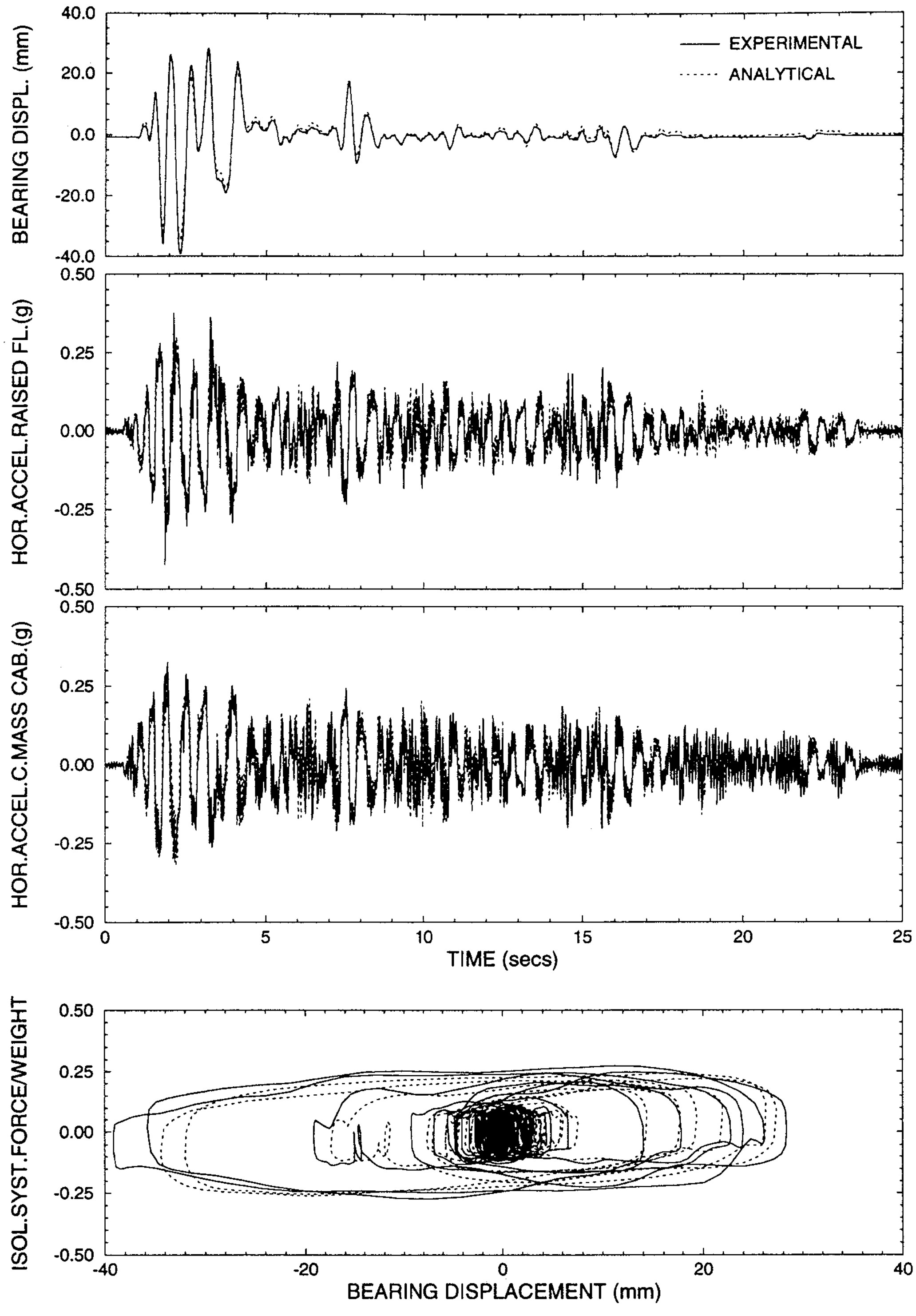


Figure 5-9 Comparison of Analytical and Experimental Results of Floor System with Isolation System 3 in El Centro 7th Floor plus Vertical Input at Length Scale of 3.

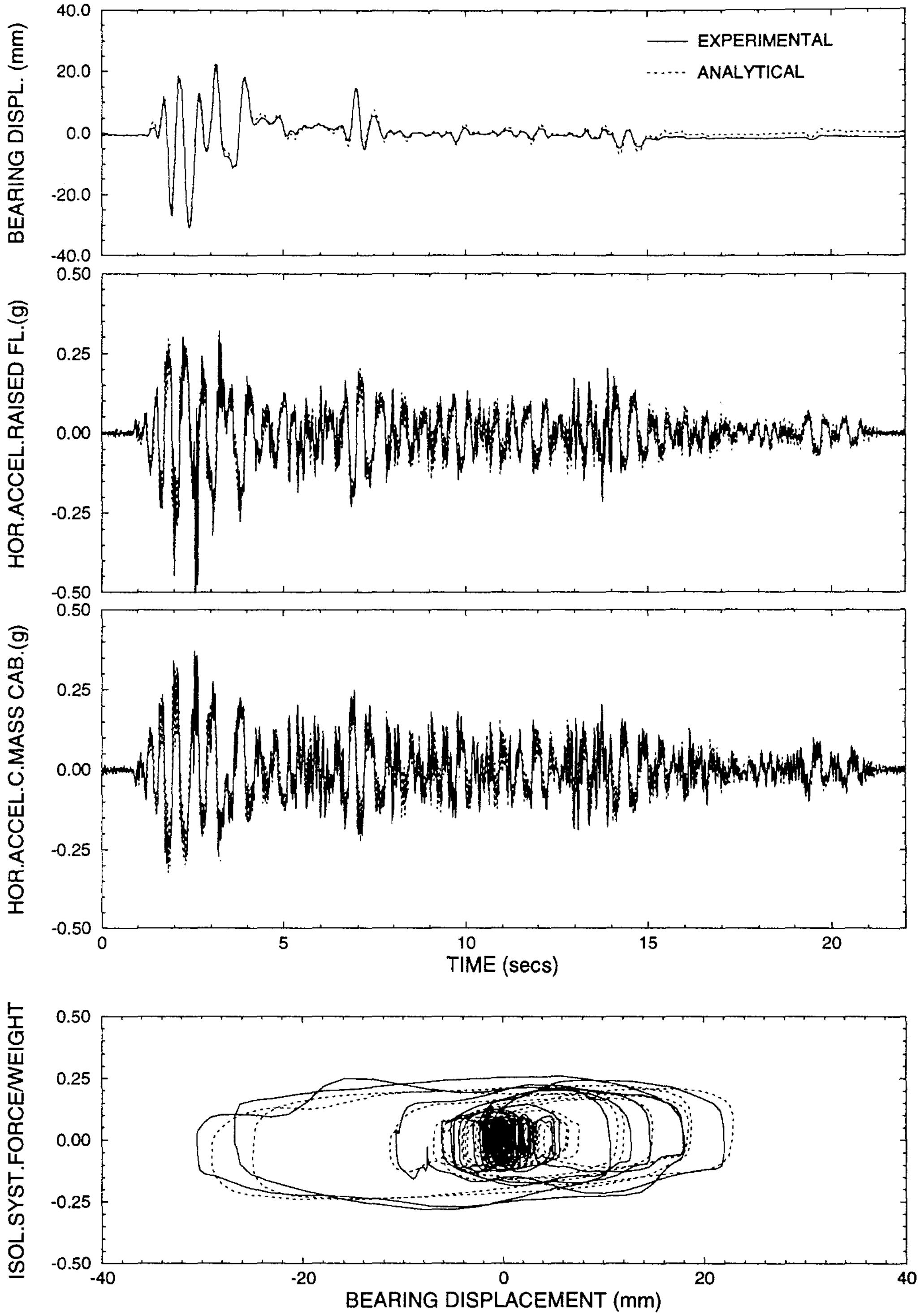


Figure 5-10 Comparison of Analytical and Experimental Results of Floor System with Isolation System 3 in El Centro 7th Floor plus Vertical Input at Length Scale of 4.

Analyses have also been performed for the case of isolation 1 by utilizing a model in which the dependency of the coefficient of friction on bearing pressure was neglected. That is, pressure p in Equation (5-11) was set equal to p_w . Results are compared to experimental results in Figures 5-11 to 5-13 . It is evident that neglect of the bearing pressure dependency of the coefficient of friction does not lead to any significant difference. For this compare Figures 5-11 to 5-13 to Figures 5-3 to 5-5.

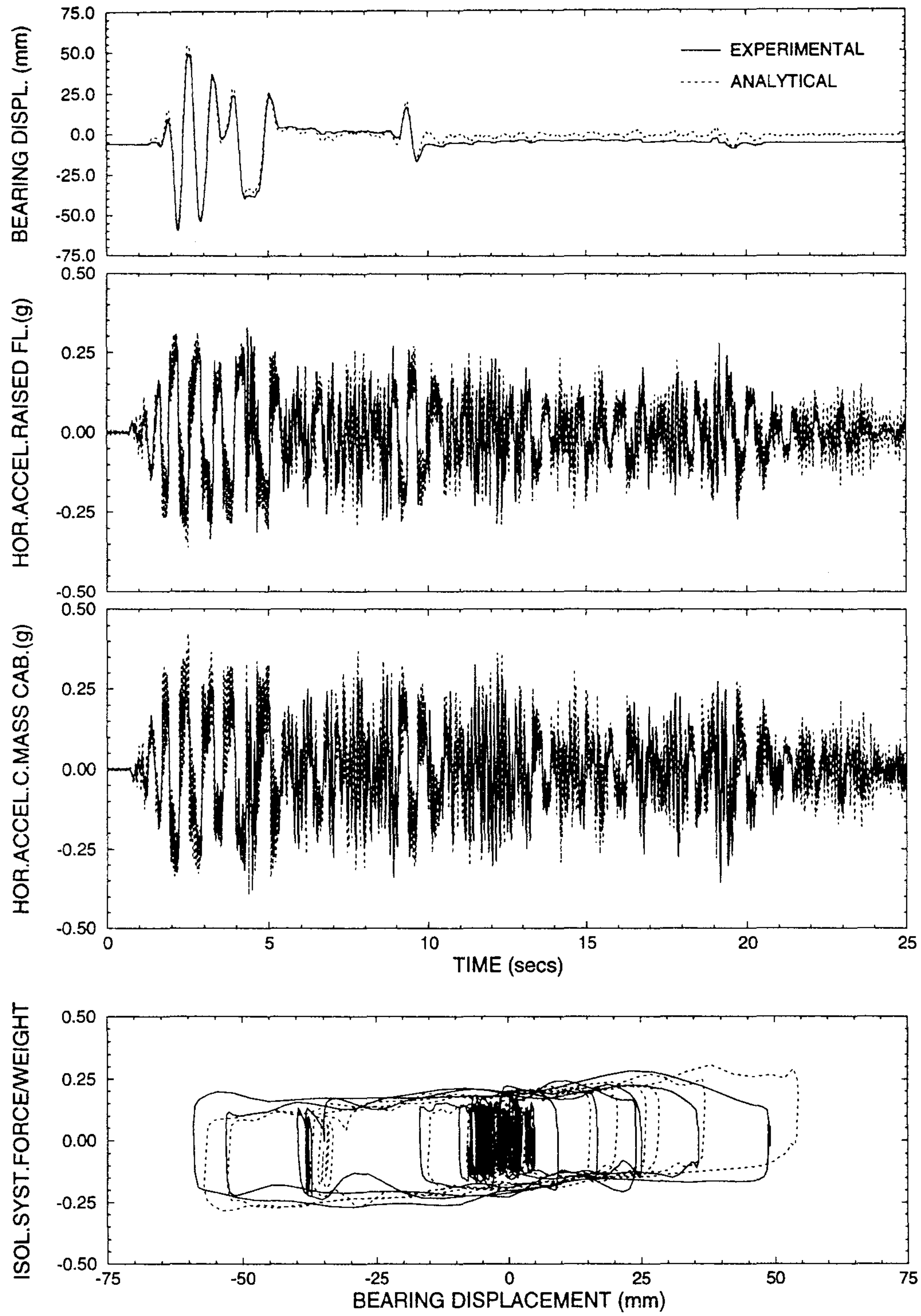


Figure 5-11 Comparison of Analytical and Experimental Response of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale 2 . Analysis Performed without Accounting for Dependence of Coefficient of Friction on Instantaneous Bearing Pressure.

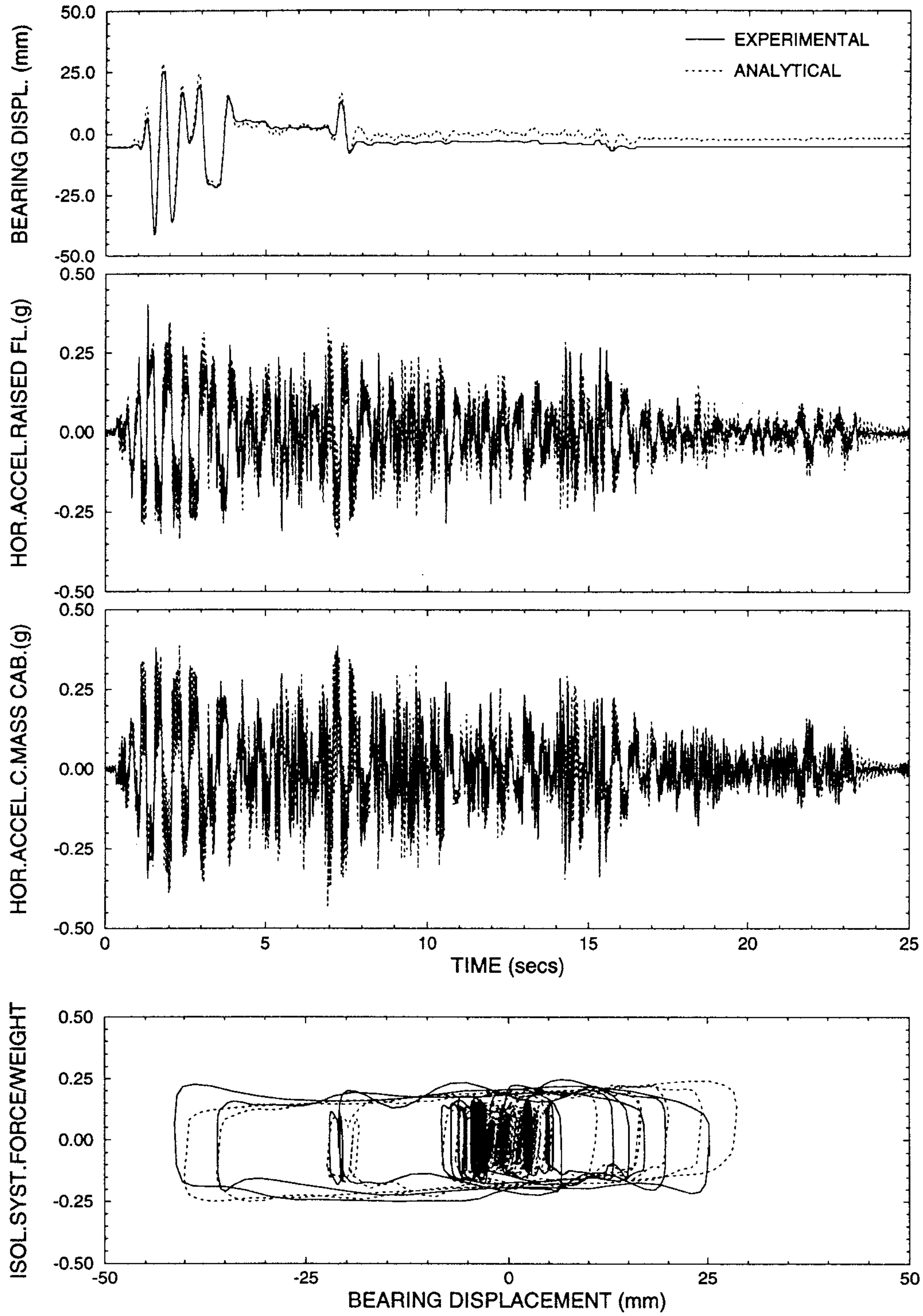


Figure 5-12 Comparison of Analytical and Experimental Response of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale 3 . Analysis Performed without Accounting for Dependence of Coefficient of Friction on Instantaneous Bearing Pressure.

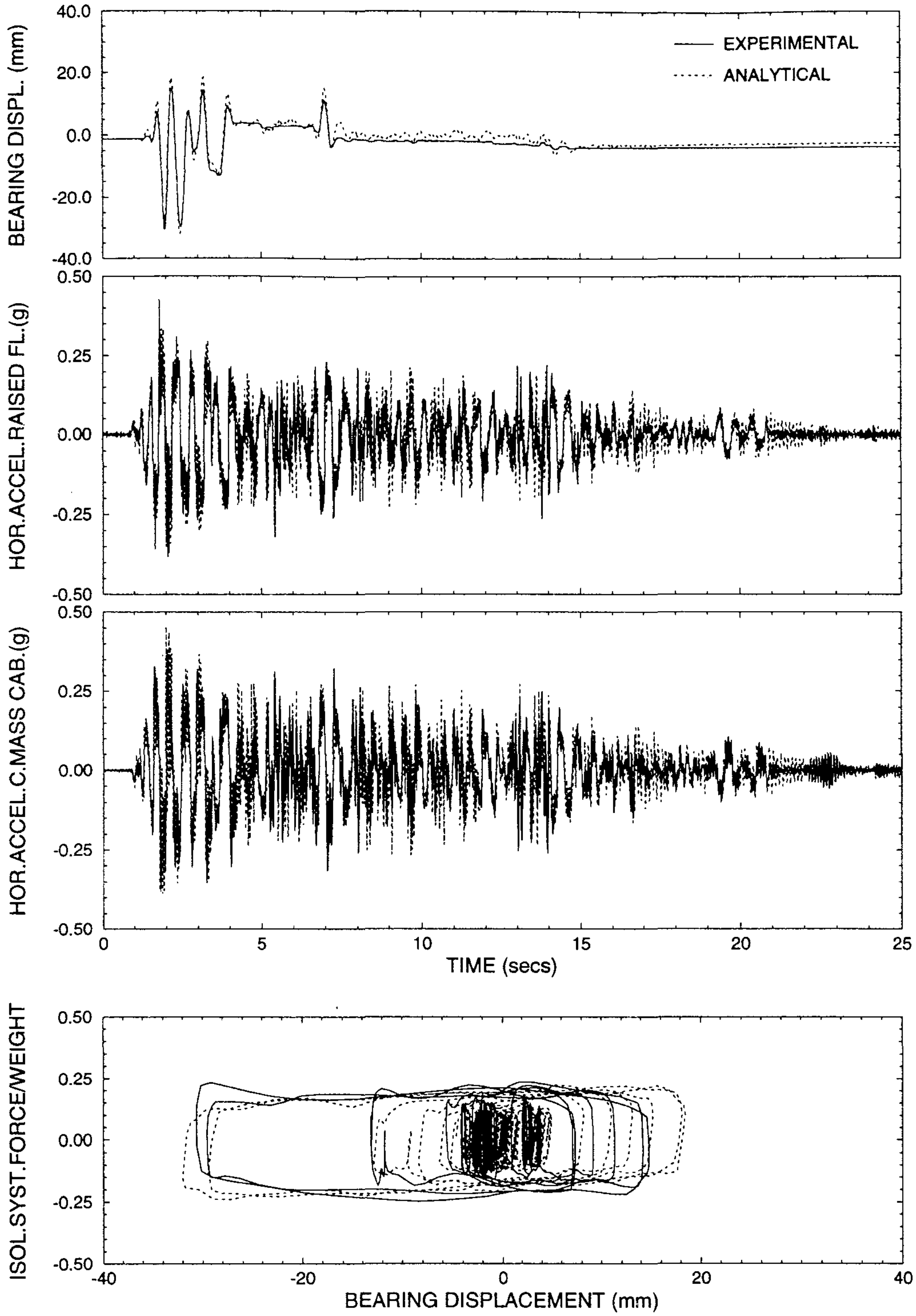


Figure 5-13 Comparison of Analytical and Experimental Response of Floor System with Isolation System 1 in El Centro 7th Floor plus Vertical Input at Length Scale 4 . Analysis Performed without Accounting for Dependence of Coefficient of Friction on Instantaneous Bearing Pressure.

5.4 Analytical Parametric Study

The analytical model of the tested floor isolation system is sufficiently accurate to allow for an extension of the experimental study to a range of parameters which could not be experimentally studied. Particularly, experimental results were not obtained at low values of friction.

The analytical study concentrated on the response of the isolated floor system in the Taft, El Centro and Pacoima Dam records, using the actual records and not those of the shake table (recall that the table did not reproduce properly the vertical ground motion). Furthermore, the parametric study was conducted in prototype scale (that is, length scale of 1).

Table 5-II lists the range of parameters of the analytical study. All parameters of the Cabinet and Raised Floor are those of the tested system except for the fundamental frequency of the Cabinet. The isolation system is described by the radius of curvature of the FPS bearings (R= 1553 and 2236 mm , which correspond to periods-Equation (2-2)- of 2.5 and 3.0 secs), the frictional properties of the bearings and the damping ratio as determined from Equation (3-2). The dependency of parameter f_{max} on the instantaneous bearing pressure is neglected. The governing equations of motion are those of Equations (5-1) to (5-7) , (5-9) and (5-12).

Table 5-II : Parameters in Analytical Parametric Study

<table>
<tr><th colspan="2">Quantity</th><th colspan="6">Range of Values</th></tr>
<tr><td>Weight of Cabinet</td><td>W_C (N)</td><td colspan="6">1780</td></tr>
<tr><td>Weight of Raised Floor</td><td>W_R (N)</td><td colspan="6">1875</td></tr>
<tr><td>Weight of Base Floor</td><td>W_B (N)</td><td colspan="6">23940</td></tr>
<tr><td>Frequency of Cabinet</td><td>f_C (Hz)</td><td colspan="2">5</td><td colspan="3">10</td><td>20</td></tr>
<tr><td>Frequency of Raised Floor</td><td>f_R (Hz)</td><td colspan="6">31.2</td></tr>
<tr><td>Damping Ratio of Cabinet</td><td>β_C</td><td colspan="6">0.020</td></tr>
<tr><td>Damping Ratio of Raised Floor</td><td>β_R</td><td colspan="6">0.036</td></tr>
<tr><td>Radius of Curvature of FPS Bearing</td><td>R (mm)
[Period(secs)]</td><td colspan="3">1553
[2.5]</td><td colspan="3">2236
[3.0]</td></tr>
<tr><td rowspan="3">Parameters in Friction Model</td><td>f_{max}</td><td>0.05</td><td colspan="2">0.10</td><td colspan="2">0.15</td><td>0.20</td></tr>
<tr><td>f_{min}</td><td>0.03</td><td colspan="2">0.04</td><td colspan="2">0.06</td><td>0.08</td></tr>
<tr><td>a (sec/mm)</td><td colspan="6">0.015</td></tr>
<tr><td>Damping Ratio of Isolation System (Eq.3-2)</td><td>β</td><td>0.00</td><td colspan="2">0.15</td><td colspan="2">0.30</td><td>0.50</td></tr>
</table>

It should be noted that the analytical study was conducted with fundamental frequency of Cabinet equal to 5 , 10 and 20 Hz . The experimental results at length scale of $S_L = 4$ (corresponding time scale $S_T = 2$ and frequency scale $S_F = 0.5$) may be extrapolated to prototype scale to obtain an additional set of results, which is valid for Cabinet frequency of 20 Hz and radius of curvature of FPS bearings $R = 2236$ mm (thus, period of 3 secs). For the extrapolation, the recorded displacements should be multiplied by a factor of 4 , whereas accelerations are the same as in the model scale.

The analytically determined peak response of the isolated floor system is presented in Figures 5-14 to 5-31 . The results demonstrate a number of significant features which could not be observed in the testing program:

(a) The flexibility of the Cabinet is significant in establishing the effectiveness of the isolation system. For a flexible Cabinet (say 5 Hz frequency), a high friction system, with or without dampers, will generate unacceptably large accelerations at the Cabinet level. It may be observed in the figures that the Cabinet accelerations in the high friction systems are large and at the level which would cause rocking of the Cabinet.

(b) A combination of very low friction ($f_{max} = 0.05$) and high viscous damping ($\beta = 0.50$) results in an acceleration response which is only marginally affected by the flexibility of the Cabinet on top of the isolated floor. This is illustrated in Figure 5-32 which compares the acceleration response at the center of mass of the Cabinet in various analyzed configurations for the El Centro and Taft motions.

The figure demonstrates the sensitivity of Cabinet response of the high friction system on the flexibility of the Cabinet.

(c) The combination of low friction and high viscous damping isolation system produces significant reduction of Cabinet acceleration in comparison to a high friction system. This significant benefit is achieved at the expense of some small increase in bearing displacement. This is also illustrated in Figure 5-32 for the Taft and El Centro motions.

Of interest is to note the ease in achieving high damping ratio values in the isolation system. For an isolation system with R= 2236 mm (period of 3 secs) on a 6 m by 6 m floor (20 ft by 20 ft), a damping ratio β= 0.50 can be achieved with two dampers in each principal direction, placed at an angle of 45° with respect to the vertical. From Equation (3-2), each damper should have a damping constant C_0 such that

$$C_0 = \frac{\beta W}{\cos^2 45^o \sqrt{Rg}} \tag{5-13}$$

Considering a weight of 178 kN (40 kips or 100 psf), we obtain C_0= 38 Ns/mm (217 lb-s/in). Based on the calculated displacement in the El Centro 7th floor motion for the system with f_{max}= 0.05 and β= 0.50, the bearing displacement demand is about 120 mm. Thus, the dampers should have a displacement capacity of at least 120xcos45° or 85 mm.

Fluid viscous dampers with damping constant of 38 Ns/mm, displacement capacity of $\pm$ 100 mm and force capacity of 25,000 N (sufficient for this application) should have length of about 600 mm and diameter of about 75 mm.

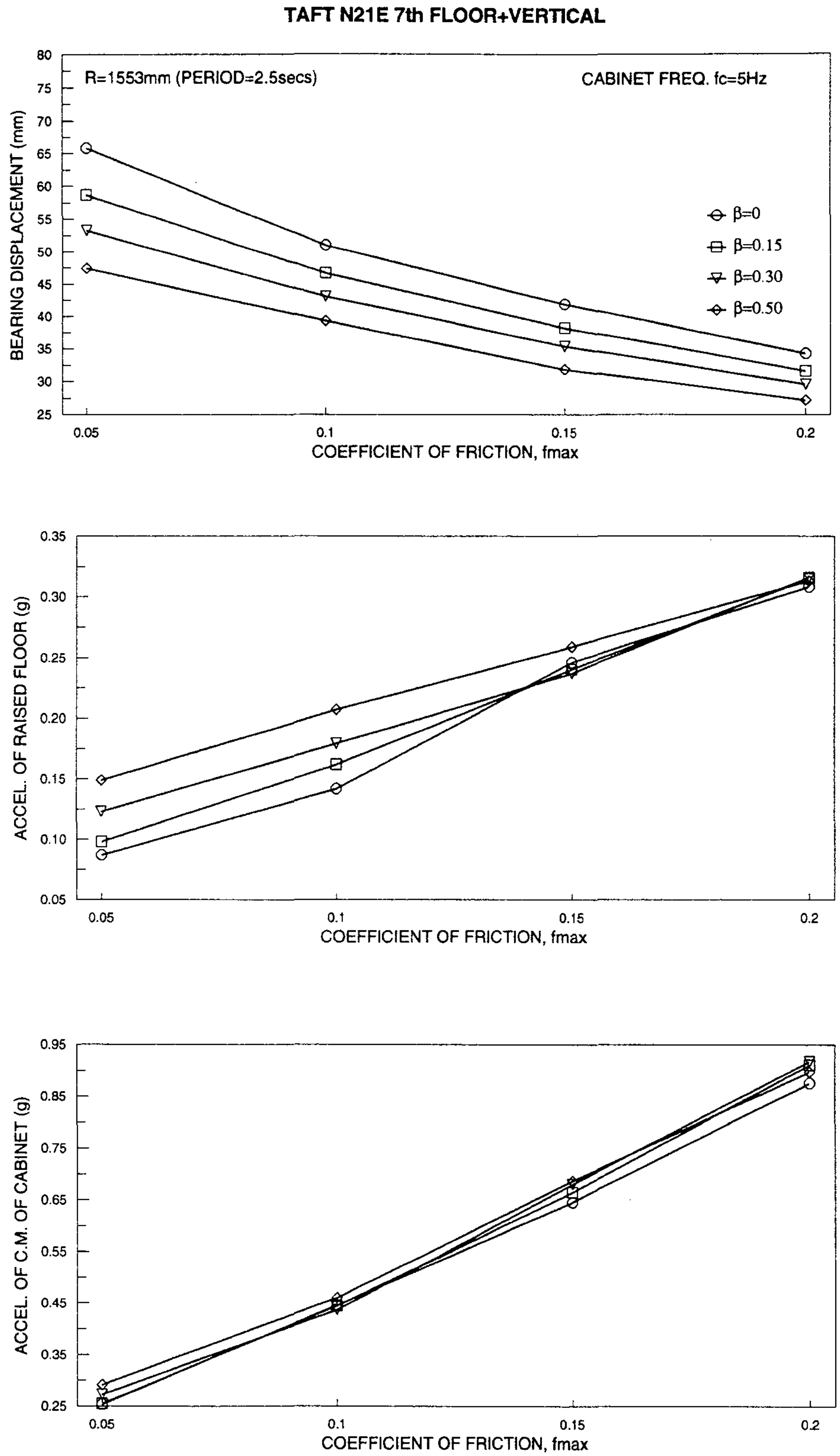


Figure 5-14 Analytical Response of Isolated Floor System with Cabinet of 5 Hz Frequency and Isolation Period of 2.5 secs in Taft 7th Floor Motion.

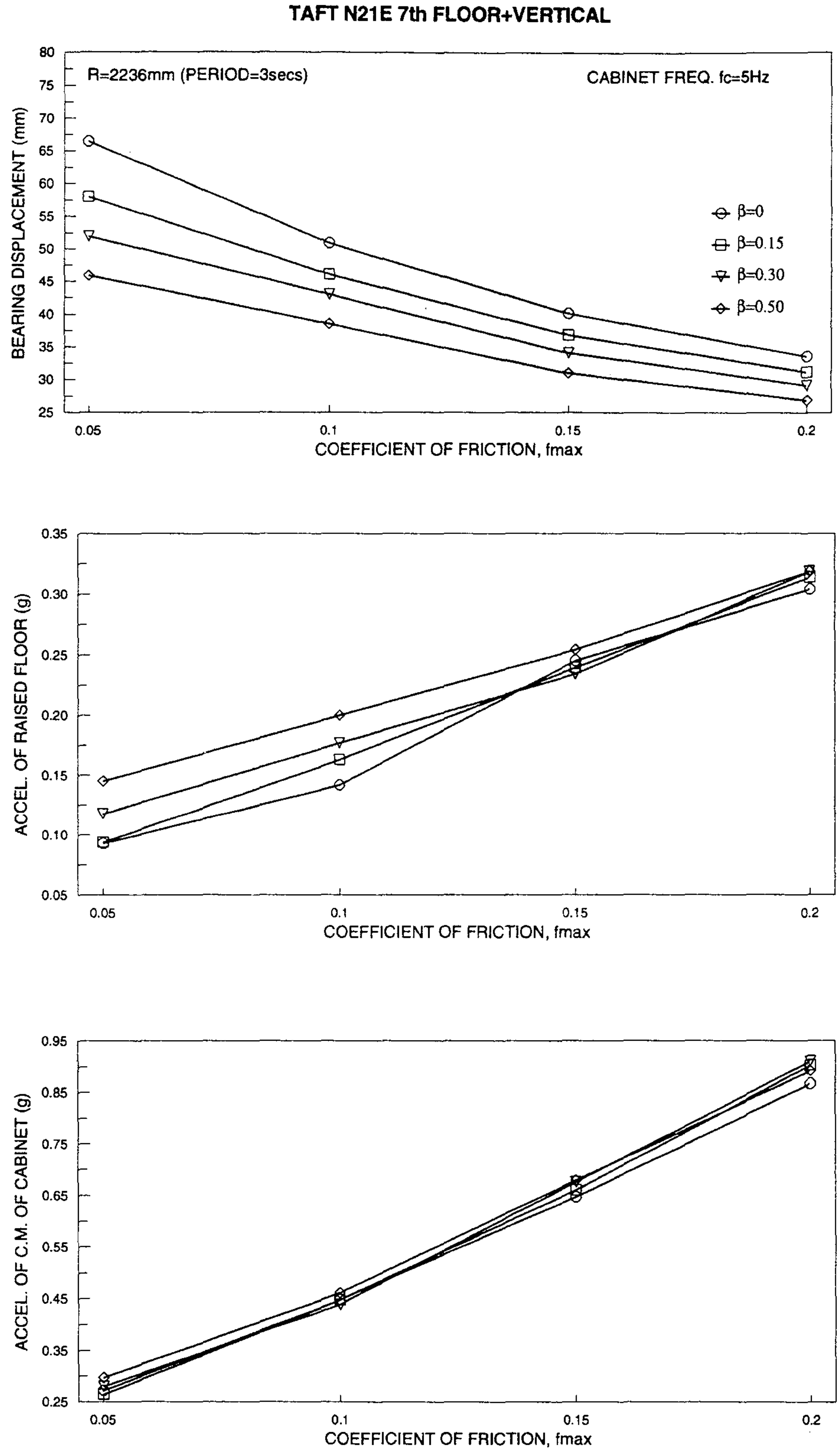


Figure 5-15 Analytical Response of Isolated Floor System with Cabinet of 5 Hz Frequency and Isolation Period of 3.0 secs in Taft 7th Floor Motion.

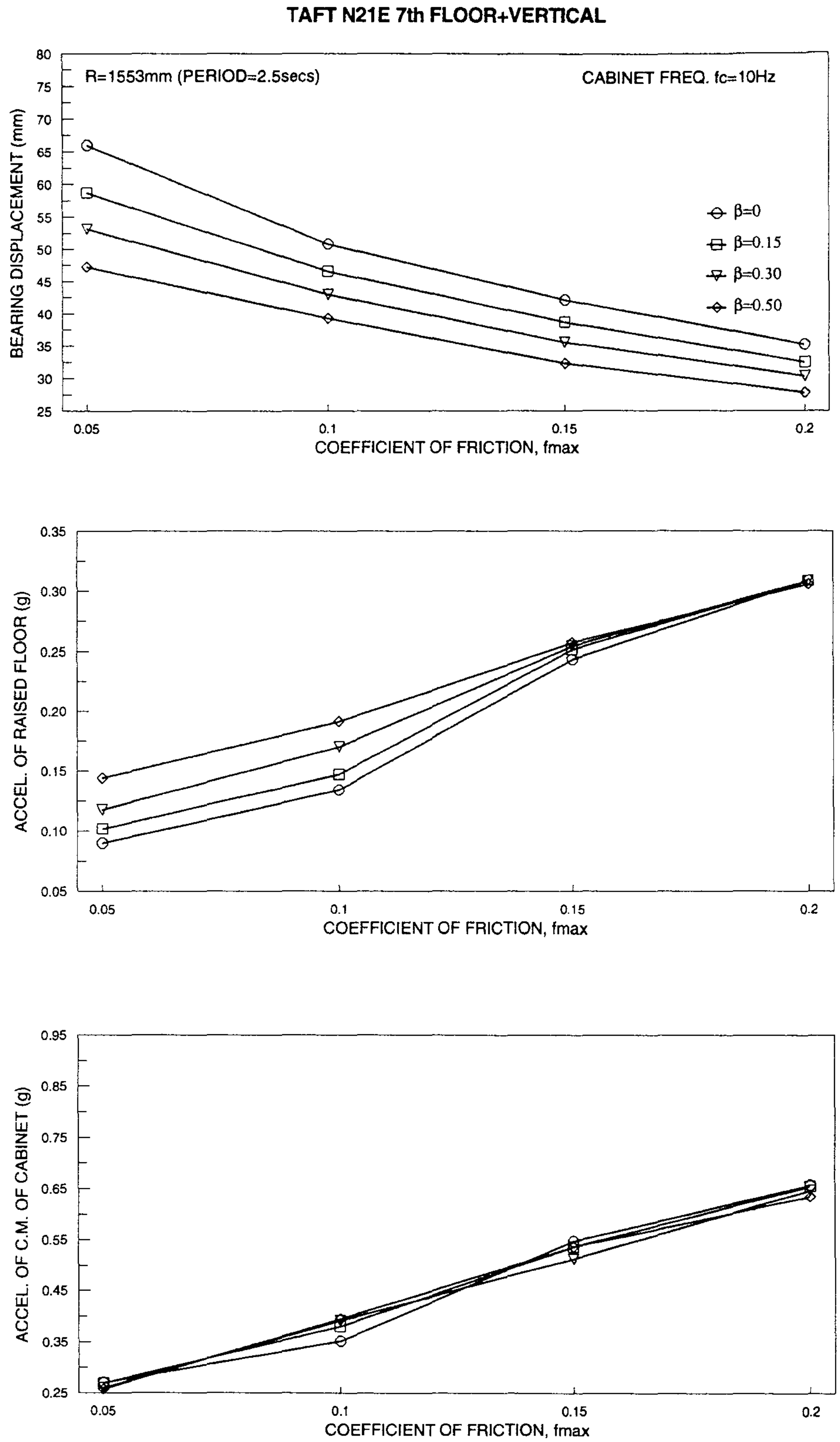


Figure 5-16 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 2.5 secs in Taft 7th Floor Motion.

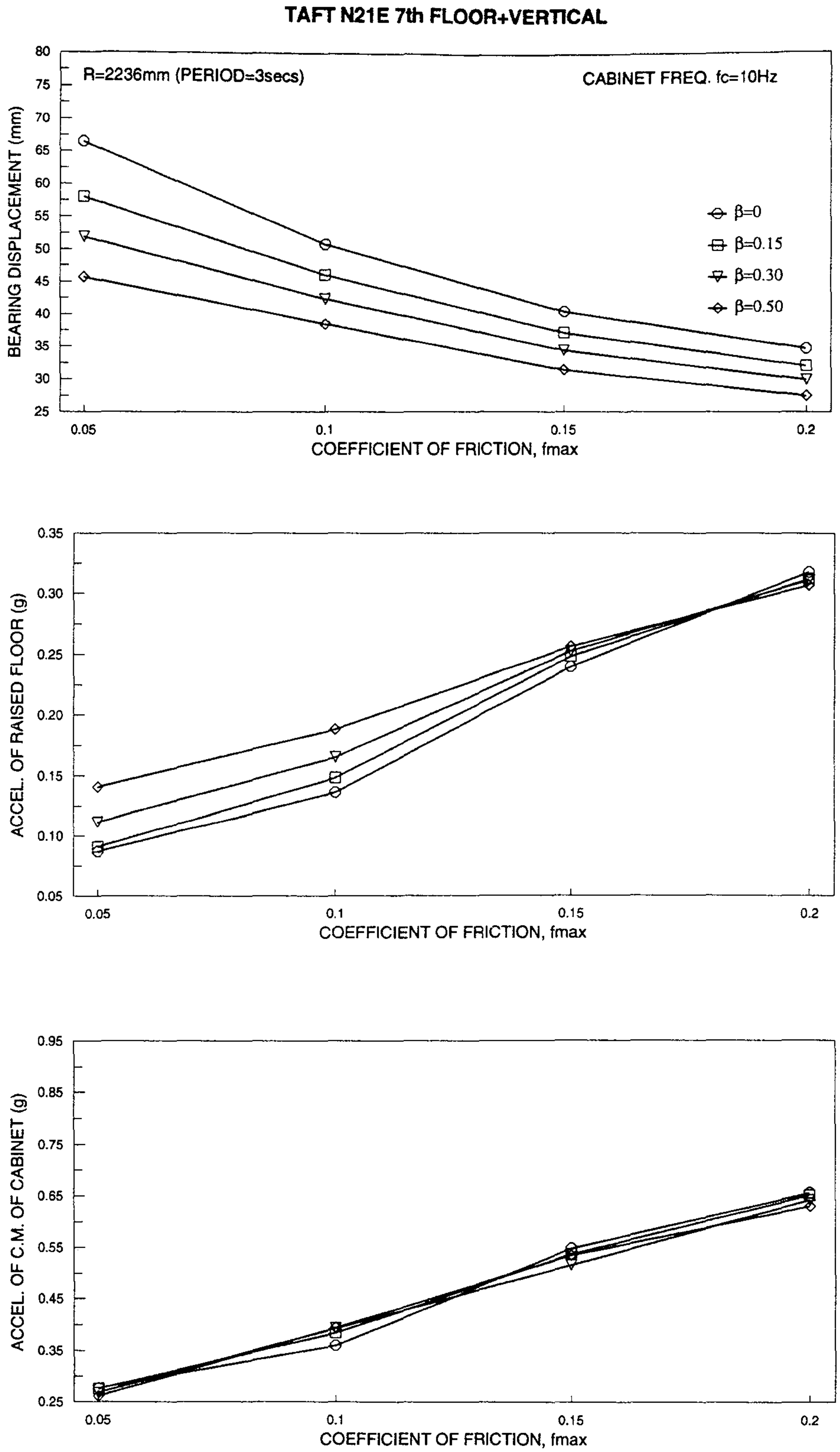


Figure 5-17 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 3.0 secs in Taft 7th Floor Motion.

TAFT N21E 7th FLOOR+VERTICAL

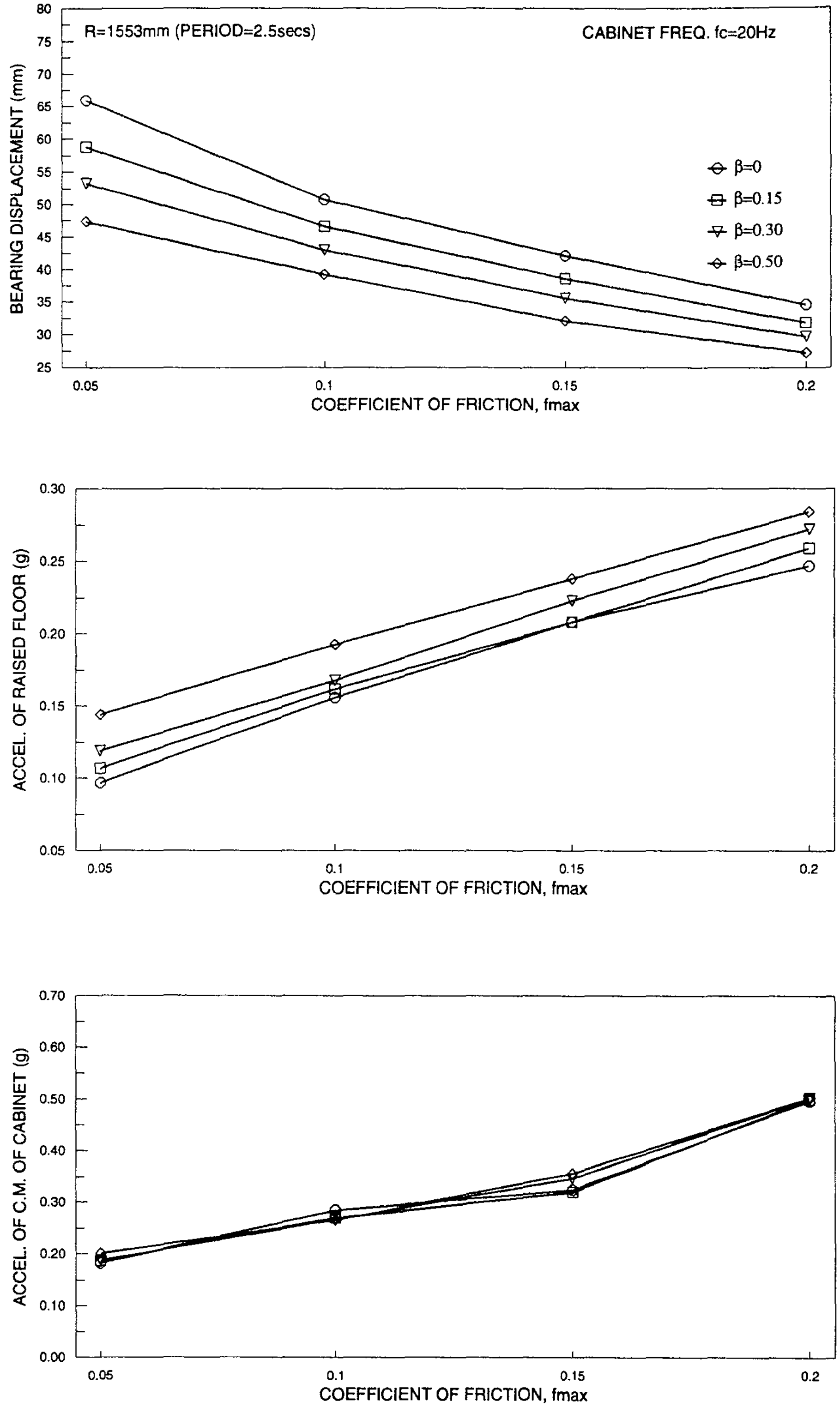


Figure 5-18 Analytical Response of Isolated Floor System with Cabinet of 20 Hz Frequency and Isolation Period of 2.5 secs in Taft 7th Floor Motion.

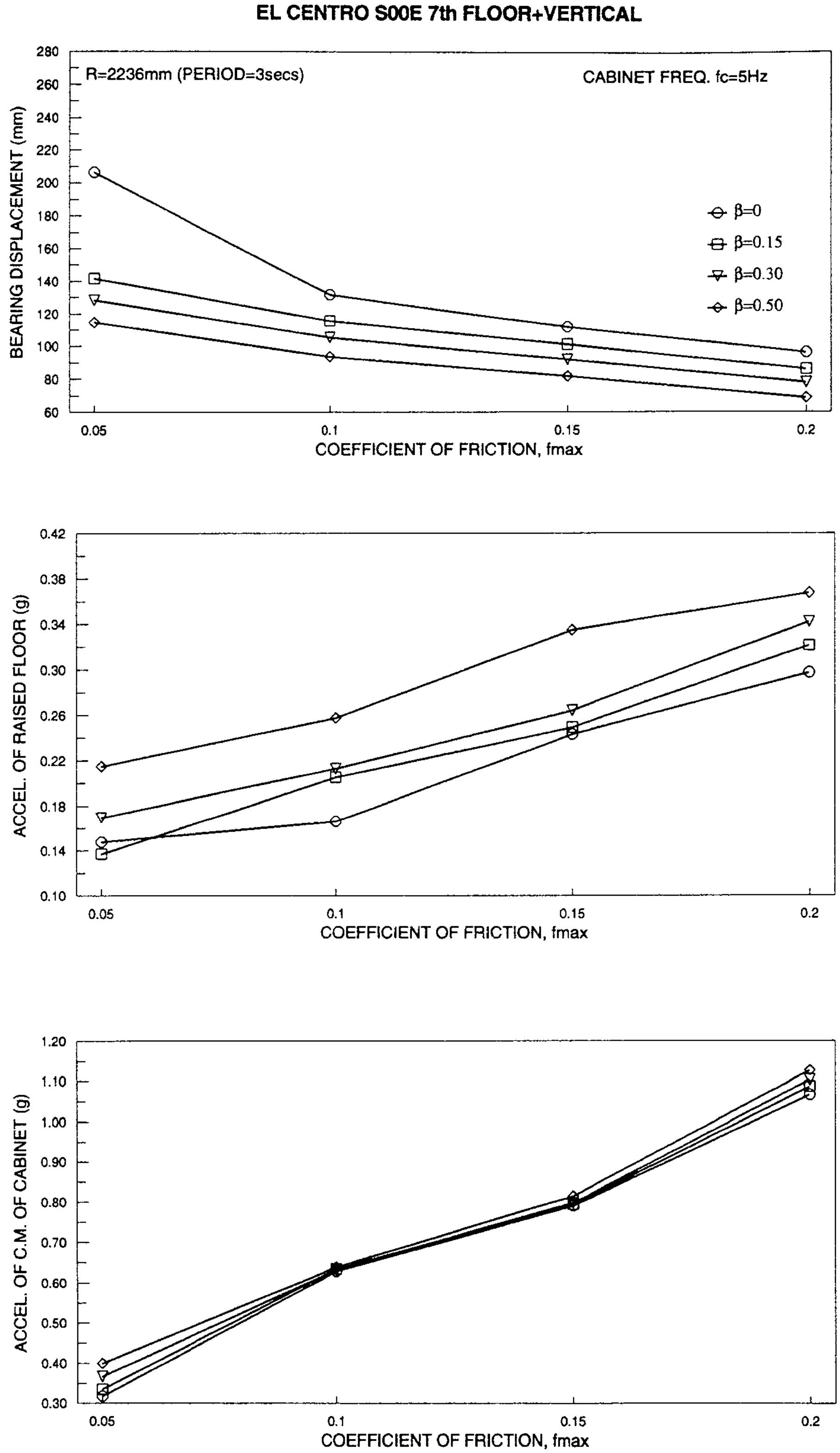


Figure 5-21 Analytical Response of Isolated Floor System with Cabinet of 5 Hz Frequency and Isolation Period of 3.0 secs in El Centro 7th Floor Motion.

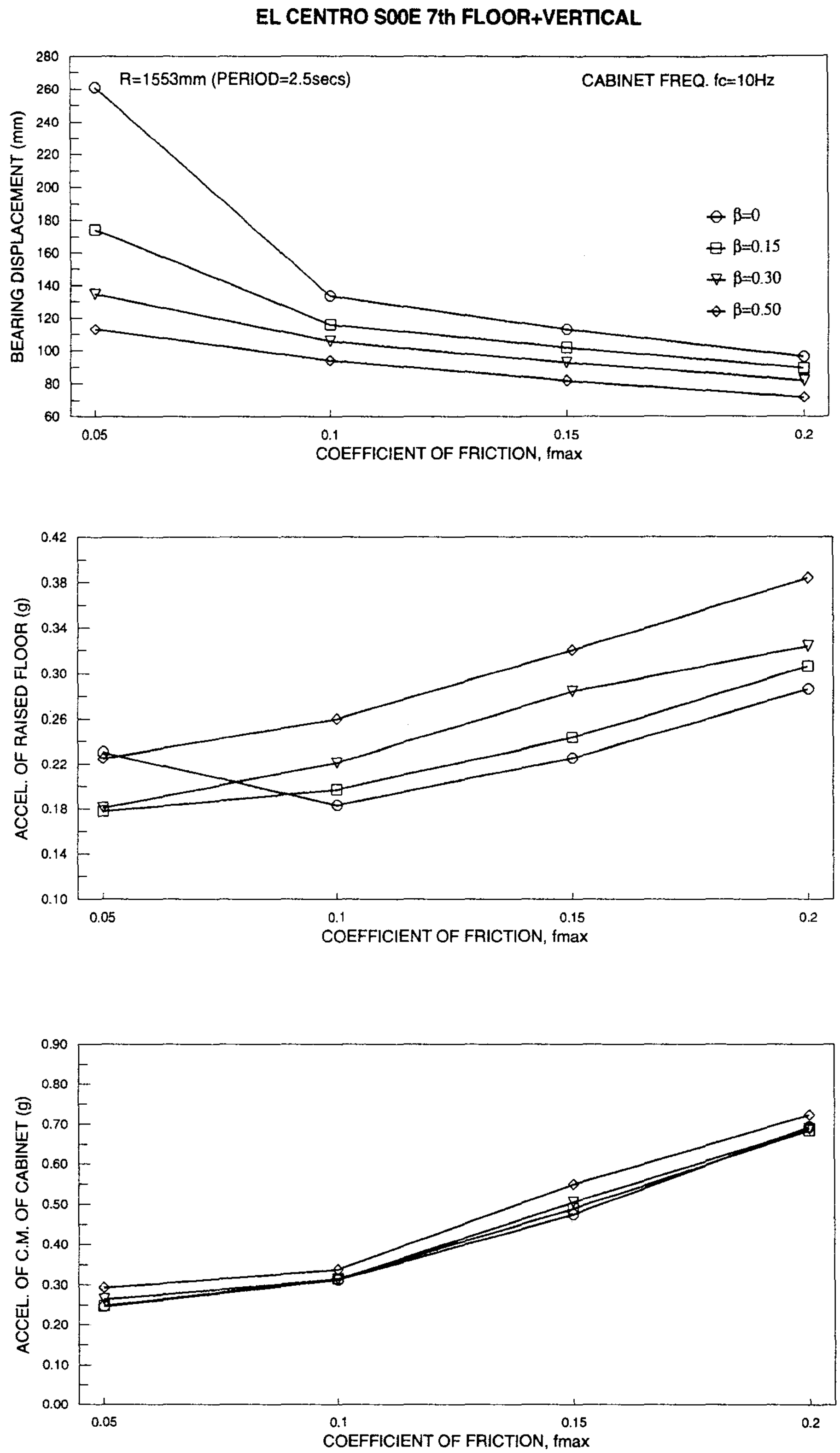


Figure 5-22 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 2.5 secs in El Centro 7th Floor Motion.

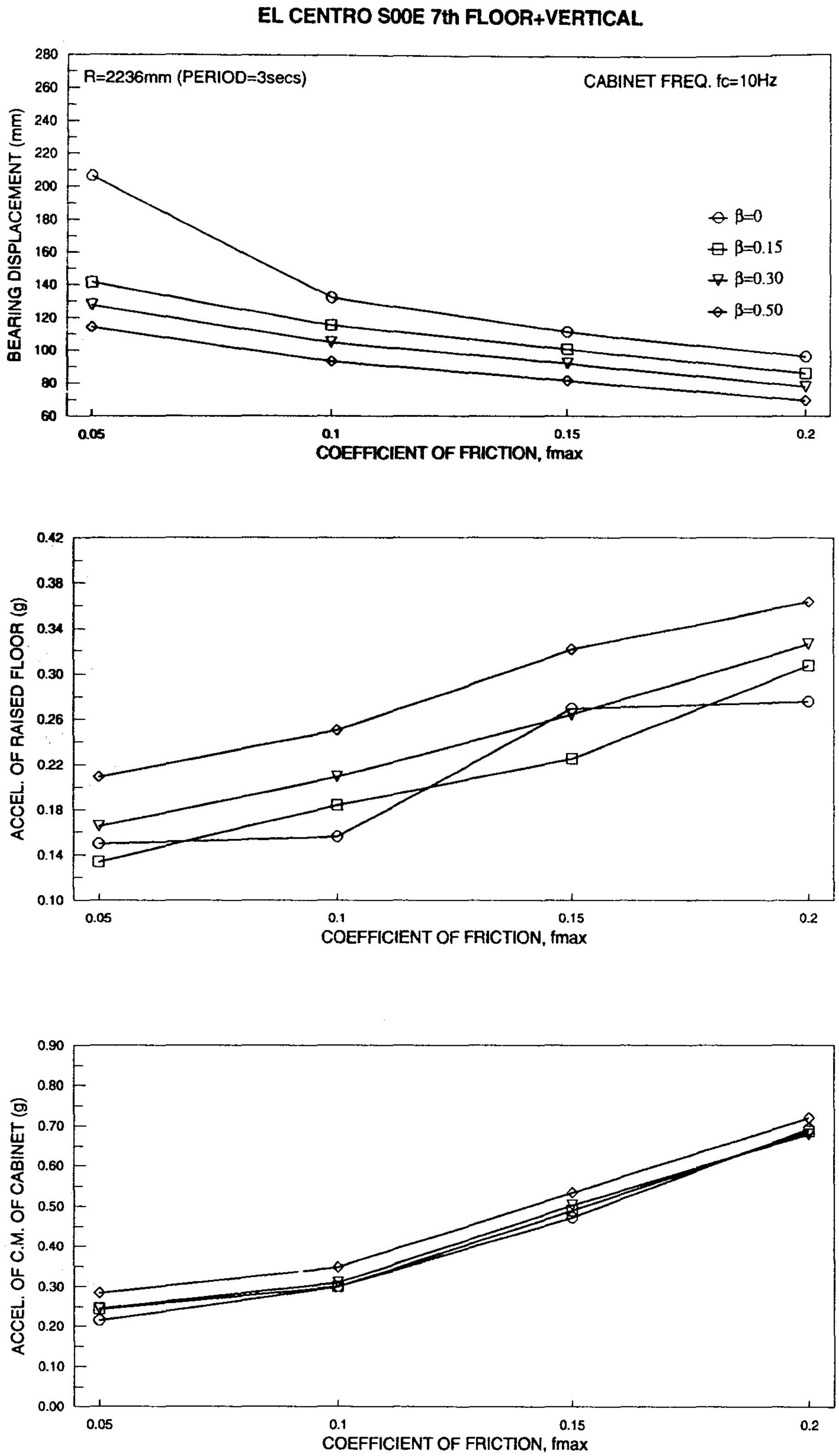


Figure 5-23 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 3.0 secs in El Centro 7th Floor Motion.

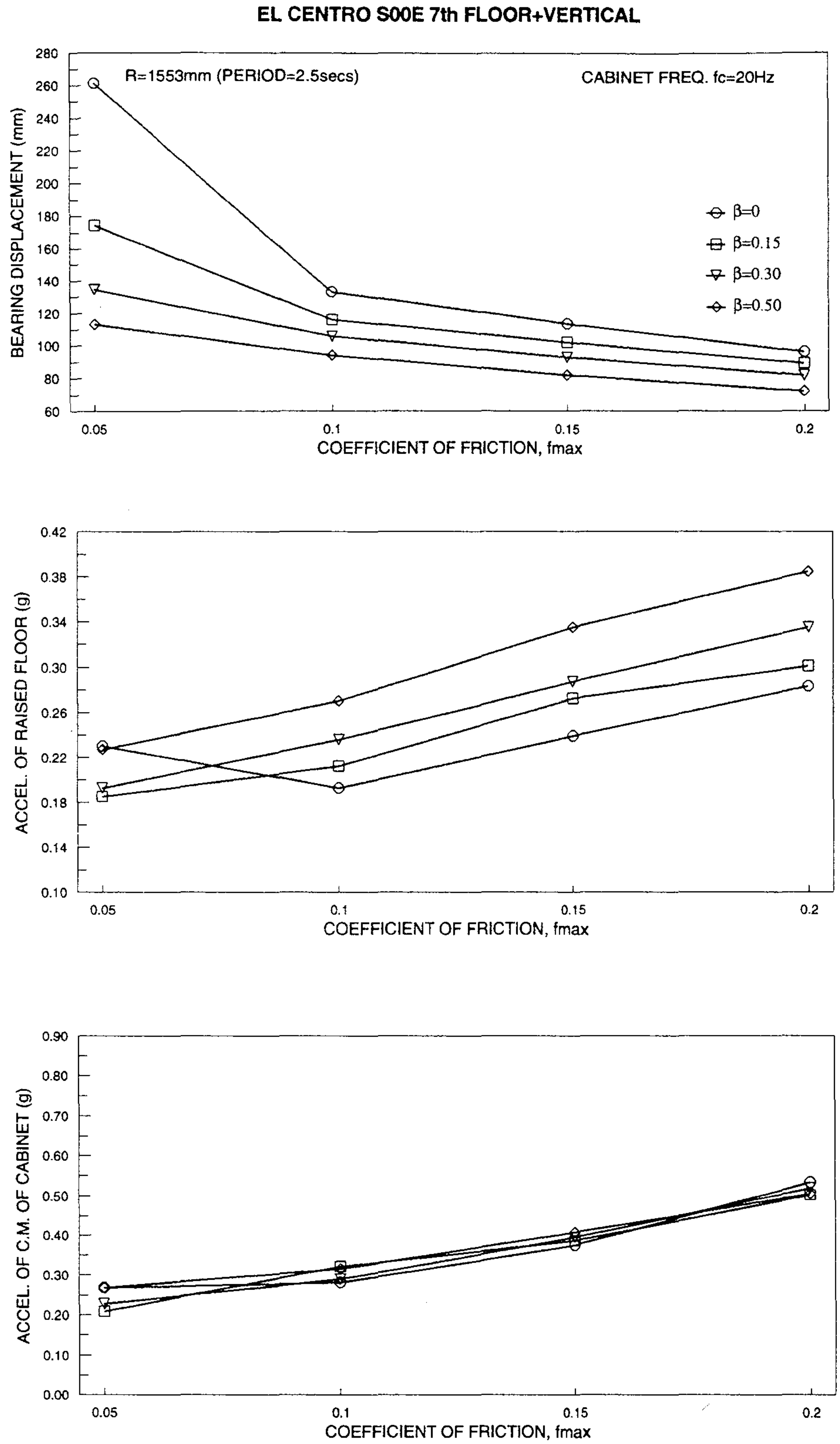


Figure 5-24 Analytical Response of Isolated Floor System with Cabinet of 20 Hz Frequency and Isolation Period of 2.5 secs in El Centro 7th Floor Motion.

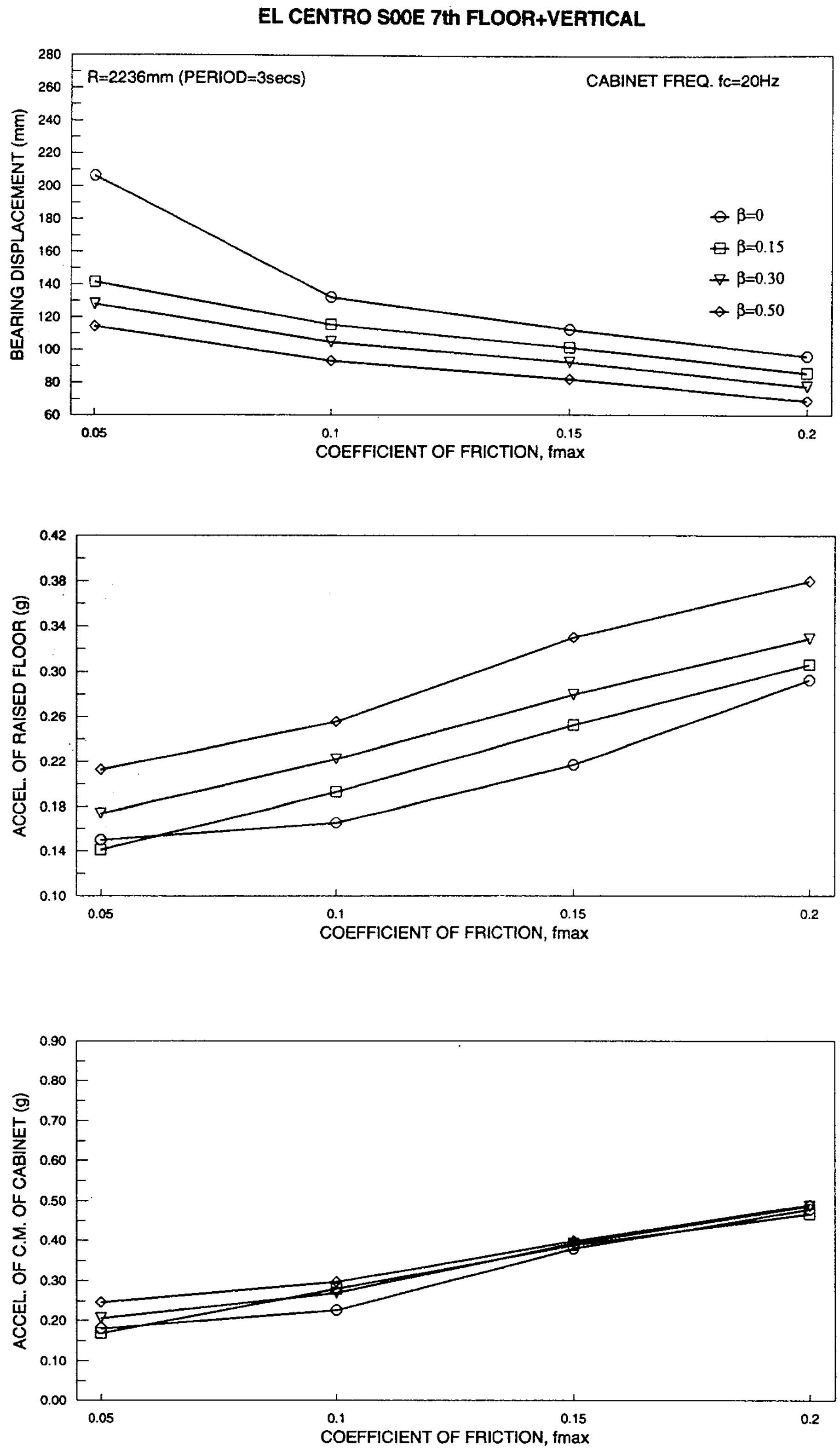


Figure 5-25 Analytical Response of Isolated Floor System with Cabinet of 20 Hz Frequency and Isolation Period of 3.0 secs in El Centro 7th Floor Motion.

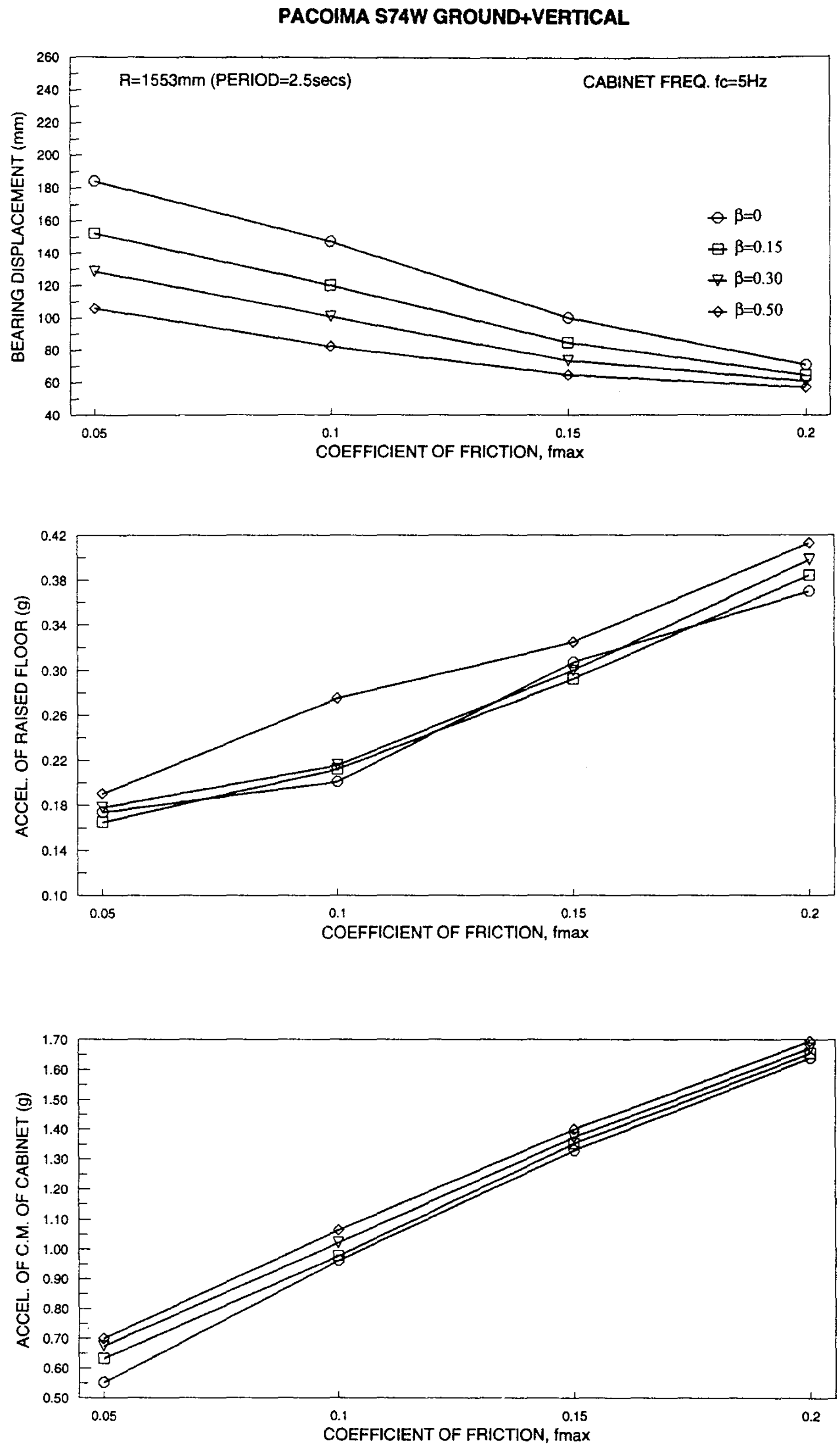


Figure 5-26 Analytical Response of Isolated Floor System with Cabinet of 5 Hz Frequency and Isolation Period of 2.5 secs in Pacoima Dam Ground Motion.

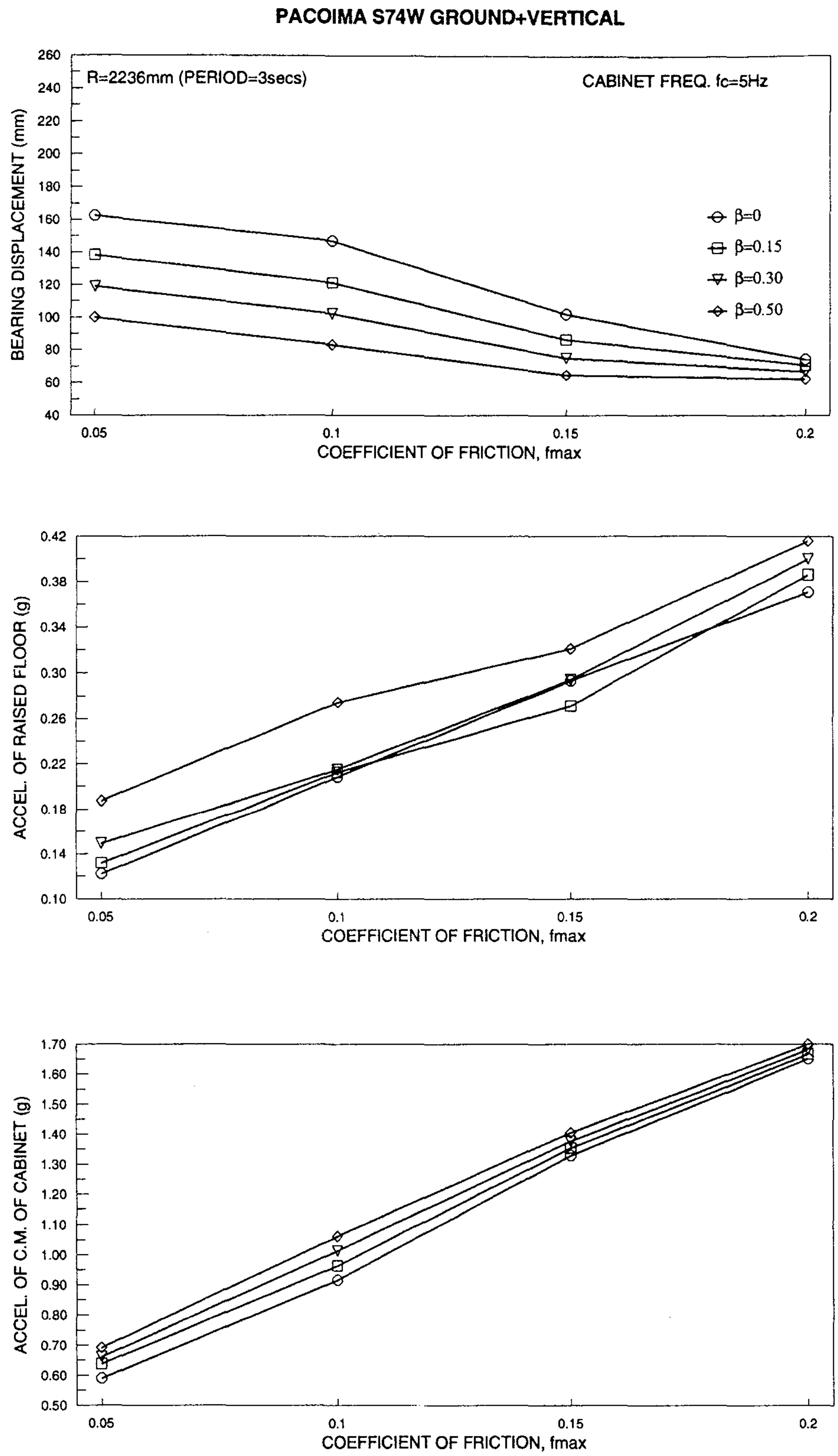


Figure 5-27 Analytical Response of Isolated Floor System with Cabinet of 5 Hz Frequency and Isolation Period of 3.0 secs in Pacoima Dam Ground Motion.

PACOIMA S74W GROUND+VERTICAL

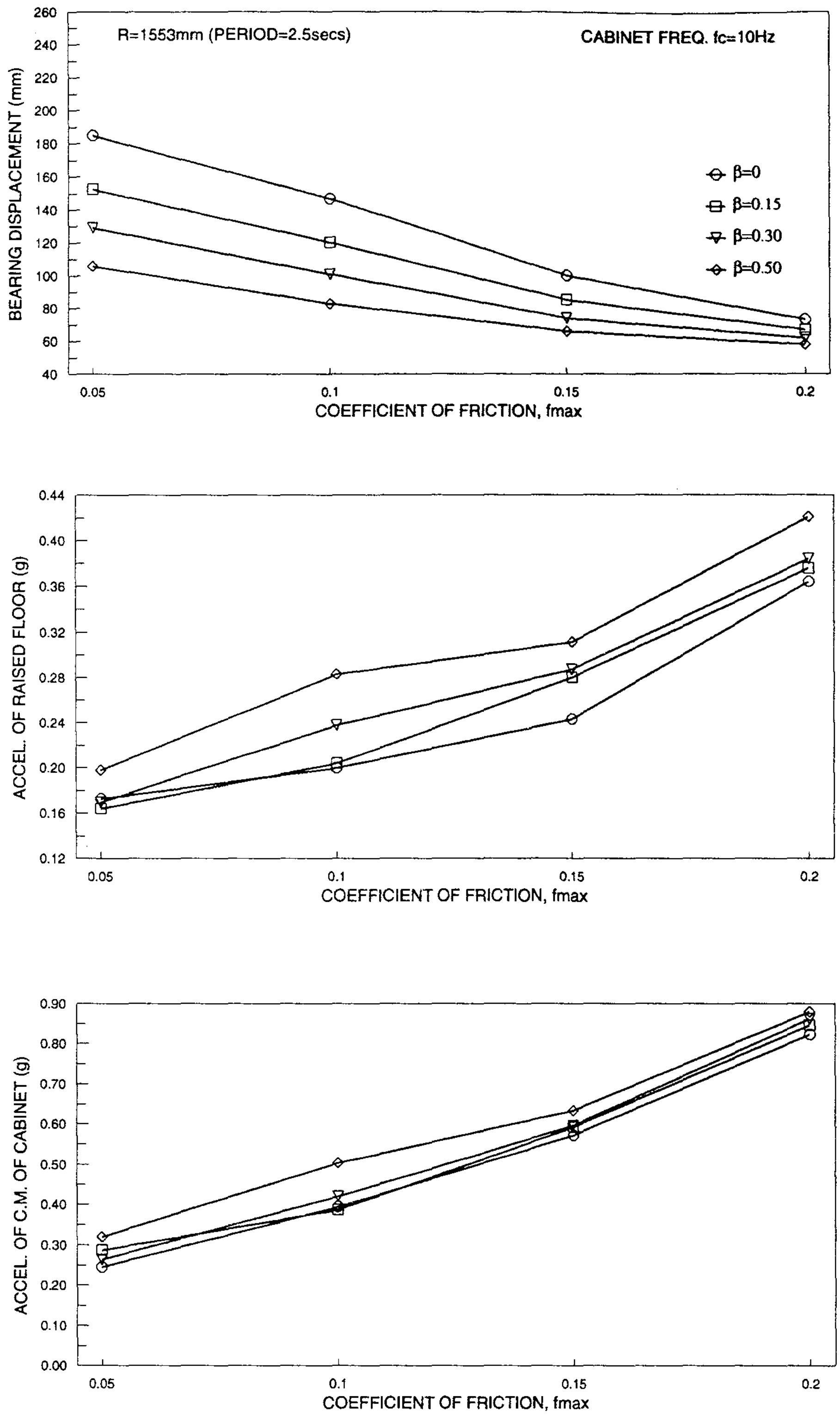


Figure 5-28 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 2.5 secs in Pacoima Dam Ground Motion.

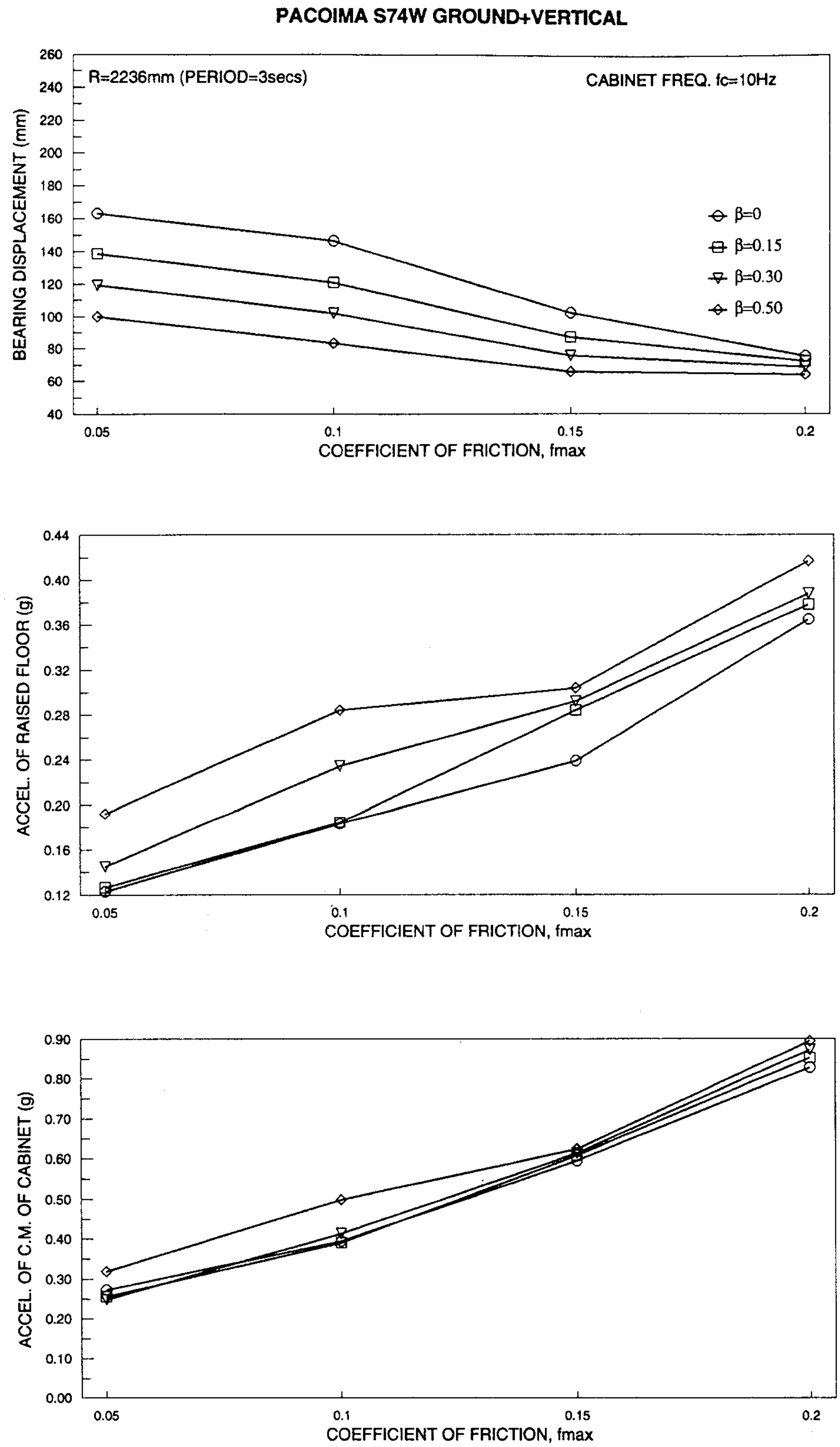


Figure 5-29 Analytical Response of Isolated Floor System with Cabinet of 10 Hz Frequency and Isolation Period of 3.0 secs in Pacoima Dam Ground Motion.

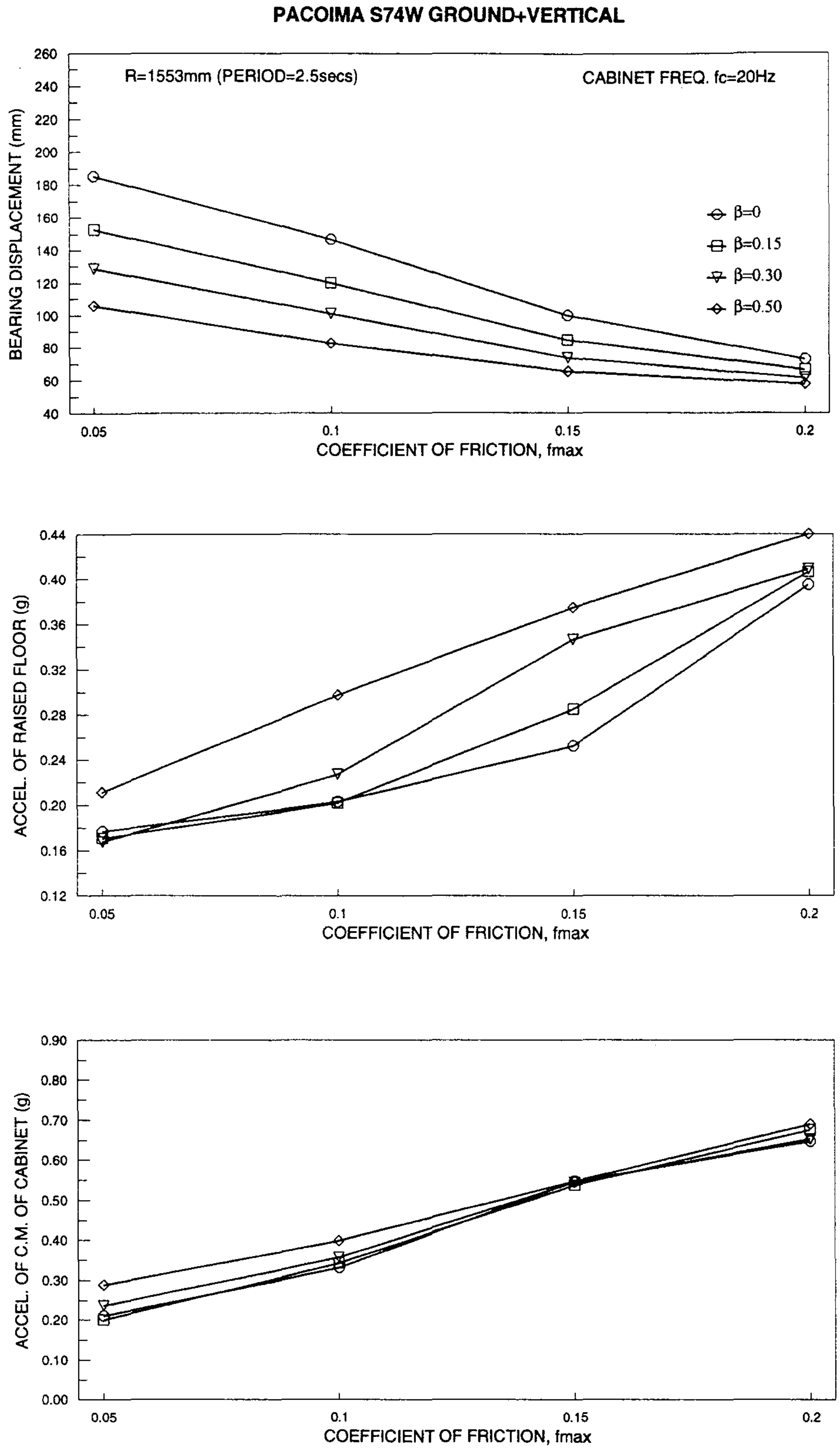


Figure 5-30 Analytical Response of Isolated Floor System with Cabinet of 20 Hz Frequency and Isolation Period of 2.5 secs in Pacoima Dam Ground Motion.

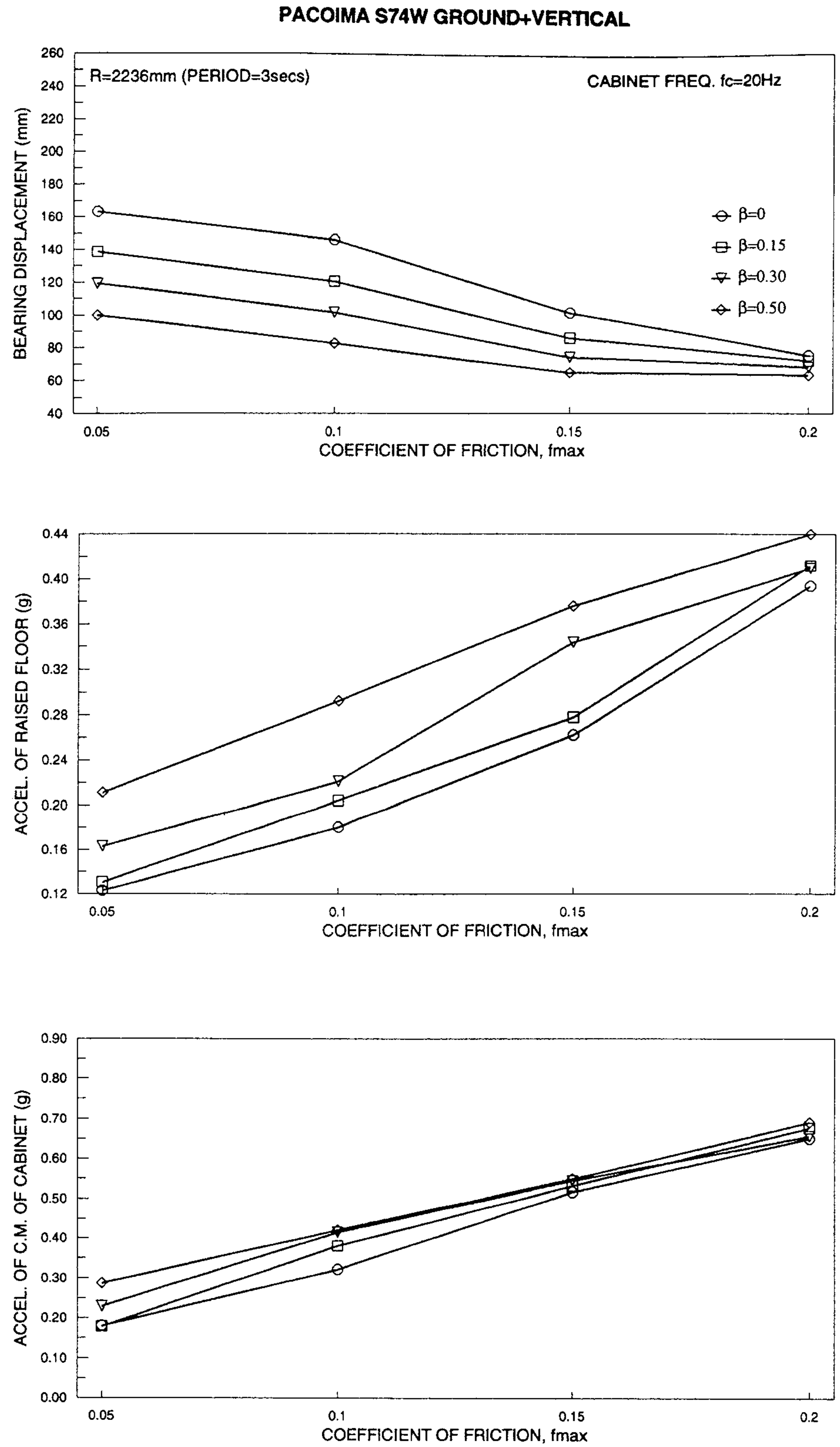
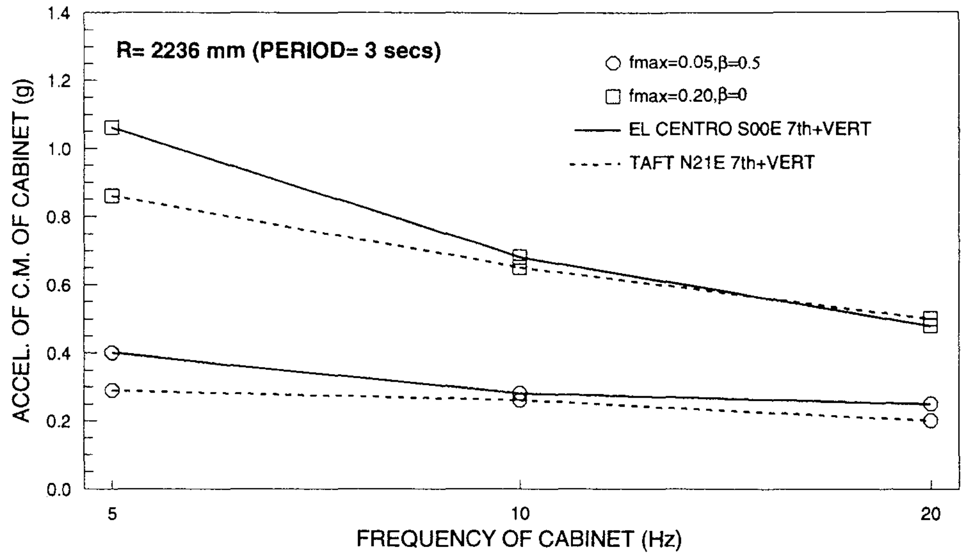


Figure 5-31 Analytical Response of Isolated Floor System with Cabinet of 20 Hz Frequency and Isolation Period of 3.0 secs in Pacoima Dam Ground Motion.



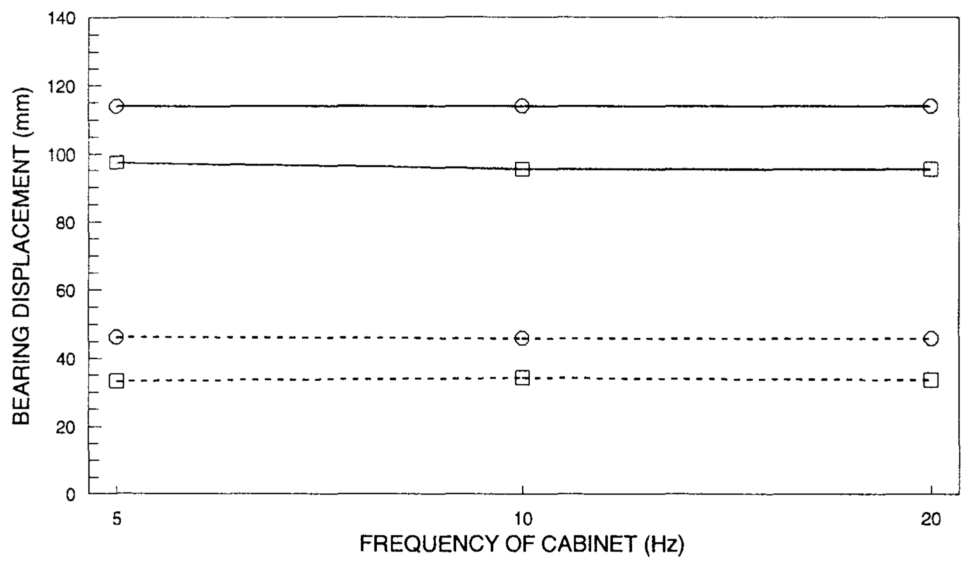


Figure 5-32 Comparison of Response of Floor System Isolated by High Friction and by a Combination of Low Friction and High Viscous Damping Isolation Systems.

SECTION 6

SUMMARY AND CONCLUSIONS

Interruption or failure of data processing systems in an earthquake may result in chaos and substantial economic loss. Seismic design provisions for buildings do not intend to limit damage or maintain function of such systems. Available options for the owner are seismic isolation of the entire building, innovative installation of single equipment or seismic isolation of computer floors. The first two have been the subject of many studies. This study concentrated on the development and testing of a computer floor system.

The studied system consisted of spherically shaped sliding bearings and fluid viscous dampers. The spherically shaped bearings provided the simplest means of achieving long isolation period without bearing instability problems. For the testing, Friction Pendulum (or FPS) bearings were used. In one tested configuration, only high friction FPS bearings were used. In two other configurations, lower friction FPS bearings and fluid viscous dampers were used. All configurations were characterized by substantial ability to dissipate energy. However, in the two configurations with fluid viscous dampers, high frictional damping was exchanged by a combination of lower frictional damping and viscous damping in an attempt to further reduce the acceleration response.

An analytical model of the tested system was developed and shown to be capable of predicting the experimental results with good accuracy. The model was then utilized to extend the experimental results over a range of parameters which could not be experimentally evaluated.

The experimental and analytical results demonstrated substantial reductions in the response of a generic computer cabinet on top of the isolated floor. Under non-isolated conditions the tested cabinet underwent rocking and developed accelerations which could cause either interruption of operation or failure. In contrast, the cabinet on the isolated floor with long isolation period (about 3 secs) did not experience rocking and developed substantially less acceleration.

It was concluded that a floor isolation system with spherically shaped bearings of isolation period of about 3 secs and, dynamic coefficient of friction of about 0.05 and fluid viscous dampers providing damping ratio of 50 % of critical was the most effective. This system resulted in the lowest acceleration response of the computer cabinet, which was also insensitive to the dynamic characteristics of the cabinet. In contrast, a high friction system resulted in high accelerations, which were also dependent on the dynamic characteristics of the cabinet.

Bearing displacements were found to be small. For the most successful long period - low friction - high viscous damping system, this displacement did not exceed 120 mm for the used seismic motions. This low value has been the result of high energy dissipation capability of the isolation system.

SECTION 7

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APPENDIX A

EXPERIMENTAL RESULTS

This Appendix contains the peak recorded response of the isolated and nonisolated floor system in each test. The reported quantities were obtained from the measurements of the instruments listed in the following table.

Table A-I : Recorded Quantity and Corresponding Instrument(s).

Acceleration Quantity	Instrument(s)	Displacement Quantity	Instrument(s)
Table Horizontal	ABLH	Table Horizontal	DBLC
Raised Floor Horizontal	ARFH	Bearing Horizontal	average(DBSW,DBSE,DBNW,DBNE)
Cabinet Level 1 (C.M.) Horizontal	ACMH	Raised Floor Horizontal	DRFW
Cabinet Level 2 Horizontal	AC2H	Cabinet C.M. Horizontal W.R.T. Raised Floor	DCMW-DRFW
Cabinet Level 3 Horizontal	AC3H	Cabinet Top Horizontal W.R.T. Raised Floor	DCTW-DRFW
Cabinet Top Horizontal	ACTH		
Table Vertical	ABLV		
Raised Floor Vertical	ARFV		
Cabinet Top Vertical	max(ACSV,ACNV)		

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E GROUND			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (--)	0.157 (0.163)	0.157 (--)
Raised Floor Horizontal	-- (--)	-- (--)	0.136 (0.154)	0.205 (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (--)	0.171 (0.144)	0.273 (--)
Cabinet Level 2 Horizontal	-- (--)	-- (--)	0.235 (0.188)	0.242 (--)
Cabinet Level 3 Horizontal	-- (--)	-- (--)	0.255 (0.256)	0.363 (--)
Cabinet Top Horizontal	-- (--)	-- (--)	0.248 (0.191)	0.303 (--)
Table Vertical	-- (--)	-- (--)	0.034 (0.125)	0.020 (--)
Raised Floor Vertical	-- (--)	-- (--)	0.046 (0.144)	0.026 (--)
Cabinet Top Vertical	-- (--)	-- (--)	0.075 (0.166)	0.063 (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (--)	31.318 (31.852)	31.902 (--)
Bearing Horizontal	-- (--)	-- (--)	5.309 (5.486)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (--)	32.963 (32.506)	31.712 (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	1.702 (1.005)	1.510 (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	2.210 (1.956)	2.235 (--)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E GROUND			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.160 (0.169)	0.175 (0.163)	0.157 (0.153)	0.159 (0.164)
Raised Floor Horizontal	0.147 (0.182)	0.135 (0.182)	0.130 (0.178)	0.272 (0.269)
Cabinet Level 1 (C.M.) Horizontal	0.183 (0.204)	0.146 (0.138)	0.149 (0.141)	0.303 (0.262)
Cabinet Level 2 Horizontal	0.212 (0.255)	0.179 (0.200)	0.186 (0.233)	0.268 (0.292)
Cabinet Level 3 Horizontal	0.298 (0.312)	0.233 (0.244)	0.247 (0.245)	0.361 (0.347)
Cabinet Top Horizontal	0.246 (0.307)	0.222 (0.210)	0.231 (0.213)	0.411 (0.365)
Table Vertical	0.033 (0.148)	0.028 (0.116)	0.030 (0.118)	0.034 (0.151)
Raised Floor Vertical	0.033 (0.146)	0.029 (0.115)	0.030 (0.124)	0.030 (0.167)
Cabinet Top Vertical	0.073 (0.188)	0.069 (0.196)	0.058 (0.218)	0.117 (0.202)
DISPLACEMENT (mm)				
Table Horizontal	22.225 (22.377)	22.047 (22.276)	22.631 (22.250)	22.200 (22.352)
Bearing Horizontal	6.452 (3.175)	3.734 (5.131)	3.404 (3.277)	N/A (N/A)
Raised Floor Horizontal	22.257 (22.314)	22.524 (22.720)	23.406 (22.511)	22.174 (22.270)
Cabinet C.M. Horizontal W.R.T. Raised Floor	0.784 (1.094)	0.824 (0.905)	0.633 (0.892)	1.500 (1.607)
Cabinet Top Horizontal W.R.T. Raised Floor	1.448 (2.819)	1.118 (1.651)	1.194 (1.778)	2.337 (2.997)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E GROUND			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.159 (0.171)	0.158 (0.155)	0.152 (0.147)	0.154 (0.162)
Raised Floor Horizontal	0.229 (0.230)	0.122 (0.133)	0.116 (0.152)	0.237 (0.279)
Cabinet Level 1 (C.M.) Horizontal	0.236 (0.218)	0.154 (0.159)	0.196 (0.190)	0.257 (0.269)
Cabinet Level 2 Horizontal	0.267 (0.241)	0.194 (0.196)	0.237 (0.257)	0.248 (0.292)
Cabinet Level 3 Horizontal	0.368 (0.387)	0.268 (0.258)	0.253 (0.261)	0.402 (0.414)
Cabinet Top Horizontal	0.295 (0.302)	0.230 (0.222)	0.296 (0.302)	0.353 (0.375)
Table Vertical	0.035 (0.142)	0.036 (0.115)	0.033 (0.124)	0.049 (0.133)
Raised Floor Vertical	0.046 (0.136)	0.039 (0.139)	0.028 (0.137)	0.036 (0.136)
Cabinet Top Vertical	0.077 (0.231)	0.081 (0.237)	0.060 (0.274)	0.130 (0.226)
DISPLACEMENT (mm)				
Table Horizontal	17.374 (17.526)	17.348 (17.424)	17.323 (17.450)	17.399 (17.450)
Bearing Horizontal	1.702 (2.565)	3.099 (4.648)	2.515 (2.362)	N/A (N/A)
Raised Floor Horizontal	17.482 (17.361)	18.028 (17.729)	17.837 (17.571)	17.336 (17.278)
Cabinet C.M. Horizontal W.R.T. Raised Floor	1.194 (1.287)	0.656 (0.938)	0.548 (0.932)	1.456 (1.638)
Cabinet Top Horizontal W.R.T. Raised Floor	1.178 (2.413)	1.168 (1.905)	1.219 (1.956)	2.184 (2.489)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E GROUND			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.149 (0.162)	-- (--)	0.155 (0.161)	0.153 (0.158)
Raised Floor Horizontal	0.203 (0.263)	-- (--)	0.121 (0.162)	0.251 (0.268)
Cabinet Level 1 (C.M.) Horizontal	0.218 (0.204)	-- (--)	0.190 (0.191)	0.275 (0.298)
Cabinet Level 2 Horizontal	0.260 (0.276)	-- (--)	0.233 (0.293)	0.209 (0.232)
Cabinet Level 3 Horizontal	0.344 (0.384)	-- (--)	0.328 (0.331)	0.389 (0.416)
Cabinet Top Horizontal	0.312 (0.322)	-- (--)	0.280 (0.326)	0.376 (0.353)
Table Vertical	0.048 (0.137)	-- (--)	-- (--)	0.046 (0.137)
Raised Floor Vertical	-- (--)	-- (--)	0.028 (0.154)	0.042 (0.127)
Cabinet Top Vertical	0.116 (0.301)	-- (--)	0.076 (0.284)	0.117 (0.185)
DISPLACEMENT (mm)				
Table Horizontal	14.427 (14.427)	-- (--)	14.199 (14.249)	13.919 (14.300)
Bearing Horizontal	0.914 (3.048)	-- (--)	1.397 (1.524)	N/A (N/A)
Raised Floor Horizontal	14.421 (14.345)	-- (--)	14.580 (14.389)	14.300 (14.319)
Cabinet C.M. Horizontal W.R.T. Raised Floor	0.857 (1.119)	-- (--)	0.614 (1.049)	1.989 (1.254)
Cabinet Top Horizontal W.R.T. Raised Floor	1.549 (2.286)	-- (--)	1.372 (1.778)	2.692 (2.667)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 5th FLOOR			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (0.295)	0.303 (0.295)	0.295 (--)
Raised Floor Horizontal	-- (--)	-- (0.248)	0.230 (0.246)	0.402 (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.247)	0.245 (0.253)	0.418 (--)
Cabinet Level 2 Horizontal	-- (--)	-- (0.278)	0.260 (0.333)	0.348 (--)
Cabinet Level 3 Horizontal	-- (--)	-- (0.337)	0.303 (0.293)	0.463 (--)
Cabinet Top Horizontal	-- (--)	-- (0.281)	0.307 (0.314)	0.494 (--)
Table Vertical	-- (--)	-- (0.140)	0.072 (0.148)	0.083 (--)
Raised Floor Vertical	-- (--)	-- (0.171)	0.148 (0.171)	0.095 (--)
Cabinet Top Vertical	-- (--)	-- (0.249)	0.137 (0.236)	0.174 (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (42.697)	42.672 (42.520)	42.723 (--)
Bearing Horizontal	-- (--)	-- (18.237)	19.304 (20.574)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (42.056)	41.764 (41.929)	42.659 (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (1.788)	1.351 (1.597)	3.312 (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (2.667)	1.854 (2.413)	4.394 (--)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 5th FLOOR			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.268 (0.269)	0.265 (0.256)	0.262 (0.257)	0.275 (0.281)
Raised Floor Horizontal	0.238 (0.281)	0.228 (0.245)	0.201 (0.216)	0.344 (0.369)
Cabinet Level 1 (C.M.) Horizontal	0.303 (0.310)	0.238 (0.228)	0.215 (0.217)	0.395 (0.356)
Cabinet Level 2 Horizontal	0.352 (0.393)	0.281 (0.320)	0.269 (0.335)	0.360 (0.454)
Cabinet Level 3 Horizontal	0.378 (0.392)	0.346 (0.367)	0.311 (0.338)	0.572 (0.502)
Cabinet Top Horizontal	0.438 (0.465)	0.315 (0.370)	0.278 (0.378)	0.440 (0.442)
Table Vertical	0.098 (0.151)	0.090 (0.143)	0.103 (0.153)	0.103 (0.146)
Raised Floor Vertical	0.070 (0.142)	0.046 (0.116)	0.045 (0.126)	0.067 (0.132)
Cabinet Top Vertical	0.148 (0.327)	0.109 (0.242)	0.111 (0.294)	0.142 (0.259)
DISPLACEMENT (mm)				
Table Horizontal	23.851 (23.952)	23.749 (23.851)	23.774 (23.851)	23.952 (23.851)
Bearing Horizontal	8.611 (7.925)	11.481 (11.760)	12.192 (11.811)	N/A (N/A)
Raised Floor Horizontal	24.048 (23.705)	24.162 (23.876)	23.946 (23.870)	23.838 (23.844)
Cabinet C.M. Horizontal W.R.T. Raised Floor	1.629 (1.697)	1.367 (1.400)	1.080 (1.367)	3.026 (2.597)
Cabinet Top Horizontal W.R.T. Raised Floor	2.743 (3.683)	1.880 (2.337)	1.727 (2.083)	4.394 (4.775)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 5th FLOOR			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.273 (0.273)	0.277 (0.284)	0.267 (0.278)	0.268 (0.263)
Raised Floor Horizontal	0.328 (0.341)	0.224 (0.251)	0.213 (0.253)	0.456 (0.367)
Cabinet Level 1 (C.M.) Horizontal	0.318 (0.338)	0.228 (0.227)	0.219 (0.235)	0.504 (0.381)
Cabinet Level 2 Horizontal	0.367 (0.410)	0.317 (0.307)	0.291 (0.323)	0.384 (0.443)
Cabinet Level 3 Horizontal	0.508 (0.538)	0.383 (0.380)	0.348 (0.355)	0.739 (0.747)
Cabinet Top Horizontal	0.455 (0.432)	0.342 (0.304)	0.336 (0.358)	0.647 (0.457)
Table Vertical	0.095 (0.152)	0.083 (0.139)	0.080 (0.133)	0.094 (0.163)
Raised Floor Vertical	0.076 (0.494)	0.062 (0.134)	0.054 (0.147)	0.191 (0.163)
Cabinet Top Vertical	0.159 (0.282)	0.143 (0.263)	0.136 (0.329)	0.270 (0.248)
DISPLACEMENT (mm)				
Table Horizontal	18.288 (18.364)	18.390 (18.339)	18.186 (18.263)	18.263 (18.237)
Bearing Horizontal	6.350 (6.401)	9.017 (9.220)	7.620 (7.772)	N/A (N/A)
Raised Floor Horizontal	18.256 (18.155)	18.637 (18.587)	18.466 (18.364)	18.167 (11.722)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.332 (2.364)	1.557 (1.608)	1.072 (1.294)	3.934 (3.281)
Cabinet Top Horizontal W.R.T. Raised Floor	3.658 (4.470)	2.489 (2.870)	2.032 (2.184)	6.299 (4.877)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 5th FLOOR			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.276 (0.277)	-- (--)	0.283 (0.286)	0.275 (0.273)
Raised Floor Horizontal	0.273 (0.286)	-- (--)	0.242 (0.272)	0.496 (0.452)
Cabinet Level 1 (C.M.) Horizontal	0.312 (0.345)	-- (--)	0.251 (0.255)	0.570 (0.534)
Cabinet Level 2 Horizontal	0.353 (0.425)	-- (--)	0.313 (0.341)	0.398 (0.405)
Cabinet Level 3 Horizontal	0.658 (0.768)	-- (--)	0.426 (0.436)	0.988 (0.997)
Cabinet Top Horizontal	0.400 (0.447)	-- (--)	0.340 (0.378)	0.646 (0.588)
Table Vertical	0.082 (0.145)	-- (--)	-- (--)	0.142 (0.223)
Raised Floor Vertical	-- (--)	-- (--)	0.046 (0.148)	0.144 (0.220)
Cabinet Top Vertical	0.144 (0.340)	-- (--)	0.111 (0.298)	0.300 (0.406)
DISPLACEMENT (mm)				
Table Horizontal	14.935 (15.138)	-- (--)	14.884 (14.834)	15.011 (14.910)
Bearing Horizontal	4.801 (5.791)	-- (--)	5.867 (5.740)	N/A (N/A)
Raised Floor Horizontal	15.005 (14.897)	-- (--)	15.107 (14.986)	14.961 (14.942)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.213 (2.611)	-- (--)	1.359 (1.405)	4.440 (3.923)
Cabinet Top Horizontal W.R.T. Raised Floor	3.327 (4.597)	-- (--)	2.210 (2.769)	7.290 (6.604)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 7th FLOOR			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (0.527)	0.525 (0.527)	0.542 (0.554)
Raised Floor Horizontal	-- (--)	-- (0.371)	0.317 (0.312)	0.789 (0.870)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.341)	0.335 (0.318)	0.544 (0.548)
Cabinet Level 2 Horizontal	-- (--)	-- (0.418)	0.396 (0.424)	0.942 (0.933)
Cabinet Level 3 Horizontal	-- (--)	-- (0.446)	0.462 (0.443)	0.923 (0.972)
Cabinet Top Horizontal	-- (--)	-- (0.408)	0.449 (0.454)	0.930 (1.035)
Table Vertical	-- (--)	-- (0.146)	0.101 (0.144)	0.117 (0.188)
Raised Floor Vertical	-- (--)	-- (0.224)	0.130 (0.172)	0.671 (0.607)
Cabinet Top Vertical	-- (--)	-- (0.243)	0.145 (0.219)	0.653 (0.648)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (53.823)	53.518 (53.594)	53.797 (53.823)
Bearing Horizontal	-- (--)	-- (31.293)	34.569 (36.068)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (51.257)	49.492 (48.463)	53.594 (53.531)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (3.377)	1.910 (2.181)	9.600 (9.735)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (4.648)	2.667 (3.023)	15.367 (16.256)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 7th FLOOR			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.477 (0.487)	0.456 (0.464)	0.452 (0.452)	0.490* (0.498)*
Raised Floor Horizontal	0.271 (0.303)	0.323 (0.369)	0.295 (0.347)	1.150 (1.409)
Cabinet Level 1 (C.M.) Horizontal	0.317 (0.311)	0.319 (0.324)	0.274 (0.270)	0.570 (0.585)
Cabinet Level 2 Horizontal	0.443 (0.463)	0.350 (0.369)	0.333 (0.381)	1.168 (1.248)
Cabinet Level 3 Horizontal	0.500 (0.505)	0.489 (0.477)	0.402 (0.379)	1.035 (1.030)
Cabinet Top Horizontal	0.499 (0.518)	0.326 (0.391)	0.295 (0.376)	1.617 (1.608)
Table Vertical	0.178 (0.199)	0.094 (0.175)	0.103 (0.168)	0.239 (0.256)
Raised Floor Vertical	0.108 (0.173)	0.081 (0.143)	0.117 (0.140)	0.342 (0.329)
Cabinet Top Vertical	0.275 (0.417)	0.209 (0.264)	0.158 (0.289)	1.498 (1.564)
DISPLACEMENT (mm)				
Table Horizontal	29.464 (29.489)	29.337 (29.362)	29.235 (29.312)	29.439 (29.515)
Bearing Horizontal	14.834 (14.834)	18.085 (18.110)	19.787 (19.431)	N/A (N/A)
Raised Floor Horizontal	25.356 (25.749)	25.984 (26.022)	26.994 (25.025)	29.483 (29.477)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.210 (2.078)	2.053 (2.208)	1.634 (1.491)	39.307 (26.816)
Cabinet Top Horizontal W.R.T. Raised Floor	3.581 (4.166)	2.794 (2.997)	2.286 (2.362)	41.504 (38.329)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 7th FLOOR			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.368 (0.384)	0.379 (0.376)	0.367 (0.369)	0.353* (0.357)*
Raised Floor Horizontal	0.368 (0.376)	0.314 (0.318)	0.264 (0.303)	0.934 (0.996)
Cabinet Level 1 (C.M.) Horizontal	0.348 (0.363)	0.289 (0.291)	0.286 (0.274)	0.653 (0.616)
Cabinet Level 2 Horizontal	0.437 (0.474)	0.329 (0.383)	0.355 (0.368)	1.193 (1.091)
Cabinet Level 3 Horizontal	0.854 (0.945)	0.535 (0.587)	0.481 (0.495)	1.298 (1.287)
Cabinet Top Horizontal	0.468 (0.485)	0.387 (0.354)	0.372 (0.380)	1.461 (1.490)
Table Vertical	0.114 (0.174)	0.091 (0.134)	0.098 (0.168)	0.226 (0.309)
Raised Floor Vertical	0.110 (0.533)	0.113 (0.173)	0.080 (0.146)	0.272 (0.308)
Cabinet Top Vertical	0.314 (0.475)	0.249 (0.361)	0.244 (0.377)	1.693 (1.616)
DISPLACEMENT (mm)				
Table Horizontal	19.939 (19.863)	19.964 (19.939)	19.990 (19.990)	19.888 (19.787)
Bearing Horizontal	11.735 (11.862)	13.360 (13.437)	12.878 (12.802)	N/A (N/A)
Raised Floor Horizontal	18.758 (18.625)	19.190 (19.241)	19.107 (19.101)	19.888 (19.825)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.356 (3.127)	2.624 (2.303)	1.735 (1.518)	23.101 (22.830)
Cabinet Top Horizontal W.R.T. Raised Floor	4.928 (5.359)	3.785 (3.810)	2.286 (2.413)	38.862 (38.024)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

TAFT N21E 7th FLOOR			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.414 (0.424)	-- (--)	0.422 (0.412)	0.418* (0.421)*
Raised Floor Horizontal	0.361 (0.375)	-- (--)	0.350 (0.407)	0.915 (0.948)
Cabinet Level 1 (C.M.) Horizontal	0.361 (0.373)	-- (--)	0.273 (0.294)	1.211 (1.116)
Cabinet Level 2 Horizontal	0.408 (0.482)	-- (--)	0.349 (0.494)	0.574 (0.632)
Cabinet Level 3 Horizontal	0.847 (0.893)	-- (--)	0.627 (0.660)	1.192 (1.276)
Cabinet Top Horizontal	0.461 (0.523)	-- (--)	0.378 (0.495)	1.646 (1.560)
Table Vertical	0.144 (0.226)	-- (--)	-- (--)	0.394 (0.424)
Raised Floor Vertical	-- (--)	-- (--)	-- (0.247)	0.514 (0.616)
Cabinet Top Vertical	0.278 (0.488)	-- (--)	0.215 (0.436)	1.767 (1.608)
DISPLACEMENT (mm)				
Table Horizontal	15.240 (15.316)	-- (--)	15.138 (15.113)	15.189 (15.164)
Bearing Horizontal	9.169 (9.423)	-- (--)	8.992 (8.788)	N/A (N/A)
Raised Floor Horizontal	15.399 (15.278)	-- (--)	15.608 (15.437)	15.246 (15.158)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.923 (3.280)	-- (--)	1.834 (1.783)	23.160 (23.689)
Cabinet Top Horizontal W.R.T. Raised Floor	4.394 (4.470)	-- (--)	3.327 (2.997)	41.173 (41.148)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E GROUND			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (--)	0.365 (0.366)	0.388 (--)
Raised Floor Horizontal	-- (--)	-- (--)	0.265 (0.332)	0.730 (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (--)	0.253 (0.342)	0.853 (--)
Cabinet Level 2 Horizontal	-- (--)	-- (--)	0.292 (0.440)	0.526 (--)
Cabinet Level 3 Horizontal	-- (--)	-- (--)	0.395 (0.383)	1.040 (--)
Cabinet Top Horizontal	-- (--)	-- (--)	0.309 (0.445)	0.973 (--)
Table Vertical	-- (--)	-- (--)	0.093 (0.331)	0.191 (--)
Raised Floor Vertical	-- (--)	-- (--)	0.122 (0.387)	0.390 (--)
Cabinet Top Vertical	-- (--)	-- (--)	0.119 (0.747)	0.839 (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (--)	59.360 (59.588)	59.665 (--)
Bearing Horizontal	-- (--)	-- (--)	24.714 (24.333)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (--)	64.021 (63.983)	59.233 (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	1.541 (1.975)	10.249 (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	2.134 (3.581)	16.688 (--)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E GROUND			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.305 (0.329)	0.322 (0.321)	0.316 (0.318)	0.369 (0.352)#
Raised Floor Horizontal	0.293 (0.343)	0.253 (0.355)	0.218 (0.338)	0.728 (0.774)
Cabinet Level 1 (C.M.) Horizontal	0.288 (0.325)	0.256 (0.308)	0.222 (0.292)	0.727 (0.501)
Cabinet Level 2 Horizontal	0.364 (0.420)	0.365 (0.415)	0.288 (0.434)	0.529 (0.587)
Cabinet Level 3 Horizontal	0.418 (0.475)	0.391 (0.431)	0.308 (0.390)	0.717 (0.686)
Cabinet Top Horizontal	0.443 (0.477)	0.360 (0.393)	0.287 (0.355)	0.964 (0.765)
Table Vertical	0.189 (0.234)	0.120 (0.238)	0.126 (0.244)	0.199 (0.341)
Raised Floor Vertical	0.108 (0.253)	0.091 (0.270)	0.090 (0.261)	0.261 (0.363)
Cabinet Top Vertical	0.208 (0.638)	0.207 (0.559)	0.209 (0.687)	0.551 (0.593)
DISPLACEMENT (mm)				
Table Horizontal	42.342 (42.393)	42.189 (42.189)	42.240 (42.215)	42.266 (42.469)
Bearing Horizontal	11.125 (13.868)	10.744 (10.541)	14.199 (14.021)	N/A (N/A)
Raised Floor Horizontal	42.183 (38.049)	42.482 (41.269)	40.437 (39.872)	42.259 (42.450)
Cabinet C.M. Horizontal W.R.T. Raised Floor	1.875 (2.175)	1.583 (1.965)	1.319 (1.697)	7.814 (7.053)
Cabinet Top Horizontal W.R.T. Raised Floor	2.972 (5.258)	2.032 (2.997)	1.803 (3.124)	13.106 (13.157)

= Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E GROUND			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.308 (0.298)	0.296 (0.291)	0.288 (0.286)	0.314 (0.314)
Raised Floor Horizontal	0.321 (0.335)	0.234 (0.262)	0.240 (0.307)	0.829 (0.710)
Cabinet Level 1 (C.M.) Horizontal	0.342 (0.348)	0.205 (0.255)	0.212 (0.222)	0.640 (0.503)
Cabinet Level 2 Horizontal	0.477 (0.512)	0.313 (0.406)	0.328 (0.400)	0.490 (0.705)
Cabinet Level 3 Horizontal	0.553 (0.575)	0.341 (0.403)	0.326 (0.363)	0.874 (0.767)
Cabinet Top Horizontal	0.574 (0.555)	0.328 (0.327)	0.320 (0.343)	0.778 (0.888)
Table Vertical	0.139 (0.208)	0.103 (0.175)	0.109 (0.179)	0.156 (0.233)
Raised Floor Vertical	0.457 (0.500)	0.094 (0.308)	0.078 (0.221)	0.224 (0.255)
Cabinet Top Vertical	0.238 (0.477)	0.121 (0.407)	0.135 (0.530)	0.595 (0.573)
DISPLACEMENT (mm)				
Table Horizontal	33.274 (33.274)	33.147 (33.096)	33.223 (33.249)	33.249 (33.147)
Bearing Horizontal	9.347 (10.719)	8.890 (8.966)	11.151 (10.236)	N/A (N/A)
Raised Floor Horizontal	33.198 (31.540)	33.903 (33.376)	31.153 (32.487)	33.052 (33.033)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.457 (2.665)	1.505 (1.949)	1.229 (1.826)	6.455 (5.636)
Cabinet Top Horizontal W.R.T. Raised Floor	3.708 (4.343)	2.286 (3.124)	1.753 (2.489)	10.414 (9.423)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E GROUND			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.283 (0.287)	-- (--)	0.280 (0.278)	0.286 (0.287)
Raised Floor Horizontal	0.304 (0.307)	-- (--)	0.239 (0.261)	0.738 (0.774)
Cabinet Level 1 (C.M.) Horizontal	0.338 (0.331)	-- (--)	0.248 (0.238)	0.713 (0.692)
Cabinet Level 2 Horizontal	0.440 (0.485)	-- (--)	0.371 (0.414)	0.465 (0.437)
Cabinet Level 3 Horizontal	0.643 (0.632)	-- (--)	0.388 (0.408)	0.954 (0.907)
Cabinet Top Horizontal	0.584 (0.575)	-- (--)	0.373 (0.343)	0.706 (0.782)
Table Vertical	0.188 (0.215)	-- (--)	-- (--)	0.184 (0.258)
Raised Floor Vertical	-- (--)	-- (--)	0.092 (0.192)	0.236 (0.260)
Cabinet Top Vertical	0.236 (0.428)	-- (--)	0.173 (0.501)	0.551 (0.603)
DISPLACEMENT (mm)				
Table Horizontal	27.483 (27.280)	-- (--)	27.280 (27.051)	27.483 (27.356)
Bearing Horizontal	7.417 (8.001)	-- (--)	8.331 (8.484)	N/A (N/A)
Raised Floor Horizontal	27.750 (27.476)	-- (--)	27.394 (26.734)	27.337 (27.508)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.192 (2.207)	-- (--)	1.400 (1.826)	5.912 (6.007)
Cabinet Top Horizontal W.R.T. Raised Floor	3.429 (3.886)	-- (--)	2.007 (2.591)	10.236 (10.922)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 5th FLOOR			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (0.430)	0.430 (0.432)	0.429 (--)
Raised Floor Horizontal	-- (--)	-- (0.374)	0.362 (0.437)	0.556 (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.403)	0.366 (0.436)	0.579 (--)
Cabinet Level 2 Horizontal	-- (--)	-- (0.496)	0.481 (0.538)	0.431 (--)
Cabinet Level 3 Horizontal	-- (--)	-- (0.452)	0.415 (0.456)	0.738 (--)
Cabinet Top Horizontal	-- (--)	-- (0.513)	0.441 (0.561)	0.629 (--)
Table Vertical	-- (--)	-- (0.323)	0.299 (0.319)	0.246 (--)
Raised Floor Vertical	-- (--)	-- (0.528)	0.410 (0.499)	0.383 (--)
Cabinet Top Vertical	-- (--)	-- (0.667)	0.216 (0.777)	0.407 (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (107.772)	107.340 (107.417)	107.772 (--)
Bearing Horizontal	-- (--)	-- (46.355)	65.888 (65.303)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (117.316)	129.997 (129.578)	107.067 (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (3.369)	2.757 (3.145)	7.741 (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (5.385)	3.632 (5.486)	12.802 (--)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 5th FLOOR			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.421 (0.430)	0.424 (0.409)	0.406 (0.409)	0.416* (0.411)*#
Raised Floor Horizontal	0.322 (0.438)	0.405 (0.404)	0.362 (0.458)	1.574 (0.914)
Cabinet Level 1 (C.M.) Horizontal	0.291 (0.372)	0.347 (0.398)	0.311 (0.374)	1.565 (0.635)
Cabinet Level 2 Horizontal	0.479 (0.642)	0.488 (0.555)	0.496 (0.537)	0.865 (1.101)
Cabinet Level 3 Horizontal	0.458 (0.557)	0.451 (0.464)	0.390 (0.474)	1.168 (0.941)
Cabinet Top Horizontal	0.459 (0.571)	0.478 (0.513)	0.431 (0.537)	2.453 (1.471)
Table Vertical	0.347 (0.351)	0.320 (0.329)	0.324 (0.367)	0.315 (0.356)
Raised Floor Vertical	0.209 (0.382)	0.380 (0.469)	0.420 (0.558)	0.475 (0.370)
Cabinet Top Vertical	0.252 (0.763)	0.280 (0.494)	0.201 (0.606)	3.292 (1.249)
DISPLACEMENT (mm)				
Table Horizontal	56.286 (56.159)	56.109 (55.931)	56.159 (55.931)	56.261 (56.210)
Bearing Horizontal	36.297 (36.068)	29.185 (29.235)	39.446 (39.421)	N/A (N/A)
Raised Floor Horizontal	50.933 (51.073)	53.467 (53.086)	53.562 (53.791)	56.166 (56.267)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.259 (2.261)	2.540 (2.613)	2.103 (2.361)	75.754 (75.575)
Cabinet Top Horizontal W.R.T. Raised Floor	2.997 (6.071)	3.023 (4.775)	2.565 (4.369)	134.112 (82.956)

* = Cabinet Rocking Observed
# = Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 5th FLOOR			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.389 (0.398)	0.384 (0.384)	0.374 (0.383)	0.382* (0.392)*
Raised Floor Horizontal	0.331 (0.363)	0.287 (0.296)	0.273 (0.337)	1.525 (1.423)
Cabinet Level 1 (C.M.) Horizontal	0.304 (0.339)	0.300 (0.298)	0.274 (0.288)	1.577 (0.948)
Cabinet Level 2 Horizontal	0.457 (0.530)	0.440 (0.432)	0.377 (0.450)	0.915 (1.533)
Cabinet Level 3 Horizontal	0.472 (0.526)	0.438 (0.431)	0.378 (0.361)	1.067 (1.051)
Cabinet Top Horizontal	0.444 (0.513)	0.340 (0.384)	0.342 (0.380)	2.860 (2.379)
Table Vertical	0.261 (0.325)	0.281 (0.297)	0.241 (0.307)	0.311 (0.308)
Raised Floor Vertical	0.111 (0.508)	0.129 (0.354)	0.113 (0.272)	0.542 (0.645)
Cabinet Top Vertical	0.239 (0.505)	0.253 (0.434)	0.208 (0.516)	3.557 (2.601)
DISPLACEMENT (mm)				
Table Horizontal	43.104 (42.850)	42.774 (42.647)	43.028 (42.697)	43.002 (42.621)
Bearing Horizontal	21.107 (26.772)	23.800 (23.673)	29.032 (29.058)	N/A (N/A)
Raised Floor Horizontal	33.280 (34.341)	38.176 (38.513)	36.601 (36.760)	42.761 (42.596)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.496 (2.605)	2.445 (2.329)	1.697 (1.830)	73.914 (63.275)
Cabinet Top Horizontal W.R.T. Raised Floor	3.353 (4.547)	3.200 (4.064)	2.286 (3.404)	127.457 (116.586)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 5th FLOOR			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.399 (0.397)	-- (--)	0.386 (0.392)	0.395* (0.392)*
Raised Floor Horizontal	0.358 (0.392)	-- (--)	0.240 (0.257)	1.017 (1.160)
Cabinet Level 1 (C.M.) Horizontal	0.338 (0.356)	-- (--)	0.267 (0.288)	1.694 (1.515)
Cabinet Level 2 Horizontal	0.461 (0.474)	-- (--)	0.363 (0.434)	0.757 (0.780)
Cabinet Level 3 Horizontal	0.528 (0.595)	-- (--)	0.421 (0.434)	1.081 (1.076)
Cabinet Top Horizontal	0.484 (0.563)	-- (--)	0.358 (0.452)	2.567 (2.453)
Table Vertical	0.244 (0.304)	-- (--)	-- (--)	0.296 (0.320)
Raised Floor Vertical	-- (--)	-- (--)	0.116 (0.156)	0.466 (0.731)
Cabinet Top Vertical	0.186 (0.457)	-- (--)	0.186 (0.439)	2.948 (2.472)
DISPLACEMENT (mm)				
Table Horizontal	34.823 (34.849)	-- (--)	34.569 (34.519)	34.849 (34.849)
Bearing Horizontal	21.387 (21.336)	-- (--)	23.749 (23.851)	N/A (N/A)
Raised Floor Horizontal	29.128 (30.213)	-- (--)	30.791 (31.325)	34.754 (34.849)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.732 (2.858)	-- (--)	1.719 (1.711)	62.770 (64.140)
Cabinet Top Horizontal W.R.T. Raised Floor	4.166 (4.801)	-- (--)	2.311 (3.073)	109.449 (110.668)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 7th FLOOR			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (--)	0.753* (--)	0.710* (0.706)*
Raised Floor Horizontal	-- (--)	-- (--)	3.729 (--)	1.882 (1.888)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (--)	1.043 (--)	0.825 (0.875)
Cabinet Level 2 Horizontal	-- (--)	-- (--)	2.048 (--)	1.553 (1.676)
Cabinet Level 3 Horizontal	-- (--)	-- (--)	1.348 (--)	1.052 (1.094)
Cabinet Top Horizontal	-- (--)	-- (--)	3.093 (--)	2.284 (2.099)
Table Vertical	-- (--)	-- (--)	1.109 (--)	0.280 (0.287)
Raised Floor Vertical	-- (--)	-- (--)	1.322 (--)	0.694 (0.564)
Cabinet Top Vertical	-- (--)	-- (--)	3.933 (--)	3.091 (2.662)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (--)	131.928 (--)	131.953 (132.080)
Bearing Horizontal	-- (--)	-- (--)	88.79++ (--)	N/A (N/A)
Raised Floor Horizontal	-- (--)	-- (--)	178.092 (--)	131.375 (131.274)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	183.937 (--)	179.557 (205.816)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (--)	248.895 (--)	208.534 (228.778)

* = Cabinet Rocking Observed
++ = Bearing Displacement Capacity Exceeded

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 7th FLOOR			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.839 (0.841)	0.817 (0.816)	0.849 (0.834)	0.846*# (0.818)*#
Raised Floor Horizontal	0.328 (0.422)	0.631 (0.736)	0.474 (0.446)	1.950 (1.837)
Cabinet Level 1 (C.M.) Horizontal	0.380 (0.392)	0.494 (0.606)	0.530 (0.626)	0.843 (1.042)
Cabinet Level 2 Horizontal	0.490 (0.598)	0.657 (0.743)	0.365 (0.428)	1.410 (1.456)
Cabinet Level 3 Horizontal	0.476 (0.625)	0.910 (0.999)	0.465 (0.512)	0.951 (0.996)
Cabinet Top Horizontal	0.538 (0.607)	0.815 (0.790)	0.487 (0.561)	1.898 (1.908)
Table Vertical	0.210 (0.350)	0.237 (0.323)	0.233 (0.353)	0.324 (0.441)
Raised Floor Vertical	0.238 (0.435)	0.499 (0.494)	0.272 (0.386)	0.466 (0.587)
Cabinet Top Vertical	0.301 (0.884)	0.408 (0.618)	0.322 (0.750)	2.145 (2.168)
DISPLACEMENT (mm)				
Table Horizontal	72.949 (71.806)	71.552 (71.577)	71.577 (71.349)	72.187 (72.009)
Bearing Horizontal	59.157 (62.433)	43.967 (50.597)	60.452 (60.198)	N/A (N/A)
Raised Floor Horizontal	73.419 (76.746)	66.231 (66.491)	71.374 (72.403)	72.028 (72.155)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.499 (2.950)	7.033 (66.491)	3.423 (3.354)	133.306 (138.551)
Cabinet Top Horizontal W.R.T. Raised Floor	4.267 (6.172)	10.718 (66.294)	4.445 (5.436)	137.922 (139.065)

* = Cabinet Rocking Observed
\# = Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 7th FLOOR			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.842 (0.826)	0.814 (0.812)	0.808 (0.804)	0.801* (0.874)*
Raised Floor Horizontal	0.403 (0.399)	0.611 (0.609)	0.404 (0.382)	1.693 (2.165)
Cabinet Level 1 (C.M.) Horizontal	0.384 (0.387)	0.512 (0.519)	0.447 (0.482)	0.900 (1.003)
Cabinet Level 2 Horizontal	0.472 (0.548)	0.583 (0.610)	0.315 (0.354)	1.537 (1.735)
Cabinet Level 3 Horizontal	0.553 (0.556)	0.807 (0.799)	0.460 (0.475)	1.270 (1.375)
Cabinet Top Horizontal	0.522 (0.521)	0.528 (0.656)	0.394 (0.398)	2.356 (2.829)
Table Vertical	0.200 (0.264)	0.292 (0.342)	0.209 (0.319)	0.449 (0.341)
Raised Floor Vertical	0.545 (0.583)	0.295 (0.512)	0.229 (0.351)	0.760 (0.520)
Cabinet Top Vertical	0.378 (0.761)	0.365 (0.594)	0.368 (0.603)	4.106 (3.958)
DISPLACEMENT (mm)				
Table Horizontal	53.391 (53.315)	53.137 (53.086)	53.391 (53.086)	53.086 (53.086)
Bearing Horizontal	41.250 (41.681)	32.741 (32.715)	42.596 (42.520)	N/A (N/A)
Raised Floor Horizontal	42.158 (45.199)	45.072 (45.142)	41.548 (42.272)	53.099 (53.289)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.162 (3.161)	4.661 (4.466)	2.396 (2.475)	98.927 (104.697)
Cabinet Top Horizontal W.R.T. Raised Floor	4.648 (5.309)	6.299 (7.112)	3.175 (4.166)	171.602 (180.111)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

EL-CENTRO S00E 7th FLOOR			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.789 (0.764)	-- (--)	0.755 (0.761)	0.713* (0.711)*
Raised Floor Horizontal	0.428 (0.449)	-- (--)	0.384 (0.383)	1.353 (1.377)
Cabinet Level 1 (C.M.) Horizontal	0.382 (0.417)	-- (--)	0.410 (0.383)	1.506 (1.480)
Cabinet Level 2 Horizontal	0.450 (0.572)	-- (--)	0.308 (0.493)	0.733 (0.775)
Cabinet Level 3 Horizontal	0.640 (0.662)	-- (--)	0.487 (0.531)	1.061 (1.086)
Cabinet Top Horizontal	0.503 (0.562)	-- (--)	0.444 (0.516)	2.438 (2.424)
Table Vertical	0.183 (0.232)	-- (--)	0.216 (--)	0.319 (0.357)
Raised Floor Vertical	-- (--)	-- (--)	0.190 (0.279)	0.662 (0.621)
Cabinet Top Vertical	0.325 (0.449)	-- (--)	0.283 (0.477)	3.236 (3.402)
DISPLACEMENT (mm)				
Table Horizontal	42.367 (42.266)	-- (--)	42.316 (42.418)	42.316 (42.367)
Bearing Horizontal	30.658 (32.080)	-- (--)	33.299 (33.426)	N/A (N/A)
Raised Floor Horizontal	32.722 (33.045)	-- (--)	35.192 (34.677)	42.456 (42.393)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.423 (3.446)	-- (--)	2.615 (2.235)	67.678 (67.678)
Cabinet Top Horizontal W.R.T. Raised Floor	5.055 (5.486)	-- (--)	3.150 (4.420)	115.519 (117.297)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

PACOIMA DAM S74W GROUND LENGTH SCALE = 1				
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (1.019)*+	0.990 (1.008)*+	-- (--)
Raised Floor Horizontal	-- (--)	-- (1.297)	0.401 (0.782)	-- (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.812)	0.526 (1.005)	-- (--)
Cabinet Level 2 Horizontal	-- (--)	-- (1.653)	0.392 (0.670)	-- (--)
Cabinet Level 3 Horizontal	-- (--)	-- (1.163)	0.596 (0.954)	-- (--)
Cabinet Top Horizontal	-- (--)	-- (2.402)	0.482 (1.628)	-- (--)
Table Vertical	-- (--)	-- (1.673)	0.182 (1.439)	-- (--)
Raised Floor Vertical	-- (--)	-- (1.056)	0.253 (1.117)	-- (--)
Cabinet Top Vertical	-- (--)	-- (3.511)	0.511 (2.559)	-- (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (104.369)	103.683 (104.597)	-- (--)
Bearing Horizontal	-- (--)	-- (41.427)	57.760 (57.074)	-- (--)
Raised Floor Horizontal	-- (--)	-- (100.838)	106.134 (105.461)	-- (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (53.824)	3.323 (10.128)	-- (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (66.243)	4.953 (15.621)	-- (--)

* = Cabinet Rocking Observed
\+ = Cabinet Uplift Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

PACOIMA DAM S74W GROUND LENGTH SCALE = 2				
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	1.004 (1.017)*+	1.033* (1.024)*+	1.028 (1.049)*+	1.045* (1.043)*+
Raised Floor Horizontal	0.566 (2.281)	1.000 (1.073)	0.471 (1.154)	1.928 (2.217)
Cabinet Level 1 (C.M.) Horizontal	0.425 (0.963)	0.685 (0.680)	0.564 (1.315)	0.895 (1.054)
Cabinet Level 2 Horizontal	0.605 (1.866)	1.179 (1.314)	0.393 (0.747)	1.834 (1.680)
Cabinet Level 3 Horizontal	0.732 (1.300)	0.968 (1.196)	0.829 (1.388)	1.146 (1.913)
Cabinet Top Horizontal	0.647 (2.533)	1.258 (1.947)	0.628 (2.256)	3.049 (2.669)
Table Vertical	0.328 (1.513)	0.279 (1.677)	0.365 (1.682)	0.513 (1.426)
Raised Floor Vertical	0.315 (1.271)	0.628 (1.067)	0.480 (1.038)	2.700 (1.133)
Cabinet Top Vertical	0.429 (3.749)	1.246 (2.911)	0.494 (3.633)	3.587 (2.983)
DISPLACEMENT (mm)				
Table Horizontal	55.016 (55.728)	54.915 (55.677)	55.169 (55.728)	54.966 (55.702)
Bearing Horizontal	34.823 (33.249)	29.566 (30.683)	39.776 (39.014)	N/A (N/A)
Raised Floor Horizontal	57.341 (56.109)	54.521 (54.115)	57.868 (55.950)	54.839 (53.473)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.150 (27.857)	14.051 (54.123)	4.283 (16.553)	39.805 (49.363)
Cabinet Top Horizontal W.R.T. Raised Floor	4.724 (35.255)	23.851 (54.102)	6.452 (23.749)	56.617 (79.553)

* = Cabinet Rocking Observed
+ = Cabinet Uplift Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

PACOIMA DAM S74W GROUND			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.832 (0.860)*+	0.858 (0.877)*+	0.841 (0.868)*+	0.887* (0.895)*+
Raised Floor Horizontal	0.525 (1.200)	0.904 (0.979)	0.520 (0.863)	1.833 (2.305)
Cabinet Level 1 (C.M.) Horizontal	0.472 (0.856)	0.553 (0.671)	0.671 (1.179)	0.757 (1.020)
Cabinet Level 2 Horizontal	0.689 (1.591)	1.024 (1.263)	0.458 (0.620)	1.009 (1.809)
Cabinet Level 3 Horizontal	0.981 (1.754)	1.018 (1.439)	0.903 (1.383)	1.388 (1.712)
Cabinet Top Horizontal	0.752 (2.017)	1.228 (1.993)	0.682 (1.713)	1.774 (2.700)
Table Vertical	0.322 (1.218)	0.353 (1.421)	0.398 (1.341)	0.396 (1.453)
Raised Floor Vertical	0.645 (1.457)	0.451 (1.210)	0.467 (1.323)	0.383 (1.681)
Cabinet Top Vertical	0.462 (2.754)	0.864 (2.996)	0.542 (2.849)	2.143 (3.477)
DISPLACEMENT (mm)				
Table Horizontal	37.821 (38.481)	37.897 (38.481)	37.719 (38.379)	37.694 (38.202)
Bearing Horizontal	23.825 (22.047)	23.673 (22.301)	29.362 (29.083)	N/A (N/A)
Raised Floor Horizontal	41.269 (37.433)	36.043 (35.859)	37.783 (37.230)	37.586 (35.839)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.437 (24.436)	8.325 (13.572)	3.459 (9.981)	28.764 (47.985)
Cabinet Top Horizontal W.R.T. Raised Floor	4.953 (35.281)	12.294 (22.631)	5.258 (18.491)	44.272 (62.611)

* = Cabinet Rocking Observed
+ = Cabinet Uplift Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

PACOIMA DAM S74W GROUND			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.842 (0.827)*+	-- (--)	0.781 (0.801)*+	0.785* (0.794)*+
Raised Floor Horizontal	0.548 (1.304)	-- (--)	0.532 (0.712)	1.542 (1.967)
Cabinet Level 1 (C.M.) Horizontal	0.434 (0.867)	-- (--)	0.571 (1.268)	1.577 (1.535)
Cabinet Level 2 Horizontal	0.736 (1.651)	-- (--)	0.378 (0.701)	0.833 (0.957)
Cabinet Level 3 Horizontal	0.825 (1.484)	-- (--)	0.841 (1.184)	1.256 (1.430)
Cabinet Top Horizontal	0.762 (1.824)	-- (--)	0.514 (1.369)	1.997 (2.064)
Table Vertical	0.314 (1.192)	-- (--)	0.345 (1.041)	0.477 (1.224)
Raised Floor Vertical	-- (--)	-- (--)	0.286 (0.963)	0.703 (1.189)
Cabinet Top Vertical	0.762 (3.002)	-- (--)	0.530 (2.445)	2.034 (2.247)
DISPLACEMENT (mm)				
Table Horizontal	29.007 (29.743)	-- (--)	29.032 (29.667)	29.134 (29.820)
Bearing Horizontal	17.145 (18.847)	-- (--)	22.022 (21.768)	N/A (N/A)
Raised Floor Horizontal	30.715 (26.753)	-- (--)	25.781 (27.184)	29.185 (28.099)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.199 (18.450)	-- (--)	3.096 (9.300)	18.958 (21.020)
Cabinet Top Horizontal W.R.T. Raised Floor	5.004 (29.870)	-- (--)	4.140 (16.154)	34.874 (33.604)

* = Cabinet Rocking Observed
+ = Cabinet Uplift Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet .
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

BELLCORE			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (0.906)*	0.869 (0.873)	-- (--)
Raised Floor Horizontal	-- (--)	-- (1.065)	0.456 (0.459)	-- (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.827)	0.425 (0.383)	-- (--)
Cabinet Level 2 Horizontal	-- (--)	-- (1.521)	0.395 (0.512)	-- (--)
Cabinet Level 3 Horizontal	-- (--)	-- (1.254)	0.629 (0.605)	-- (--)
Cabinet Top Horizontal	-- (--)	-- (2.218)	0.485 (0.592)	-- (--)
Table Vertical	-- (--)	-- (0.325)	0.134 (0.333)	-- (--)
Raised Floor Vertical	-- (--)	-- (0.542)	0.178 (0.427)	-- (--)
Cabinet Top Vertical	-- (--)	-- (2.454)	0.225 (0.473)	-- (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (58.979)	58.903 (58.979)	-- (--)
Bearing Horizontal	-- (--)	-- (54.000)	73.787 (72.695)	-- (--)
Raised Floor Horizontal	-- (--)	-- (56.629)	56.159 (55.264)	-- (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (49.197)	4.764 (6.244)	-- (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (74.778)	6.325 (9.068)	-- (--)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

BELLCORE			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	1.025 (1.032)	1.069 (1.057)	1.042 (1.031)	1.069* (1.062)*#
Raised Floor Horizontal	0.433 (0.412)	0.750 (0.693)	0.360 (0.357)	2.208 (2.089)
Cabinet Level 1 (C.M.) Horizontal	0.420 (0.426)	0.718 (0.701)	0.394 (0.434)	0.809 (0.903)
Cabinet Level 2 Horizontal	0.486 (0.571)	0.971 (0.903)	0.317 (0.356)	1.568 (1.696)
Cabinet Level 3 Horizontal	0.752 (0.788)	1.164 (1.181)	0.544 (0.542)	1.215 (1.239)
Cabinet Top Horizontal	0.560 (0.592)	1.228 (1.069)	0.385 (0.493)	2.263 (2.396)
Table Vertical	0.179 (0.337)	0.221 (0.373)	0.203 (0.372)	0.283 (0.384)
Raised Floor Vertical	0.163 (0.347)	0.510 (0.464)	0.239 (0.364)	0.622 (2.258)
Cabinet Top Vertical	0.316 (0.594)	0.869 (0.943)	0.279 (0.536)	2.613 (3.069)
DISPLACEMENT (mm)				
Table Horizontal	30.734 (30.709)	30.607 (30.505)	30.683 (30.810)	30.886 (30.861)
Bearing Horizontal	46.457 (46.660)	28.296 (36.601)	36.525 (38.837)	N/A (N/A)
Raised Floor Horizontal	31.668 (36.297)	25.616 (25.495)	24.949 (25.375)	30.994 (31.071)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.910 (4.177)	13.873 (25.487)	3.167 (3.388)	117.483 (97.198)
Cabinet Top Horizontal W.R.T. Raised Floor	5.385 (7.137)	24.232 (25.502)	4.140 (4.115)	121.564 (110.744)

* = Cabinet Rocking Observed
# = Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

BELLCORE			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	1.009 (1.016)	1.055 (1.039)	1.005 (1.014)	1.031* (1.041)*#
Raised Floor Horizontal	0.467 (0.494)	0.652 (0.519)	0.412 (0.374)	1.820 (1.921)
Cabinet Level 1 (C.M.) Horizontal	0.463 (0.455)	0.592 (0.579)	0.416 (0.418)	1.093 (0.987)
Cabinet Level 2 Horizontal	0.659 (0.624)	0.779 (0.732)	0.327 (0.326)	1.427 (1.399)
Cabinet Level 3 Horizontal	0.805 (0.866)	0.889 (0.973)	0.638 (0.712)	1.188 (1.235)
Cabinet Top Horizontal	0.668 (0.670)	0.927 (0.823)	0.430 (0.477)	2.262 (2.181)
Table Vertical	0.164 (0.353)	0.187 (0.363)	0.142 (0.362)	0.292 (0.399)
Raised Floor Vertical	0.533 (0.709)	0.224 (0.535)	0.260 (0.378)	1.125 (0.881)
Cabinet Top Vertical	0.321 (0.776)	0.658 (0.592)	0.273 (0.605)	2.481 (2.649)
DISPLACEMENT (mm)				
Table Horizontal	20.498 (20.676)	20.523 (20.777)	20.371 (20.853)	20.676 (20.955)
Bearing Horizontal	31.648 (33.503)	21.590 (23.089)	25.349 (27.203)	N/A (N/A)
Raised Floor Horizontal	19.158 (26.238)	16.256 (18.256)	16.186 (17.196)	21.298 (21.152)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.891 (3.969)	7.342 (6.812)	3.334 (3.158)	67.782 (55.491)
Cabinet Top Horizontal W.R.T. Raised Floor	5.334 (6.553)	11.405 (10.262)	4.597 (4.064)	97.892 (98.069)

* = Cabinet Rocking Observed
# = Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

BELLCORE			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.972 (0.984)	-- (--)	1.005 (0.996)	1.077* (1.070)*
Raised Floor Horizontal	0.528 (0.601)	-- (--)	0.425 (0.435)	1.946 (1.761)
Cabinet Level 1 (C.M.) Horizontal	0.457 (0.507)	-- (--)	0.414 (0.439)	1.305 (1.463)
Cabinet Level 2 Horizontal	0.733 (0.779)	-- (--)	0.323 (0.317)	0.915 (0.932)
Cabinet Level 3 Horizontal	0.914 (1.013)	-- (--)	0.658 (0.728)	1.392 (1.239)
Cabinet Top Horizontal	0.775 (0.805)	-- (--)	0.429 (0.540)	2.364 (2.140)
Table Vertical	0.153 (0.359)	-- (--)	0.153 (0.372)	0.329 (0.458)
Raised Floor Vertical	-- (--)	-- (--)	0.183 (0.377)	0.558 (0.749)
Cabinet Top Vertical	0.407 (0.753)	-- (--)	0.308 (0.637)	2.361 (2.317)
DISPLACEMENT (mm)				
Table Horizontal	15.240 (15.570)	-- (--)	15.240 (15.570)	15.494 (15.926)
Bearing Horizontal	24.917 (25.908)	-- (--)	18.720 (20.320)	N/A (N/A)
Raised Floor Horizontal	15.850 (20.447)	-- (--)	10.967 (12.878)	16.415 (16.478)
Cabinet C.M. Horizontal W.R.T. Raised Floor	4.394 (4.485)	-- (--)	3.369 (2.959)	68.732 (36.614)
Cabinet Top Horizontal W.R.T. Raised Floor	6.401 (7.315)	-- (--)	4.801 (3.785)	106.020 (66.167)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 1			LENGTH SCALE = 1	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	-- (--)	-- (0.424)	0.429 (0.426)	-- (--)
Raised Floor Horizontal	-- (--)	-- (0.380)	0.356 (0.348)	-- (--)
Cabinet Level 1 (C.M.) Horizontal	-- (--)	-- (0.374)	0.351 (0.336)	-- (--)
Cabinet Level 2 Horizontal	-- (--)	-- (0.396)	0.396 (0.370)	-- (--)
Cabinet Level 3 Horizontal	-- (--)	-- (0.441)	0.422 (0.411)	-- (--)
Cabinet Top Horizontal	-- (--)	-- (0.432)	0.380 (0.366)	-- (--)
Table Vertical	-- (--)	-- (0.201)	0.075 (0.214)	-- (--)
Raised Floor Vertical	-- (--)	-- (0.179)	0.123 (0.204)	-- (--)
Cabinet Top Vertical	-- (--)	-- (0.209)	0.180 (0.227)	-- (--)
DISPLACEMENT (mm)				
Table Horizontal	-- (--)	-- (55.626)	55.550 (55.524)	-- (--)
Bearing Horizontal	-- (--)	-- (40.996)	61.493 (60.046)	-- (--)
Raised Floor Horizontal	-- (--)	-- (54.223)	55.016 (55.239)	-- (--)
Cabinet C.M. Horizontal W.R.T. Raised Floor	-- (--)	-- (2.378)	2.597 (2.319)	-- (--)
Cabinet Top Horizontal W.R.T. Raised Floor	-- (--)	-- (5.258)	3.581 (5.207)	-- (--)

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 1			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.426 (0.432)	0.427 (0.425)	0.426 (0.437)	0.432* (0.423)*
Raised Floor Horizontal	0.310 (0.301)	0.349 (0.367)	0.283 (0.289)	1.209 (1.208)
Cabinet Level 1 (C.M.) Horizontal	0.350 (0.355)	0.316 (0.318)	0.257 (0.265)	0.848 (0.846)
Cabinet Level 2 Horizontal	0.399 (0.408)	0.363 (0.420)	0.291 (0.326)	1.576 (1.579)
Cabinet Level 3 Horizontal	0.561 (0.567)	0.514 (0.505)	0.373 (0.358)	1.117 (1.088)
Cabinet Top Horizontal	0.485 (0.466)	0.352 (0.389)	0.307 (0.350)	2.184 (2.293)
Table Vertical	0.063 (0.170)	0.077 (0.181)	0.084 (0.177)	0.206 (0.266)
Raised Floor Vertical	0.048 (0.154)	0.061 (0.164)	0.069 (0.151)	0.476 (0.453)
Cabinet Top Vertical	0.108 (0.220)	0.151 (0.237)	0.117 (0.211)	2.773 (2.992)
DISPLACEMENT (mm)				
Table Horizontal	28.143 (28.245)	28.016 (28.143)	28.042 (28.143)	28.321 (28.296)
Bearing Horizontal	31.394 (29.413)	24.790 (27.102)	30.988 (29.489)	N/A (N/A)
Raised Floor Horizontal	33.414 (33.528)	29.489 (30.067)	28.969 (29.636)	28.169 (28.251)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.561 (2.550)	2.494 (30.067)	1.576 (1.543)	82.493 (81.280)
Cabinet Top Horizontal W.R.T. Raised Floor	3.810 (5.080)	3.302 (30.048)	2.108 (3.277)	132.029 (131.699)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 1		LENGTH SCALE = 3		
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.440 (0.440)	0.417 (0.423)	0.417 (0.415)	0.445* (0.445)*
Raised Floor Horizontal	0.372 (0.365)	0.328 (0.326)	0.282 (0.287)	1.145 (1.082)
Cabinet Level 1 (C.M.) Horizontal	0.364 (0.376)	0.281 (0.269)	0.254 (0.253)	0.788 (0.761)
Cabinet Level 2 Horizontal	0.466 (0.491)	0.326 (0.344)	0.320 (0.326)	1.454 (1.478)
Cabinet Level 3 Horizontal	0.643 (0.693)	0.523 (0.516)	0.428 (0.414)	1.247 (1.296)
Cabinet Top Horizontal	0.461 (0.496)	0.346 (0.331)	0.317 (0.336)	2.019 (2.173)
Table Vertical	0.055 (0.168)	0.071 (0.179)	0.066 (0.176)	0.167 (0.259)
Raised Floor Vertical	0.421 (0.536)	0.132 (0.220)	0.086 (0.191)	0.733 (0.814)
Cabinet Top Vertical	0.138 (0.231)	0.131 (0.219)	0.145 (0.220)	2.420 (2.299)
DISPLACEMENT (mm)				
Table Horizontal	18.974 (19.025)	18.872 (18.898)	18.771 (18.923)	18.796 (18.923)
Bearing Horizontal	19.914 (18.644)	20.295 (20.726)	20.676 (21.438)	N/A (N/A)
Raised Floor Horizontal	20.993 (21.768)	20.504 (21.171)	20.053 (20.873)	18.777 (18.904)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.499 (3.594)	2.592 (2.605)	1.473 (1.557)	44.064 (45.401)
Cabinet Top Horizontal W.R.T. Raised Floor	5.207 (5.258)	3.607 (3.734)	2.108 (2.718)	75.870 (77.800)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 1			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.456 (0.461)	-- (--)	0.441 (0.446)	0.439* (0.451)*
Raised Floor Horizontal	0.347 (0.374)	-- (--)	0.292 (0.317)	1.073 (1.066)
Cabinet Level 1 (C.M.) Horizontal	0.371 (0.388)	-- (--)	0.273 (0.267)	1.281 (1.369)
Cabinet Level 2 Horizontal	0.452 (0.536)	-- (--)	0.330 (0.379)	0.634 (0.648)
Cabinet Level 3 Horizontal	0.776 (0.774)	-- (--)	0.489 (0.490)	1.111 (1.095)
Cabinet Top Horizontal	0.463 (0.481)	-- (--)	0.368 (0.413)	1.798 (1.851)
Table Vertical	0.066 (0.168)	-- (--)	-- (--)	0.146 (0.272)
Raised Floor Vertical	-- (--)	-- (--)	0.098 (0.187)	0.482 (0.482)
Cabinet Top Vertical	0.150 (0.280)	-- (--)	0.160 (0.262)	1.951 (1.768)
DISPLACEMENT (mm)				
Table Horizontal	14.275 (14.148)	-- (--)	14.046 (13.995)	14.275 (14.122)
Bearing Horizontal	15.189 (14.656)	-- (--)	16.383 (17.018)	N/A (N/A)
Raised Floor Horizontal	15.596 (18.307)	-- (--)	15.151 (15.831)	14.135 (14.218)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.686 (3.181)	-- (--)	1.640 (1.756)	33.350 (36.467)
Cabinet Top Horizontal W.R.T. Raised Floor	5.690 (4.953)	-- (--)	2.337 (2.743)	58.039 (60.401)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 2			LENGTH SCALE = 2	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.910 (0.918)	0.911 (0.920)	0.963 (1.075)	0.950* (0.963)*
Raised Floor Horizontal	0.351 (0.408)	0.889 (0.737)	0.416 (0.480)	2.278 (2.043)
Cabinet Level 1 (C.M.) Horizontal	0.345 (0.370)	0.682 (0.640)	0.391 (0.465)	1.088 (1.169)
Cabinet Level 2 Horizontal	0.476 (0.494)	0.923 (0.937)	0.442 (0.642)	2.010 (2.048)
Cabinet Level 3 Horizontal	0.608 (0.657)	1.023 (1.108)	0.552 (0.548)	1.305 (1.413)
Cabinet Top Horizontal	0.476 (0.513)	0.993 (1.045)	0.428 (0.624)	2.717 (3.194)
Table Vertical	0.152 (0.386)	0.187 (0.378)	0.199 (0.512)	0.341 (0.395)
Raised Floor Vertical	0.151 (0.327)	0.350 (0.447)	0.227 (0.545)	-- (3.279)
Cabinet Top Vertical	0.267 (0.491)	0.742 (0.808)	0.506 (0.824)	3.935 (3.779)
DISPLACEMENT (mm)				
Table Horizontal	46.685 (46.888)	46.482 (46.736)	46.533 (46.584)	46.584 (46.711)
Bearing Horizontal	75.895 (73.482)	51.156 (50.902)	63.805 (64.973)	N/A (N/A)
Raised Floor Horizontal	59.804 (58.579)	48.222 (45.333)	43.548 (45.491)	46.584 (46.698)
Cabinet C.M. Horizontal W.R.T. Raised Floor	2.889 (3.153)	10.620 (8.471)	2.499 (3.069)	158.582 (151.798)
Cabinet Top Horizontal W.R.T. Raised Floor	4.953 (7.544)	17.043 (13.640)	3.810 (4.191)	190.348 (171.806)

* = Cabinet Rocking Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 2			LENGTH SCALE = 3	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.934 (0.928)	0.946 (0.945)	0.929 (0.942)	0.968* (0.978)*#
Raised Floor Horizontal	0.346 (0.442)	0.648 (0.662)	0.423 (0.469)	2.243 (2.557)
Cabinet Level 1 (C.M.) Horizontal	0.380 (0.417)	0.565 (0.718)	0.350 (0.388)	0.955 (0.910)
Cabinet Level 2 Horizontal	0.459 (0.567)	0.756 (0.954)	0.473 (0.565)	1.642 (1.725)
Cabinet Level 3 Horizontal	0.656 (0.611)	0.951 (1.068)	0.575 (0.597)	1.242 (1.314)
Cabinet Top Horizontal	0.473 (0.551)	0.815 (0.889)	0.405 (0.494)	2.685 (3.090)
Table Vertical	0.198 (0.347)	0.208 (0.379)	0.198 (0.383)	0.372 (0.471)
Raised Floor Vertical	0.507 (0.686)	0.327 (0.761)	0.213 (0.385)	1.667 (1.928)
Cabinet Top Vertical	0.317 (0.581)	0.543 (0.776)	0.254 (0.656)	3.348 (3.730)
DISPLACEMENT (mm)				
Table Horizontal	31.496 (31.445)	31.471 (31.420)	31.267 (31.318)	31.344 (31.547)
Bearing Horizontal	55.524 (52.832)	36.271 (35.509)	41.707 (42.520)	N/A (N/A)
Raised Floor Horizontal	42.761 (42.793)	30.258 (29.445)	28.702 (28.848)	31.560 (31.528)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.100 (3.462)	7.249 (7.545)	2.057 (2.492)	75.222 (88.165)
Cabinet Top Horizontal W.R.T. Raised Floor	4.394 (5.817)	11.252 (10.490)	2.769 (2.896)	129.972 (149.428)

* = Cabinet Rocking Observed
# = Cabinet Sliding Observed

Recorded Peak Response of Isolated Raised Floor and Cabinet.
Value in Parenthesis is for Combined Horizontal and Vertical Input Motion.

IBM LEVEL - 2			LENGTH SCALE = 4	
	ISOLATION SYSTEM 1	ISOLATION SYSTEM 2	ISOLATION SYSTEM 3	WITHOUT ISOLATION
ACCELERATION (g)				
Table Horizontal	0.897 (0.880)	-- (--)	0.899 (0.920)	0.950* (0.948)*
Raised Floor Horizontal	0.273 (0.482)	-- (--)	0.460 (0.551)	2.751 (2.040)
Cabinet Level 1 (C.M.) Horizontal	0.403 (0.407)	-- (--)	0.340 (0.404)	1.485 (1.520)
Cabinet Level 2 Horizontal	0.590 (0.584)	-- (--)	0.487 (0.526)	0.879 (0.863)
Cabinet Level 3 Horizontal	0.663 (0.768)	-- (--)	0.659 (0.751)	1.278 (1.395)
Cabinet Top Horizontal	0.585 (0.591)	-- (--)	0.463 (0.564)	2.504 (2.515)
Table Vertical	0.208 (0.390)	-- (--)	-- (--)	0.338 (0.603)
Raised Floor Vertical	-- (--)	-- (--)	0.164 (0.352)	0.594 (0.756)
Cabinet Top Vertical	0.257 (0.648)	-- (--)	0.231 (0.529)	2.785 (2.928)
DISPLACEMENT (mm)				
Table Horizontal	23.749 (24.130)	-- (--)	23.597 (23.952)	23.800 (24.181)
Bearing Horizontal	44.475 (43.078)	-- (--)	32.080 (32.283)	N/A (N/A)
Raised Floor Horizontal	33.077 (35.090)	-- (--)	21.844 (21.838)	24.054 (24.022)
Cabinet C.M. Horizontal W.R.T. Raised Floor	3.454 (3.705)	-- (--)	2.505 (2.665)	58.393 (56.372)
Cabinet Top Horizontal W.R.T. Raised Floor	5.182 (6.045)	-- (--)	3.099 (3.048)	95.504 (95.910)

* = Cabinet Rocking Observed

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