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A SEISMIC SHAKE TABLE FOR TESTING OVERHEAD EQUIPMENT

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Abstract

A shake table has been designed specifically for testing of large pieces of overhead mounted equipment such as cable tray and conduit raceways, HVAC ducting, piping, false ceilings, and lighting. Specimens filling a volume 40 ft long x 15 ft wide x 15 ft deep and weighing up to six tons can be accommodated. Input motions of ±8 cm, ±80 cm/sec, and ±2 g are possible. Control and measurement instrumentation, including a computerized vibration analysis system, are described. Typical results are presented.

Introduction

Proof and fragility testing of structures and components to demonstrate their seismic capacity is common today. The importance of nuclear power plants, pipelines, hospitals and other critical facilities requires that their equipment and structures withstand high levels of earthquake excitation.

Analysis alone is often insufficient to demonstrate the seismic capacity of complex equipment. In such cases, the equipment is often subjected to earthquake base excitation on a shake table. Most current tables are not suited to testing ceiling mounted equipment or equipment of great length. Our project required a special purpose table to investigate the dynamic properties and seismic capacity of cable tray and conduit raceway systems. This paper deals with the design and operation of this table which is also well suited to testing of HVAC ducting, piping, false ceilings, and lighting fixtures.

Shake Table Description

This shake table consists of an open steel frame supported on five linkages (inverted pendulum). The angle of the linkages determines the relative amounts of vertical and horizontal base motion.* The shake table can be set to move in either of two perpendicular horizontal directions (not simultaneously, but in either case with simultaneous vertical motion). The shake table can also be rigidly fixed to simulate rigid support mounting. A sketch of the shake table is shown in Figure 1. It is shown set for transverse and vertical excitation. The legs must be rotated 90° to produce longitudinal and vertical excitation.

The shake table is designed so that it can support a 4-bay, 5-support, 40 ft long cable tray or conduit raceway configuration with a maximum ceiling to bottom raceway support dimension of 13 ft. Two runs of raceway, side by side, can be accommodated. Additional support points can be easily added. A maximum test specimen weight of 12,000 lb is the design loading for the table.

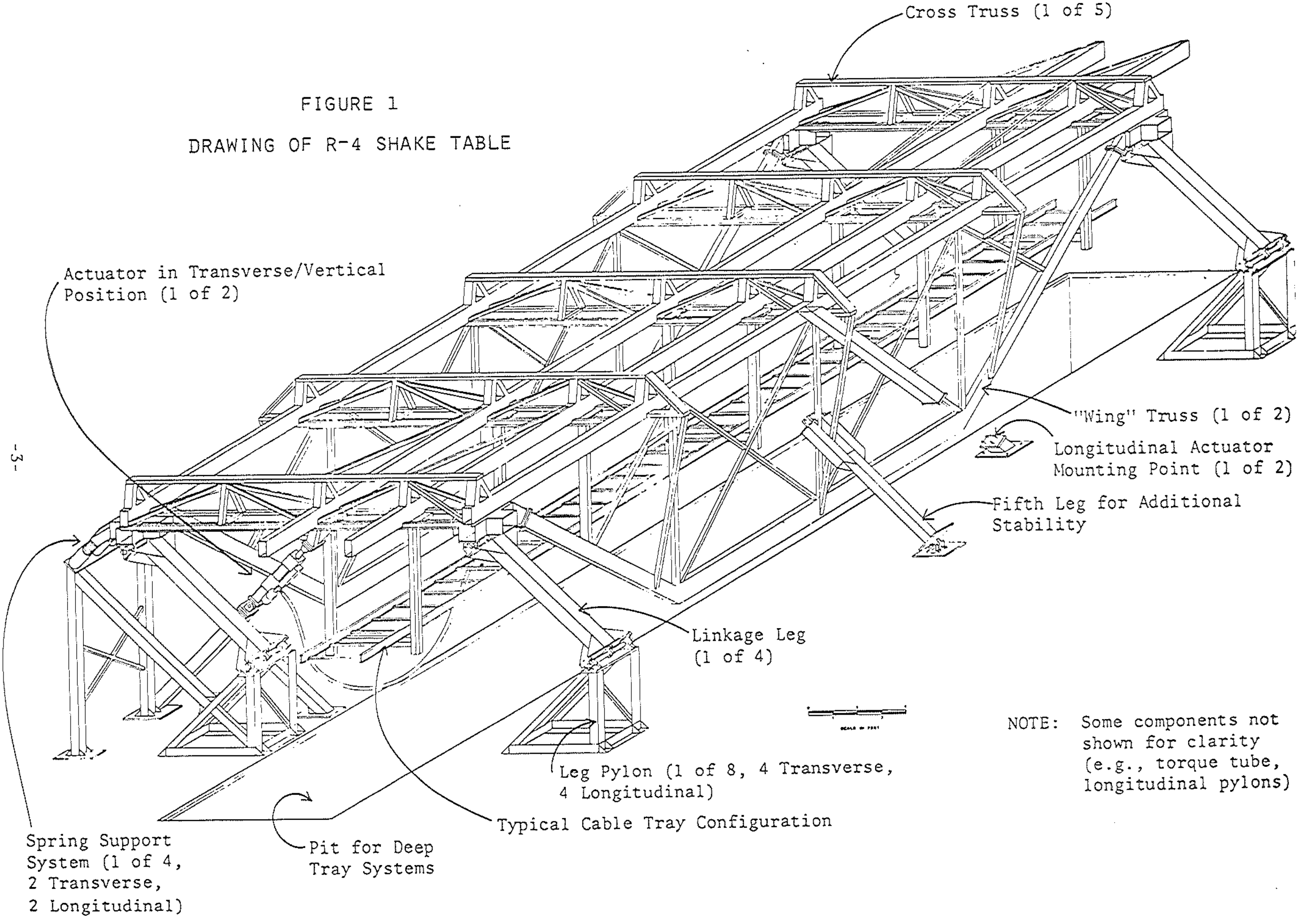
The shake table is designed so that when loaded, it has no significant modes within the range of 0.0 Hz to 20 Hz. This is to insure that the dynamic characteristics of the cable trays are not modified by the dynamics of the table. The table rests on a highly reinforced concrete foundation approximately 20 in. thick and 50 ft by 30 ft in size, with a 5 ft deep pit. The foundation weight is approximately 250,000 lb. The table is attached to surface steel embedded in the concrete of the foundation.

The sinusoidal support motions achievable are shown in Figure 2, with and without a test specimen load. Peak displacement is limited to ±3 in. by actuator stroke. The maximum achievable vlocity of 30 in./sec is governed by the fluid flow of the actuator serve-valve. Peak acceleration is a function of the total mass of the system being excited and the maximum force output of the actuators. The unloaded table, for example, has a mass of 10,000 lbm. The actuators are capable of developing 22,000 lbf total; therefore, the peak acceleration vector (resultant of horizontal and vertical components) for the unloaded table is 2.2. When loaded with a 10,000 lbm raceway system, it will be capable of an input acceleration of about 1.1 g resultant at the attachment points.

*This type of excitation, often referred to as "vector biaxial," implies that the support motion input is zero in one horizontal direction, $\chi(t)$ in the other horizontal direction, and $\alpha\chi(t)$ in the vertical direction, where α is the chosen ratio of vertical to horizontal motion. The time trace $\chi(t)$ is an arbitrarily specified earthquake-like motion. For this project the ratio has been chosen to be unity.

FIGURE 1

DRAWING OF R-4 SHAKE TABLE



NOTE: Some components not shown for clarity (e.g., torque tube, longitudinal pylons)

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FIGURE 2

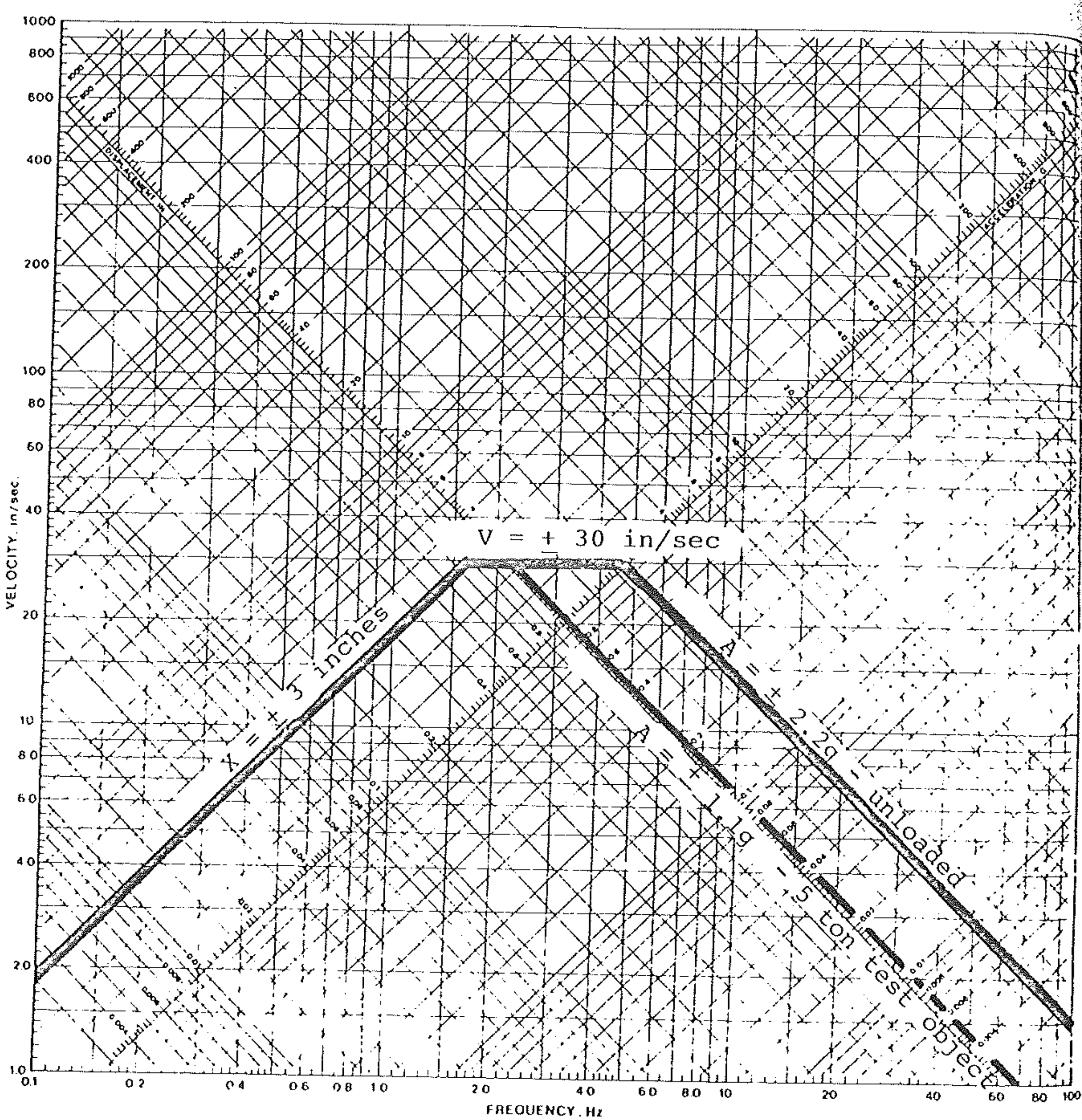
Test # ___-___ Run # ___-___ Time ___-___ Date ___-___ Recorded by ___-___ Page # ___-___

Test Specimen: SHAKE TABLE

Purpose of Test: THEORETICAL MAXIMUM TABLE INPUT

Direction: TRANSVERSE OR LONGITUDINAL, BOTH WITH VERTICAL

Comments: Shown is 45 degree resultant. Horizontal and Vertical inputs equal 0.707 of this value.



Maximum sinusoidal support motion can be maintained continuously for approximately one minute. Earthquake-like motions with a maximum input comparable to the maximum sinsuoidal motions indicated can also be maintained for approximately one minute. The support input will be magnified by the raceways, depending on their damping ratios, and the raceway response will be several times the values indicated as shown in Figure 3.

Pumping capacity and accumulator storage allows earthquakes to be sustained at the highest levels for about 30 seconds. Due to the extremely low frequency, high amplitude displacements typical of most earthquakes, it is necessary to high-pass filter the earthquake prior to using it to drive the table. Low-pass filtering at 33 Hz is also used. The oil in the actuator is not rigid and at some frequency it resonates with the driven mass ("oil column resonance"). Control electronics partially compensate for this phenomenon. For the ANCO shake table, with typical test specimens, oil column resonance occurs at approximately 16 Hz. Further note that the test specimen is not a rigid mass but a dynamic object whose impedance varies with frequency. Thus, the peak acceleration achievable at any frequency depends to some extent on the dynamics of the object being driven. Lastly, the shake table has resonances above 20 Hz. Drive energy above 20 Hz is selectively amplified and attenuated by different parts of the shake table.

The shake table is driven by a computerized vibration analysis system using a minicomputer. This system also records and analyzes up to 64 channels of data. Figure 4 illustrates the shake table instrumentation. The computer software is further discussed in another paper of this conference.[1]

Typical Results

To date electronic instrumentation, nuclear power plant electrical penetrations, electrical switchgear, and cable trays and conduit raceways have been tested on the shake table. By far the most extensive program involved over 500 different configurations of cable trays and conduit raceways.[2] The objectives of these tests were to determine realistic damping values, verify modeling assumptions, and to demonstrate that a wide variety of raceway systems possessed high seismic capacities, and to determine the effects of cable stiffness, raceway tray and hanger type, manufacture and configuration.

FIGURE 3

MAXIMUM OBTAINABLE HORIZONTAL AND
VERTICAL RESPONSE SPECTRA
R-4 VECTOR BIAXIAL SHAKE TABLE

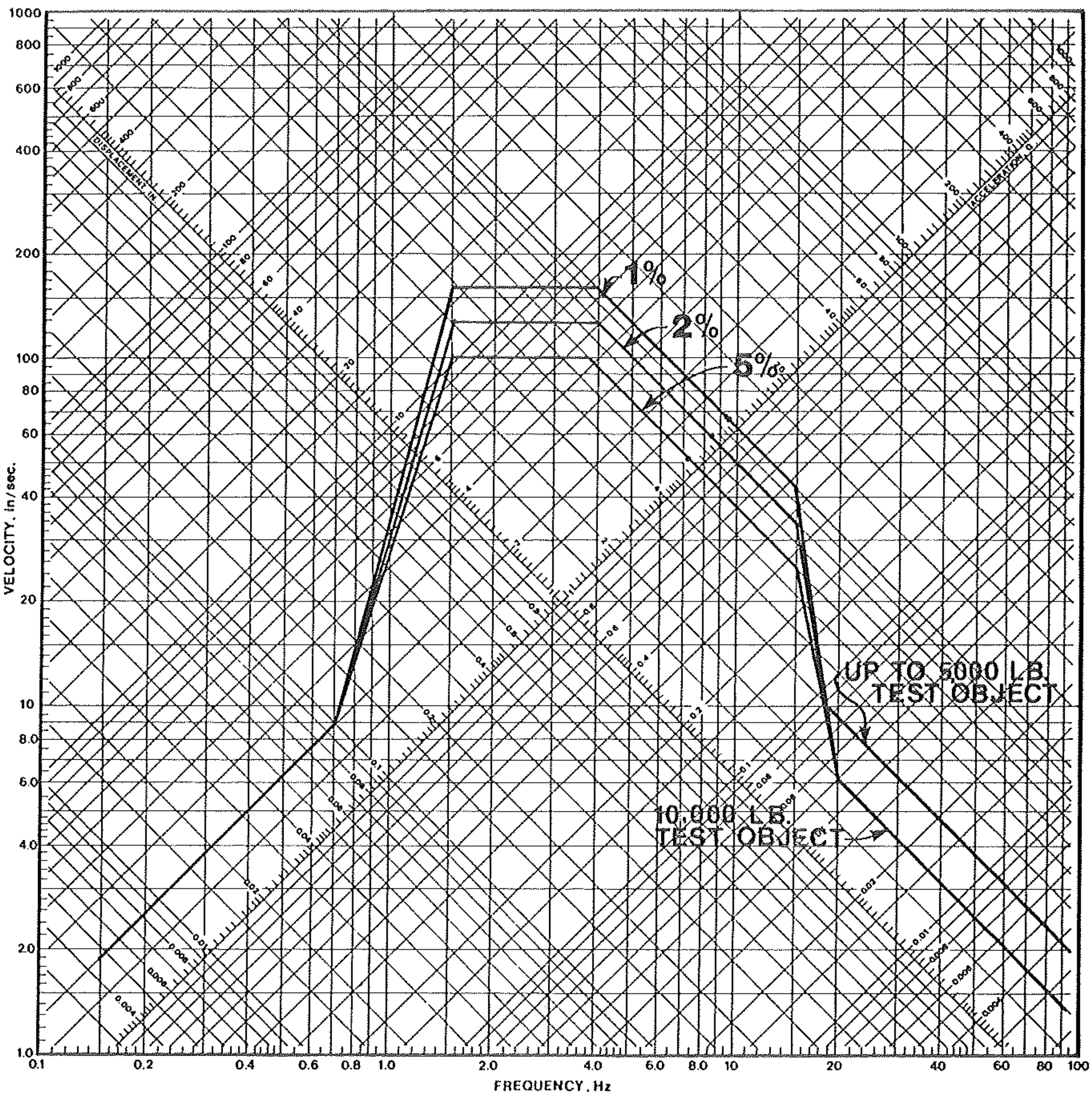
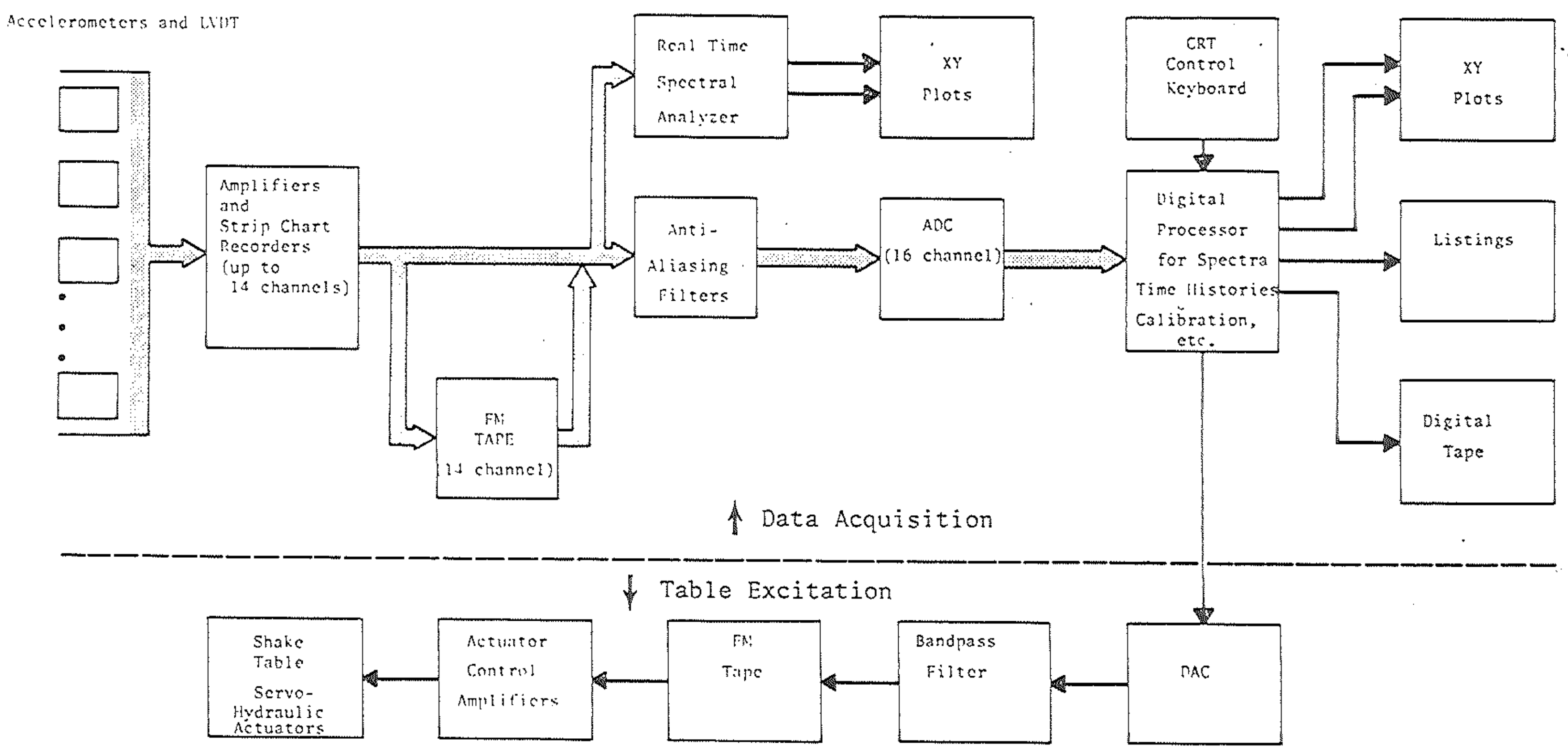


FIGURE 4: SHAKE TABLE INSTRUMENTATION



Figures 5 through 7 present typical results. In Figure 5, the resonant frequencies and dampings of rigidly mounted raceways with 50 lb/ft of cable are compared. As can be seen, manufacture type does not have a strong effect on dynamic properties and damping is very high (10-40 percent). Figure 6 shows trends in resonant frequency and damping with response amplitude. Frequencies typically degrade slightly and damping increases dramatically with increased response during seismic excitation. Figure 7 shows typical rigid base mode shapes identified by locking the table in place and using a small sinusoidal vibrator mounted on the cable tray. The program also demonstrated that most raceway configurations are suitable for use in seismic areas.

Conclusions

A shake table has been developed that can expose ceiling mounted equipment to earthquake motion. Its size and versatility also allows it to accommodate large, "semi infinite" structures realistically and, with the addition of certain braces, base mounted equipment as well. A minicomputer based system serves to drive the table with any desired input and to acquire and process many channels of response measurement in a timely and well documented manner.

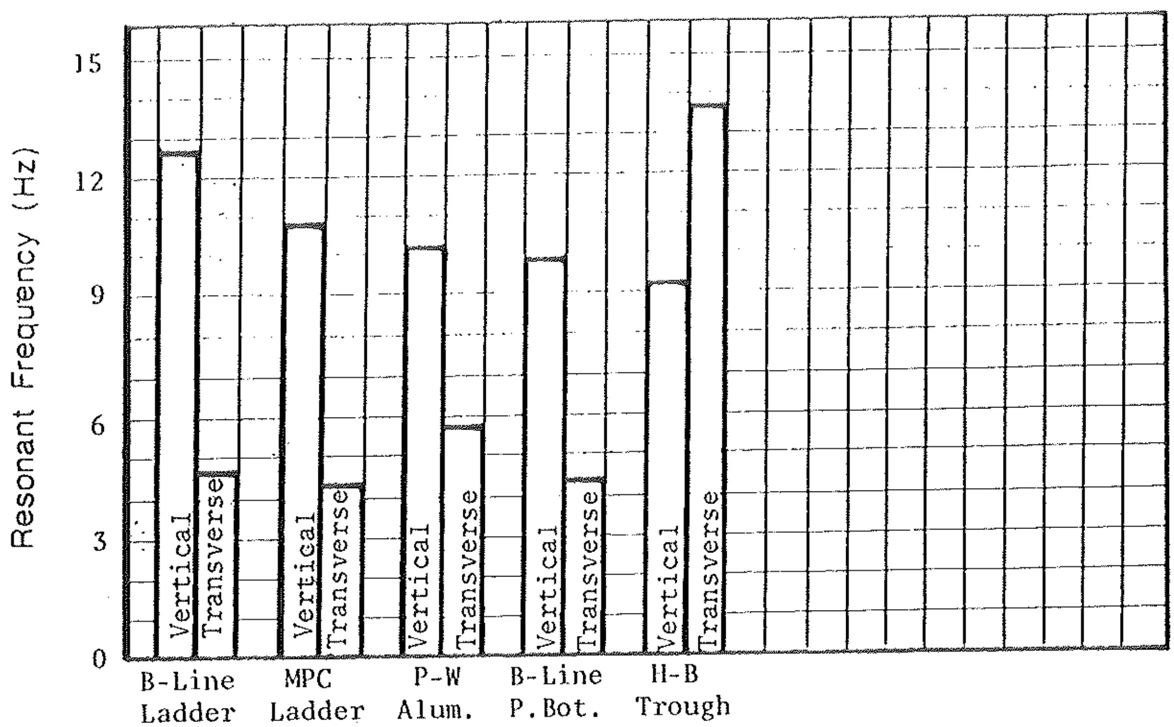
Acknowledgments

The development of this shake table facility required the efforts of many people at ANCO, MTS Corporation (suppliers of the hydraulic actuators and control system), and Bechtel Power Corporation (sponsors of the initial cable tray and conduit testing program). These efforts are greatfully acknowledged.

Figure 5

Test No.(s) I-1 to I-5 Run No.(s) XZ e&g - YZ e&g

Title Comparison of tray vertical and transverse resonant frequencies at 0.5 g input (at 100% cable loading)



Test No.(s) I-1 to I-5 Run No.(s) XZ e&g - YZ e&g

Title Comparison of tray vertical and transverse damping ratios at 0.5 g input (at 100% cable loading)

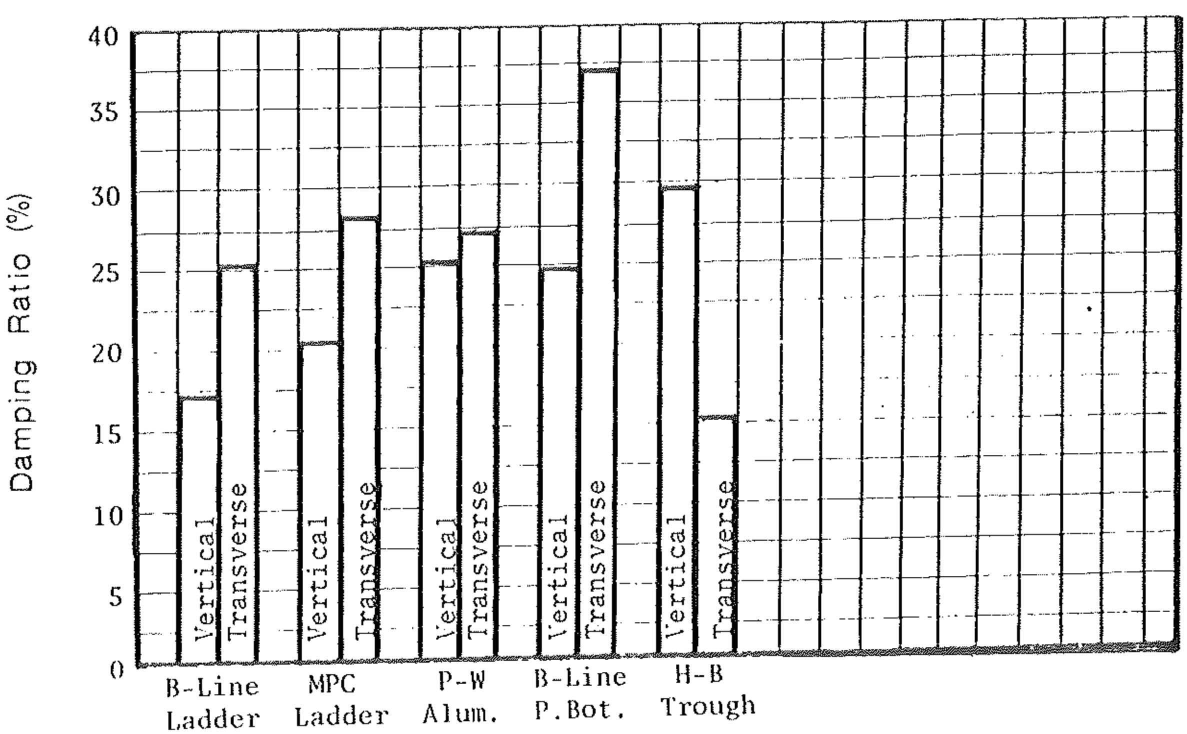
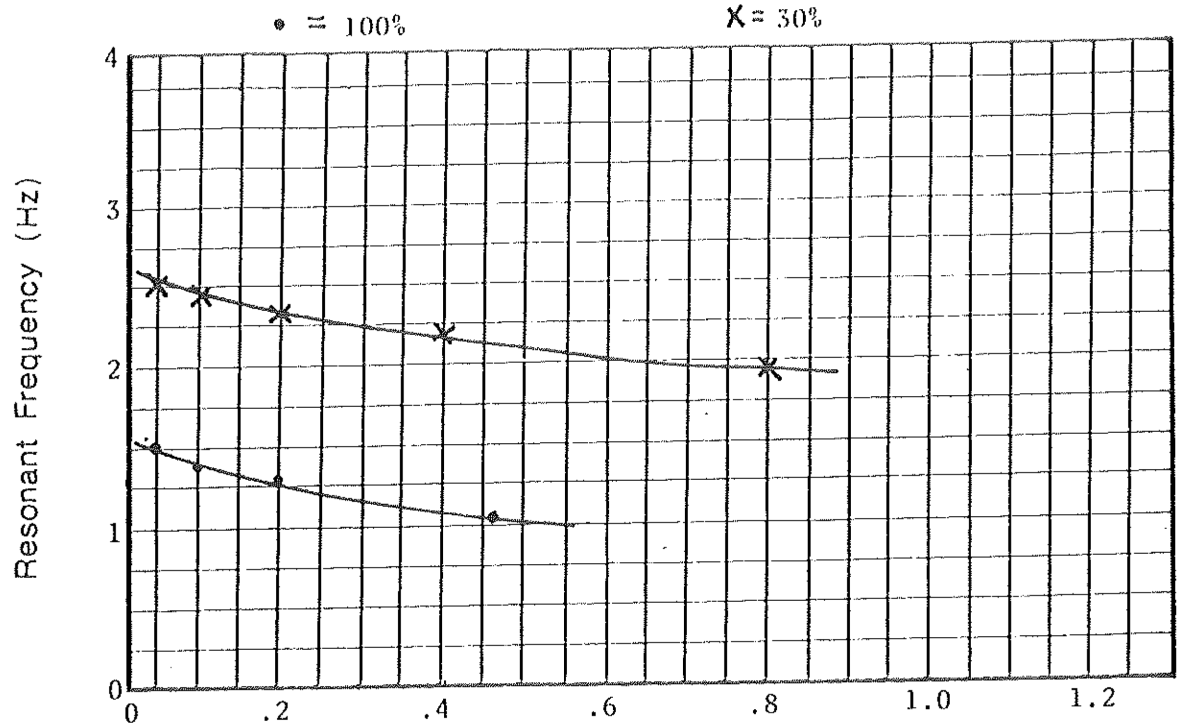


Figure 6

Test No.(s) II-5A,5B,5C Run No.(s) Ya

Title Trends in lowest longitudinal mode frequency for 3 tier 2' strut hangers at different % cable loads



Test No.(s) II-5A,5B,5C Run No.(s) Ya

Title Trends in lowest longitudinal mode damping ratios for 3 tier 2' strut hangers at different % cable loads

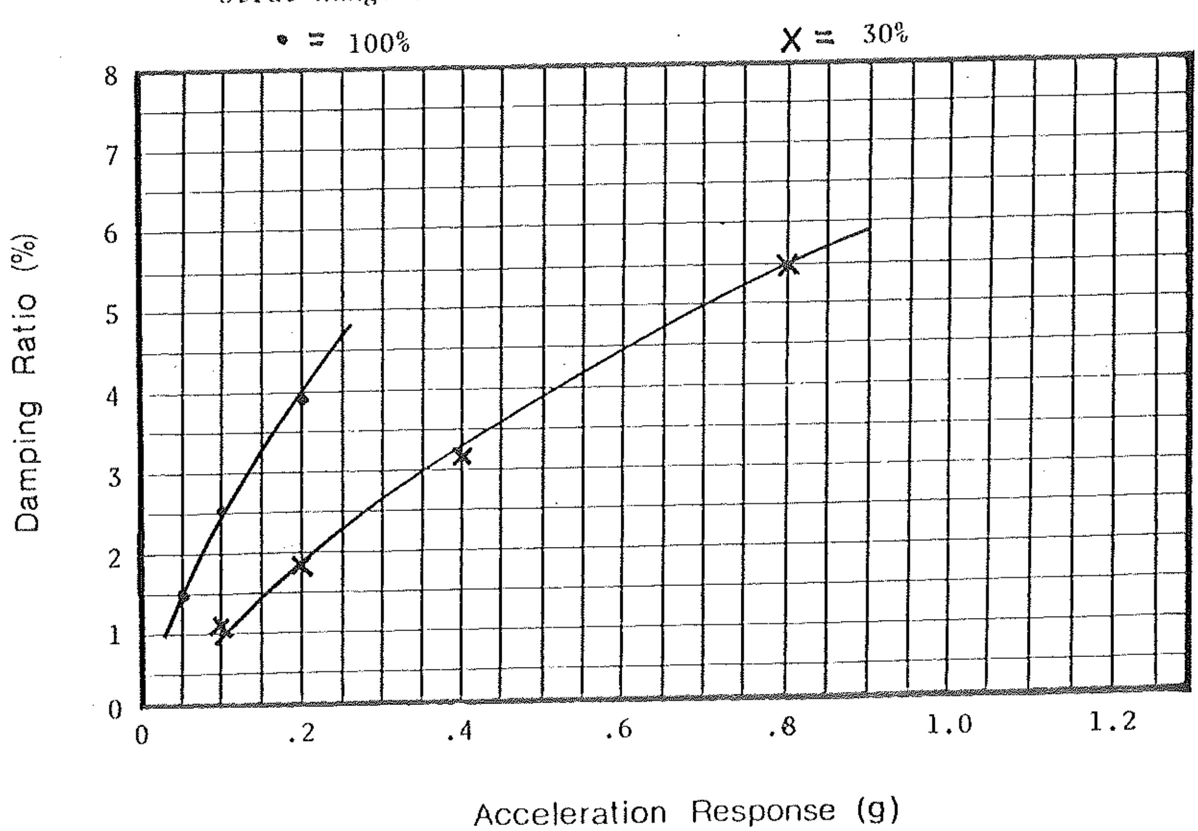
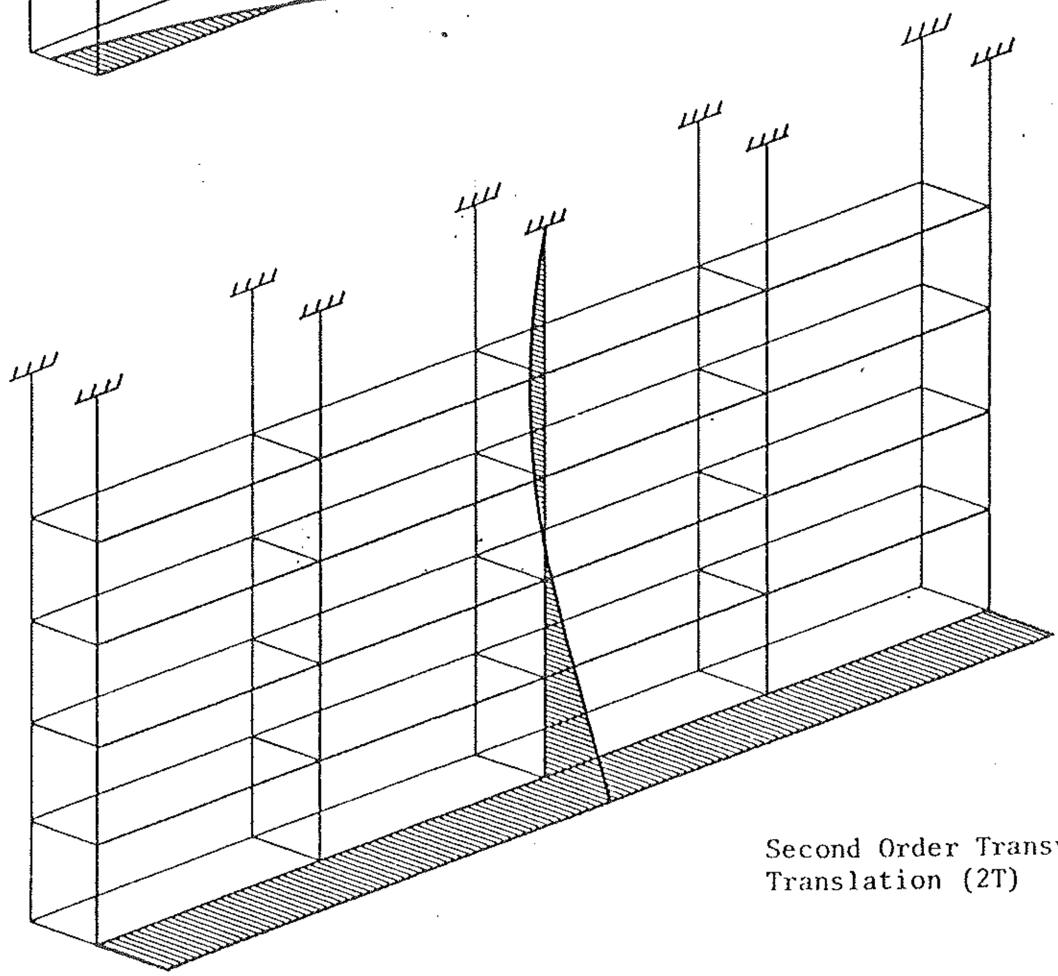


FIGURE 7

First Order Floating Beam Bending
All Trays in Phase (1FBIP)



Second Order Transverse
Translation (2T)

REFERENCES

1. R.B. Spencer, "A Minicomputer Based Vibration Test and Analysis System," to be presented at the ISA 25th International Instrumentation Symposium, 7-10 May 1979.

2. ANCO Engineers, Inc., "Cable Tray and Conduit Raceway Seismic Test Program," Report No. 1053-21.1-4, prepared for and in collaboration with Bechtel Power Corporation, 15 December 1978.