NOTICE

This report was prepared by the State University of New York at Buffalo, IBM, and Florida Atlantic University as a result of research sponsored by the National Center for Earthquake Engineering Research (NCEER) through grants from the National Science Foundation, the New York State Science and Technology Foundation, and other sponsors. Neither NCEER, associates of NCEER, its sponsors, the State University of New York at Buffalo IBM, and Florida Atlantic University, nor any person acting on their behalf:

a. makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe upon privately owned rights, or

b. assumes any liabilities of whatsoever kind with respect to the use of, or the damage resulting from the use of, any information, apparatus, method or process disclosed in this report.

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, the New York State Science and Technology Foundation, or other sponsors.

Seismic Testing of Installation Methods for Computers and Data Processing Equipment

by

K. Kosar[1], T.T. Soong[2], K.L. Shen[3], J.A. HoLung[4] and Y.K. Lin[5]

April 12, 1993

Technical Report NCEER-93-0007

NCEER Project Numbers 91-5221 and 92-5201

NSF Master Contract Number BCS 90-25010
and
NYSSTF Grant Number NEC-91029

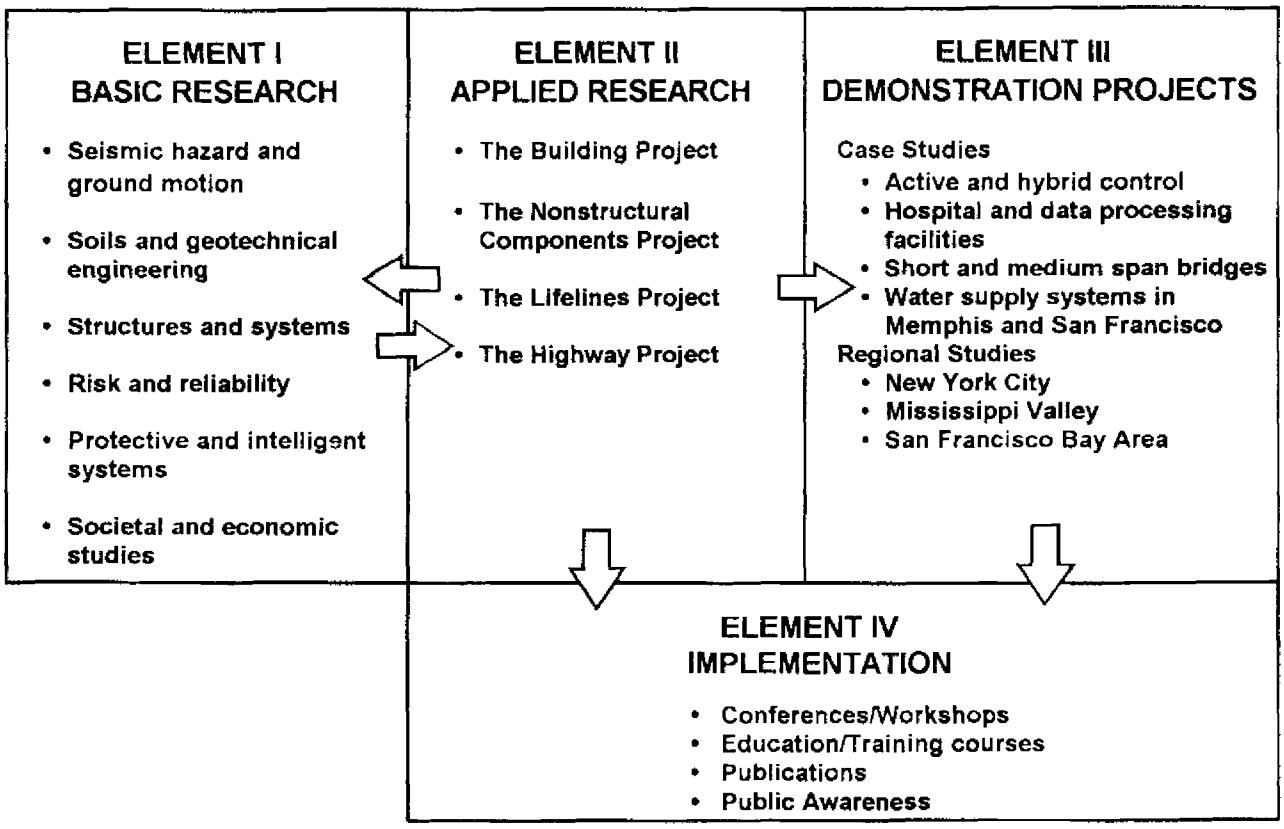
1 Product Engineer, Vibratech, Inc., formerly Research Assistant, Department of Civil Engineering, State University of New York at Buffalo
2 Samuel P. Capen Professor, Department of Civil Engineering, State University of New York at Buffalo
3 Research Assistant, Department of Civil Engineering, State University of New York at Buffalo
4 Engineer/Scientist, Entry Systems Technology, IBM
5 Schmidt Chair in Engineering, Center for Applied Stochastics Research, Florida Atlantic University

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo
Red Jacket Quadrangle, Buffalo, NY 14261

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

This report addresses seismic safety of computers and data processing systems. Under a joint research program with IBM, seismic tests on a variety of computer systems using a wide spectrum of installation methods were conducted in order to assess their effectiveness in mitigating damaging effects to these systems in a seismic environment. Results from three two-week test sessions are presented and analyzed in this report and the performances of several installation methods are evaluated.

ABSTRACT

The basic objective of the test program described in this report was to investigate seismic response of computers and data processing equipment and to evaluate a variety of possible earthquake resistant installation methods ranging from those currently in use to more advanced designs using energy absorbing materials. This report documents results and assesses their significant based on three two-week test sessions performed jointly by NCEER and IBM investigators from June, 1991 through June, 1992.

These tests were conducted on different mainframe systems utilizing a variety of earthquake inputs and different installation methods. The equipment response to the earthquake inputs is analyzed to enable a quantitative evaluation of the installation methods. Discussions and conclusions regarding the equipment sensitivity to earthquakes and the performance of selected installation methods are presented.

ACKNOWLEDGEMENTS

This work was supported in part by the National Center for Earthquake Engineering Research under Grant Nos. NCEER-91-5221 and NCEER-92-5201C and by the IBM Corporation under the NCEER/IBM Joint Research Program on Seismic Performance and Safety Enhancement of Computers and Data Processing Equipment. The 3M Company provided the viscoelastic dampers used in this study. Aeroflex International and SVP Inc. contributed the wire ropes. Their contributions are gratefully acknowledged.

The authors are indebted to the following individuals who participated and contributed to this test program:

The 3M Company: Dr. M.L. Lai and Dr. E.J. Nielsen

IBM: Mr. R.A. Frey, Mr. G.N. Nikolsky, Mr. K. Larsen, and Mr. E. Caukin

The State University of New York at Buffalo: Dr. M.C. Constantinou, Mr. G.F. Demetriades, Mr. M. Pitman, Mr. D. Walch, Mr. P. Pattarroyo, and Mr. R. Cizdziel

TABLE OF CONTENTS

Page

1 INTRODUCTION AND TEST OBJECTIVES 1-1

2 TEST SET-UP 2-1

2.1 The Earthquake Simulator 2-1
2.2 Raised Floor 2-1
2.3 Instrumentation 2-1
2.4 Input Accelerations 2-2

3 TEST EQUIPMENT AND INSTALLATION METHODS 3-1

3.1 Test Equipment 3-1

3.1.1 June 1991 Test 3-1
3.1.2 August 1991 Test 3-1
3.1.3 June 1992 Test 3-2

3.2 Installation Methods 3-2

3.2.1 IBM 9370, June 1991 3-2
3.2.2 IBM 9371, June 1991 3-4
3.2.3 IBM 9221, August 1991 3-4
3.2.4 Frame 1, Frame 8 and Endicott Frame, June 1992 3-5

4 TEST MATRICES AND TEST RESULTS 4-1

4.1 Test Matrices 4-1

4.1.1 June 1991 Test 4-1
4.1.2 August 1991 Test 4-1
4.1.3 June 1992 Test 4-1

4.2 Test Results 4-1

5 DISCUSSION OF TEST RESULTS AND RECOMMENDATIONS 5-1

5.1 June 1991 Test 5-1
5.2 August 1991 Test 5-2
5.3 June 1992 Test 5-2

6 REFERENCES 6-1

APPENDIX - SUMMARY OF TEST RESULTS A-1

LIST OF FIGURES

Figure	Title	Page
2-1	Schematic Sketch of the Shaking Table	2-5
2-2	Installation Details of Raised Floor	2-6
2-3	Fully Assembled Raised Floor	2-7
2-4	Accelerometer Locations	2-8
2-5	Location of Markers	2-9
2-6	Temposonic Transducer Locations	2-10
2-7	Acceleration Response Spectra for IBM1, IBM2, and Bellcore Inputs	2-11
2-8	Raised-floor Input Accelerations: El Centro Earthquake	2-12
2-9	Raised-floor Input Accelerations: Taft Earthquake	2-13
2-10	Raised-floor Input Accelerations: IBM, Bellcore and Pacoima	2-14
3-1	IBM 9370 and 9371 Systems	3-8
3-2	Stabilizing Foot	3-9
3-3	Frame-8, Frame-1 and Endicott Frame	3-10
3-4	Bungee Cord Installation	3-11
3-5	Spring Installations	3-12
3-6	Toggle Bar Installation	3-13
3-7	Viscoelastic Damper Installation	3-13
3-8	Wire Rope Installation	3-14
3-9	Fixed Base Installation	3-14
3-10	Wire Cable Installation (Frey and Nikolsky, 1992)	3-15
3-11	Spring Installation (Frey and Nikolsky, 1992)	3-15

3-12	Toggle Bar Installation with NTT Leveler (Frey and Nikolsky, 1992)	3-15
4-1	IBM 9370, IBM2 Input	4-9
4-2	IBM 9370, Bellcore Input	4-10
4-3	IBM 9370, Taft RC-7 Input	4-11
4-4	IBM 9370, El Centro RC-7 Input	4-12
4-5	IBM 9371, IBM2 Input	4-13
4-6	IBM 9371, Bellcore Input	4-14
4-7	IBM 9371, Taft RC-7 Input	4-15
4-8	IBM 9371, El Centro RC-7 Input	4-16
4-9	IBM 9221, IBM2 Input	4-17
4-10	IBM 9221, El Centro RC-7 Input	4-18
4-11	Frame-8, IBM1 Input	4-19
4-12	Frame-8, IBM2 Input	4-20
4-13	Frame-8, Bellcore Input	4-21
4-14	Frame-8, El Centro RC-7 Input	4-22
4-15	Frame-1, IBM1 Input	4-23
4-16	Frame-1, IBM2 Input	4-24
4-17	Frame-1, Bellcore Input	4-25
4-18	Frame-1, El Centro RC-7 Input	4-26
4-19	Endicott Frame, IBM1 Input	4-27
4-20	Endicott Frame, IBM2 Input	4-28
4-21	Endicott Frame, Bellcore Input	4-29
4-22	Endicott Frame, El Centro RC-7 Input	4-30

LIST OF TABLES

Table	Title	Page
2-1	Accelerometer and Displacement Transducer Locations and Designations	2-4
3-1	Sizes and Dimensions of Test Equipment	3-7
4-1	Test Matrix for IBM-9370, June 1991	4-3
4-2	Test Matrix for IBM-9371, June 1991	4-4
4-3	Maximum Acceleration Levels for June 1991	4-4
4-4	Test Matrix for IBM 9221, August 1991	4-5
4-5	Maximum Acceleration Levels for August 1991	4-5
4-6	Test Matrix for Frame-8, June 1992	4-6
4-7	Test Matrix for Frame-1, June 1992	4-7
4-8	Test Matrix for Endicott Frame, June 1992	4-8
4-9	Maximum Acceleration Levels for June 1992	4-8
A-1	Maximum Acceleration Values (g's), Locked Caster Case, IBM-9370, June 1991	A-2
A-2	Maximum Acceleration Values (g's), Bungee Cords Case, IBM-9370, June 1991	A-3
A-3	Maximum Acceleration Values (g's), 4-Toggle Bar Case, IBM-9370, June 1991	A-4
A-4	Maximum Acceleration Values (g's), 2-Spring Case, IBM-9370, June 1991	A-5
A-5	Maximum Acceleration Values (g's), F-Damper Case, IBM-9370, June 1991	A-6
A-6	Maximum Acceleration Values (g's), D-Damper Case, IBM-9370, June 1991	A-7

A-7 Maximum Acceleration Values (g's), 4-Hz, Wire Rope Case, IBM-970, June 1991 ..... A-8

A-8 Maximum Acceleration Values (g's), 4-Wire Rope Case, IBM-9370, June 1991 ..... A-9

A-9 Maximum Acceleration Values (g's), Fixed Base Case, IBM-9370, June 1991 ..... A-10

A-10 Maximum Acceleration Values (g's), On Glides Case, IBM-9371, June 1991 ..... A-11

A-11 Maximum Acceleration Values (g's), E-Damper Case, IBM-9371, June 1991 ..... A-12

A-12 Maximum Acceleration Values (g's), Fixed in Rear Case, IBM-9371, June 1991 ..... A-13

A-13 Maximum Acceleration Values (g's), Bolted to Slab Case, IBM-9371, June 1991 ..... A-14

A-14 Maximum Acceleration Values (g's), Locked Caster Case, IBM-9221, August 1991 ..... A-15

A-15 Maximum Acceleration Values (g's), VE Dampers, Case 1, IBM-9221, August 1991 ..... A-16

A-16 Maximum Acceleration Values (g's), VE Dampers, Case 2, IBM-9221, August 1991 ..... A-17

A-17 Maximum Acceleration Values (g's), VE Dampers, Case 3, IBM-9221, August 1991 ..... A-18

A-18 Maximum Acceleration Values (g's), 4-Toggle Bar Free Casters, 40-Durometer, IBM-9221, August 1991 ..... A-19

A-19 Maximum Acceleration Values (g's), 4-Toggle Bar Free Casters, 80-Durometer, IB-9221, August 1991 ..... A-20

A-20 Maximum Acceleration Values (g's), Toggle Bars, 80-Durometer Bushings, Frame-8, June 1992 ..... A-21

A-21 Maximum Acceleration Values (g's), 3/16 Wire Ropes, 80-Durometer Bushings, Frame-8, June 1992 ..... A-22

A-22 Maximum Acceleration Values (g's), 3/16 Wire Ropes Teflon Bushings, Frame-8, June 1992 ..... A-23

A-23 Maximum Acceleration Values (g's), 5/32 Wire Ropes and Springs with Teflon Bushings, Frame-8, June 1992 ..... A-24

A-24 Maximum Acceleration Values (g's), 5/32 Wire Ropes and Brackets with Teflon Bushings, Frame-8, June 1992 ..... A-25

A-25 Maximum Acceleration Values (g's), Toggle Bars, Aluminum Bushings, Frame-8, June 1992 ..... A-26

A-26 Maximum Acceleration Values (g's), Toggle Bars Loose, Aluminum Bushings, Frame-8, June 1992 ..... A-27

A-27 Maximum Acceleration Values (g's), Normal Levelers, Plastic Coating, X-Axis, Frame-8, June 1992 ..... A-28

A-28 Maximum Acceleration Values (g's), Normal Levelers, Plastic Coating, Y-Axis, Frame-8, June 1992 ..... A-29

A-29 Maximum Acceleration Values (g's), Normal Levelers, Plastic Coating, X-Axis, Endicott Frame, June 1992 ..... A-30

A-30 Maximum Acceleration Values (g's), Toggle Bars, 80-Durometer, Endicott Frame, June 1992 ..... A-31

A-31 Maximum Acceleration Values (g's), Toggle Bars and NTT Levelers, 80-Durometer, Endicott Frame, June 1992 ..... A-32

A-32 Maximum Acceleration Values (g's), Toggle Bars and Casters, Aluminum Bushings, Endicott Frame, June 1992 ..... A-33

A-33 Maximum Acceleration Values (g's), Toggle Bars and NTT Levelers, Aluminum Bushings, Endicott Frame, June 1992 ..... A-34

A-34 Maximum Acceleration Values (g's), Toggle Bars Loose, Aluminum Bushings, Endicott Frame, June 1992 ..... A-35

A-35 Maximum Acceleration Values (g's), Casters, Non-operational, Frame-1, June 1992 ..... A-36

A-36 Maximum Acceleration Values (g's), NTT Levelers, Frame-1, June 1992 ..... A-37

A-37 Maximum Acceleration Values (g's), Normal Levelers, Plastic Coating, Frame-1, June 1992 ..... A-38

A-38 Maximum Acceleration Values (g's), Toggle Bars, 80-Durometer Bushings, Frame-1, June 1992 ..... A-39

A-39 Maximum Acceleration Values (g's), Toggle Bars, Aluminum Bushings, Frame-1, June 1992 ..... A-40

A-40 Maximum Acceleration Values (g's), 5/32 Wire Ropes, Teflon Bushings, Frame-1, June 1992 ..... A-41

A-41 Maximum Acceleration Values (g's), NTT Levelers with Toggle Bars, Aluminum Bushings, Frame-1, June 1992 ..... A-42

A-42 Maximum Acceleration Values (g's), NTT Levelers with 3/16 Wire Ropes, Aluminum Bushings, Frame-1, June 1992 ..... A-43

A-43 Maximum Acceleration Values (g's), 3/16 Wire Ropes, Teflon Bushings, Frame-1, June 1992 ..... A-44

A-44 Maximum Acceleration Values (g's), Springs with 3/16 Wire Ropes, Frame-1, June 1992 ..... A-45

A-45 Maximum Acceleration Values (g's), Springs with 3/16 Wire Ropes, Frame-1, June 1992 ..... A-46

A-46 Maximum Acceleration Values (g's), Fixed to Ground, X-Axis, Frame-1, June 1992 ..... A-47

A-47 Maximum Acceleration Values (g's), Fixed to Ground, Y-Axis, Frame-1, June 1992 ..... A-48

A-48 Maximum Acceleration Values (g's), Fixed to Ground, One-Bolt, X-Axis, Frame-1, June 1992 ..... A-49

SECTION 1

INTRODUCTION AND TEST OBJECTIVES

Equipment such as computers and data processing systems play a vital role in modern society. Industries and business concerns rely on computing centers for data processing, process control, communications, research and other functions. Any interruption or failure in the operation of these systems due to earthquakes and other vibrational effects can lead to total chaos and substantial economic loss. Moreover, life safety can be a serious concern when these systems are tied to life saving operations such as those performed in a hospital.

Since the advent of sophisticated data processing facilities, there has been limited opportunity to evaluate the impact of earthquakes upon their design and function. Most information on seismic damage to computer equipment is obtained from reconnaissance reports and inspections following earthquake occurrences While no quantitative damage measures can be cited, observations after recent earthquakes point to the importance of earthquake hazard mitigation measures for computer and data processing systems (Gates and Scawthorn, 1982; Green and Frey, 1990).

The choice of an appropriate method of installation plays a key role in insuring seismic safety of computers. As one part of a joint NCEER/IBM research program, seismic tests on a variety of data processing equipment using a wide spectrum of installation methods were conducted in order to assess their effectiveness in preventing or minimizing damaging effects to these equipment in a seismic environment. The methods of installation selected represented a cross section of restraining techniques and covered the range from free casters to innovative energy dissipation devices.

The seismic tests described in this report encompass three two-week test sessions conducted in June, 1991; August, 1991; and June, 1992. The major test objective was to evaluate different installation methods applied to typical and functional data processing equipment, and to gain insight into and assess their suitability for use in a given seismic region. Another objective was to include several different test inputs in the program with the hope that the test results would lead to reductions and improved efficiency in future seismic tests.

It is noted that some parts of these test series have been described in other publications. For example, the performance of wire ropes during the June 1991 test is

discussed in Demetriodes et al. (1992), and some of the test results and their implications are described in Frey (1992), Frey and Nikolsky (1992), and Holung and Lin (1993). This report provides comprehensive test results obtained from all three test series and an overall assessment of their significance.

SECTION 2

TEST SET-UP

2.1 The Earthquake Simulator

The three test series were carried out on the shaking table at the State University of New York at Buffalo, which provided the base motion to the equipment being tested. The shaking table has a dimension of 3.66 m×3.66 m (12 ft×12 ft) with a capacity of 50 mtons (110 kips) and an advanced control system. It has five degrees of freedom (DOF) actively controlled, with three DOF's programmable directions (horizontal, vertical, and roll) and the other two DOF's corrected for cross coupling only. The sixth degree of freedom horizontal-transverse) is restrained by hydrostatic bearings which provide free sliding with lateral displacement/force control.

The system has two horizontal actuators with a capacity of 32 mtons (70 kips), which can provide a horizontal acceleration of 0.625 g with maximum payload. Four vertical actuators with a total capacity of 100 mtons (220 kips) can accelerate the system with 1.05 g at maximum payload. With lighter payloads, the system can produce larger accelerations (up to 4.0g horizontally and 8.0g vertically). A schematic sketch of the system is shown in Fig. 2-1.

2.2 Raised Floor

All the tests were conducted on a 6 ft×6 ft raised floor surface that was constructed on top of a concrete slab attached to the shaking table. The installation details, as shown in Fig. 2-2, conform to standards normally applied to earthquake installations (FIMS, 1987). Additional braces were provided at the ends to simulate the added support of building walls and cut-outs in the raised floor surface to accommodate signal and power cable attachments. A photograph of the completed raised floor assembly is shown in Fig. 2-3.

2.3 Instrumentation

Horizontal and vertical acceleration measurements using accelerometers were made at many locations on the shaking table, the raised floor, and the equipment being tested. The placements and designations for the accelerometers attached to the equipment are shown in Fig. 2-4, although not all of the instruments were used in every test. A complete

listing of accelerometer locations and designations is provided in Table 2-1. For all measurements, the sampling rate was set at 100 samples/second.

The horizontal displacements of the equipment were measured by means of permanent markers attached to the front and rear surfaces, as shown in Fig. 2-5. For some of the early tests, Temposonic displacement transducers were attached to the shaking table and to the equipment although they were not used in many of the later tests due to attachment difficulties in some cases and excessive sliding motion of the equipment in some other cases. The locations of the Temposonic transducers attached to the equipment are shown in Fig. 2-6, and a complete listing is also given in Table 2-1.

2.4 Input Accelerations

Several types of input accelerations representing some typical past earthquakes and simulated test response spectra were used in the test program. In addition, simulated earthquake inputs at different floor levels of a seven-story reinforced concrete (RC) building were generated. The particular earthquake inputs selected were those of El Centro (1940, lateral component = S00E), and Taft (1952, lateral component = N21E). The notation "EL C RC-X" or "TAFT RC-X" refers to the lateral or horizontal component of a simulated motion that would be experienced at story level X of the 7-story reinforced concrete building with El Centro or Taft ground input. This short-hand notation is abbreviated even more in certain sections of this report for convenience.

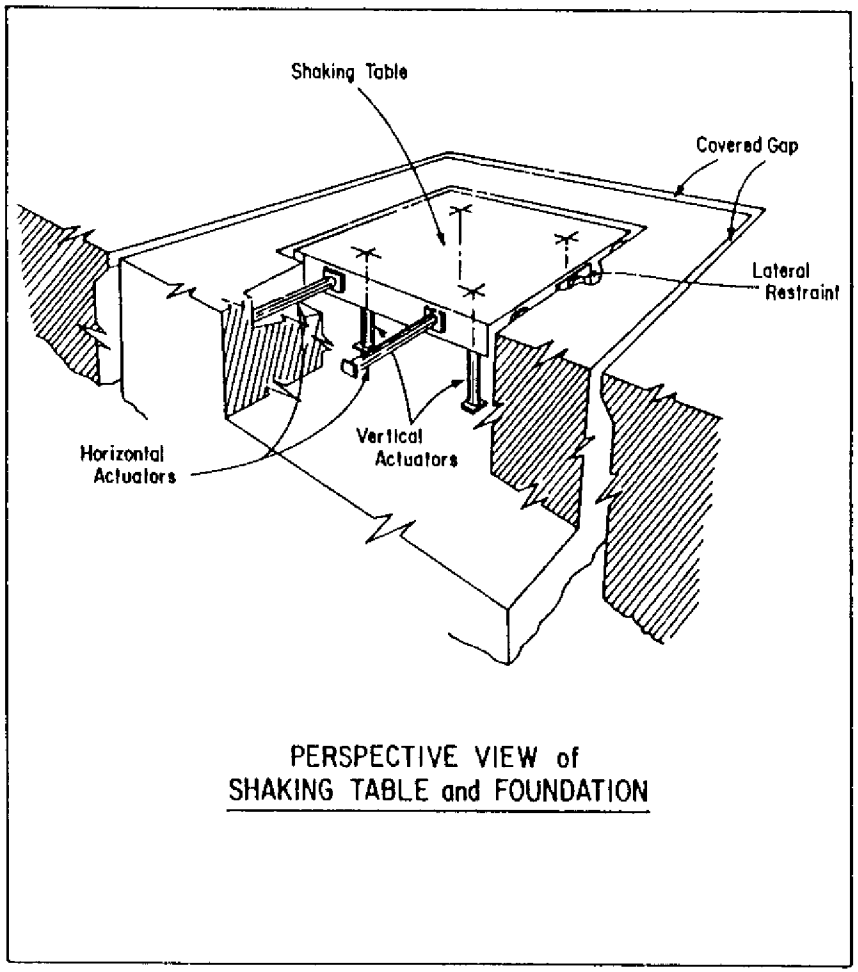
A test input proposed by Bellcore (Bellcore, 1988) for the upper stories in Zone 4 earthquakes, and two IBM developed inputs (IBM, 1991), were also used. The IBM inputs, denoted by IBM1 and IBM2, represent two functional test levels. At the first level, the machine is expected to operate normally, and at the second level, also referred to as the structural/safety level, gross structural failures should not occur although the machine may not remain functional. The acceleration response spectra of these inputs are shown in Fig. 2-7, from which time histories were generated as input accelerations from the shaking table. The duration of IBM inputs was initially set at 40 seconds, consistent with the total recording time for the other inputs, but was shortened to 20 seconds later in the test program. Also, the IBM1 input was only used in a limited number of the early tests until it was observed that the machine could in fact withstand the IBM2 test level while operating.

In some test runs, the actual recorded ground vertical accelerations for the El Centro and Taft earthquakes were used instead of the 1/3-scaled amplitude of the lateral

component used in most cases. Also, in one test trial, the lateral and vertical components of the Pacoima earthquake were also used. These exceptions are marked accordingly in Sec. 4 when the test matrices and test results are discussed. A sample of the test inputs as measured on the raised floor surface is shown in Figs. 2-8 through 2-10.

Table 2-1 Accelerometer and Displacement Transducer Locations and Designations

SHAKING TABLE	
ALAT	reference accel. lateral direction (X-axis)
AVRT	reference accel. vertical direction (Z-axis)
DLAT	displ. lateral direction
DVRT	displ. vertical direction
CONCRETE SLAB	
ASEX	accel. slab east x-direction
ASWX	accel. slab west x-direction
ASCZ	accel. slab center z-direction
RAISED FLOOR	
AFEX	accel. floor east x-direction
AFCZ	accel. floor center z-direction
AFEZ	accel. floor east z-direction
AFWX	accel. floor west x-direction
AFWZ	accel. floor west z-direction
EQUIPMENT	
LRFX	accel. lower right front x-direction
LRRX	accel. lower right rear x-direction
TRFX	accel. top right front x-direction
TRRX	accel. top right rear x-direction
LRRZ	accel. lower right rear z-direction
LRRY	accel. lower right rear y-direction
TRFZ	accel. top right front z-direction
TRRZ	accel. top right rear z-direction
TLEZ	accel. top left front z-direction
TLRZ	accel. top left rear z-direction
DSDX	accel. DASD (IBM 9332) x-direction
DSDY	accel. DASD (IBM 9332) y-direction
DSDZ	accel. DASD (IBM 9332) z-direction
DNEX	displ. north east x-direction
DNWX	displ. north west x-direction
DNWY	displ. north west y-direction
DSWY	displ. south west y-direction



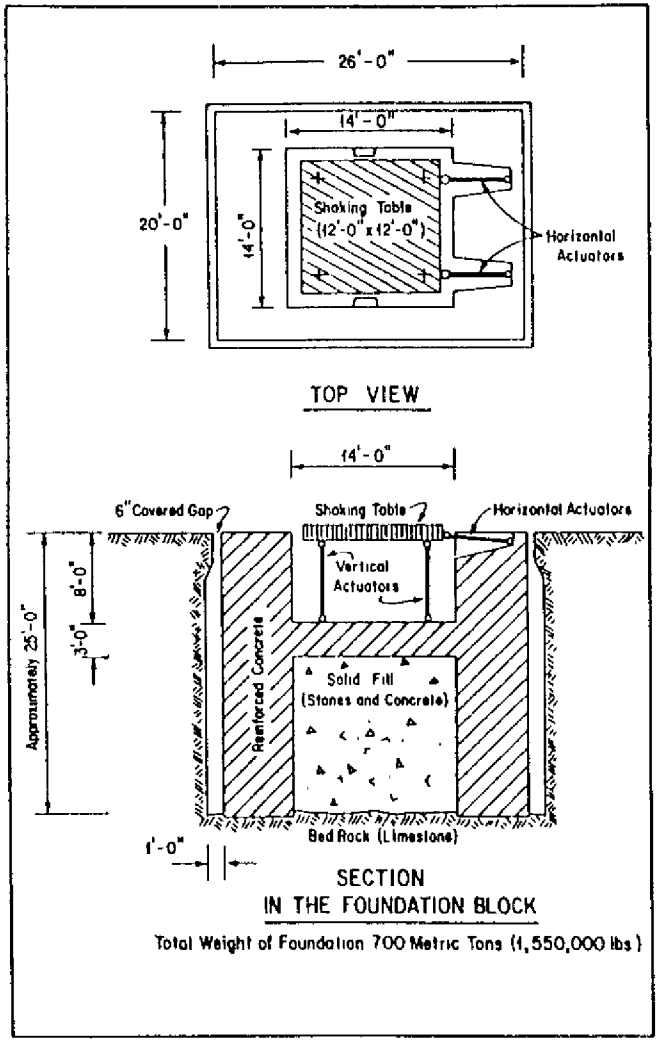


Fig. 2-1 Schematic Sketch of the Shaking Table

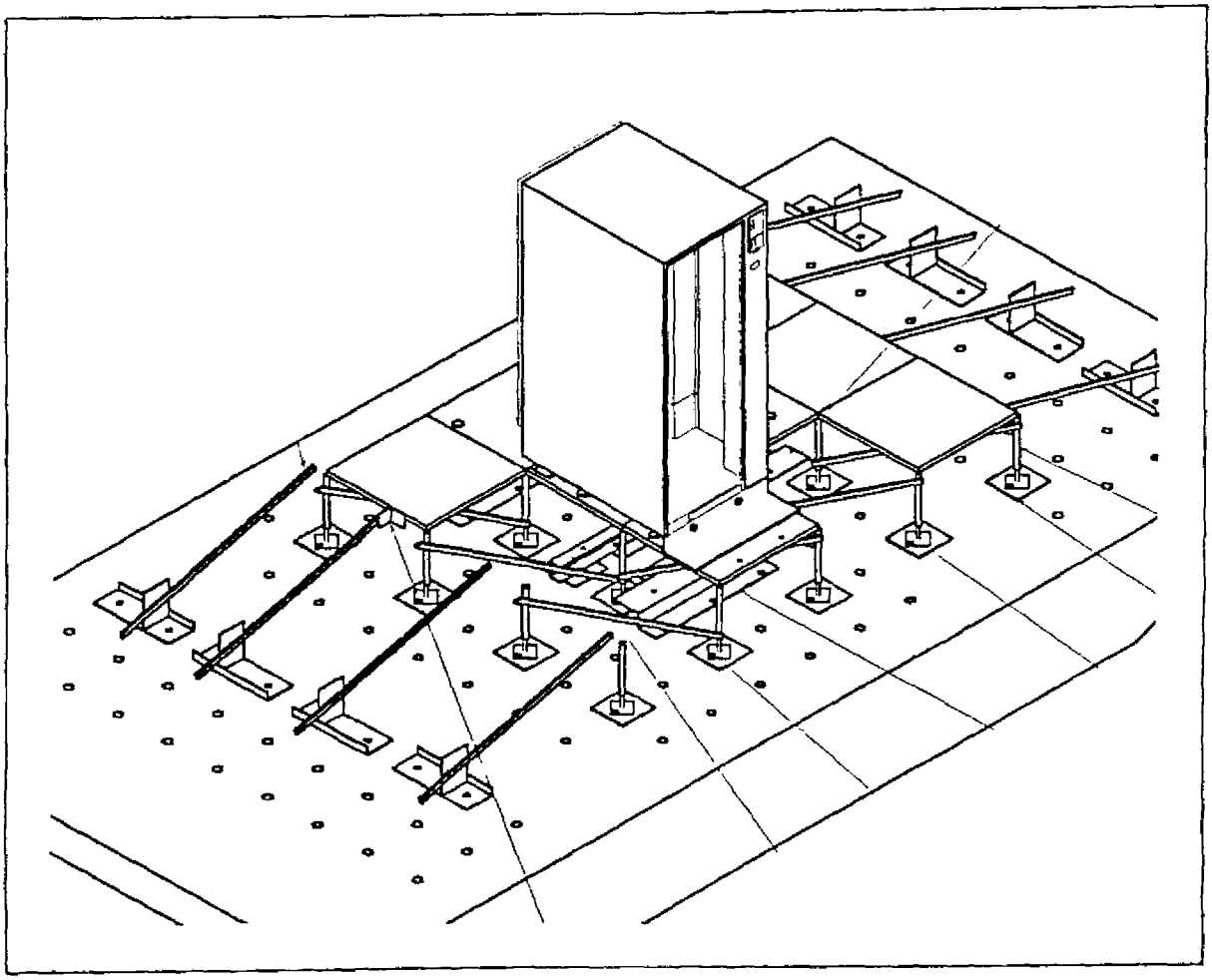


Fig. 2-2 Installation Details of Raised Floor

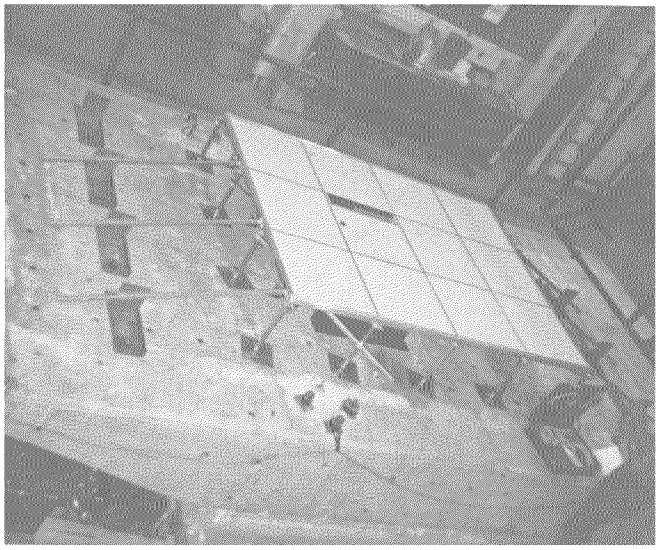


Fig. 2-3 Fully Assembled Raised Floor

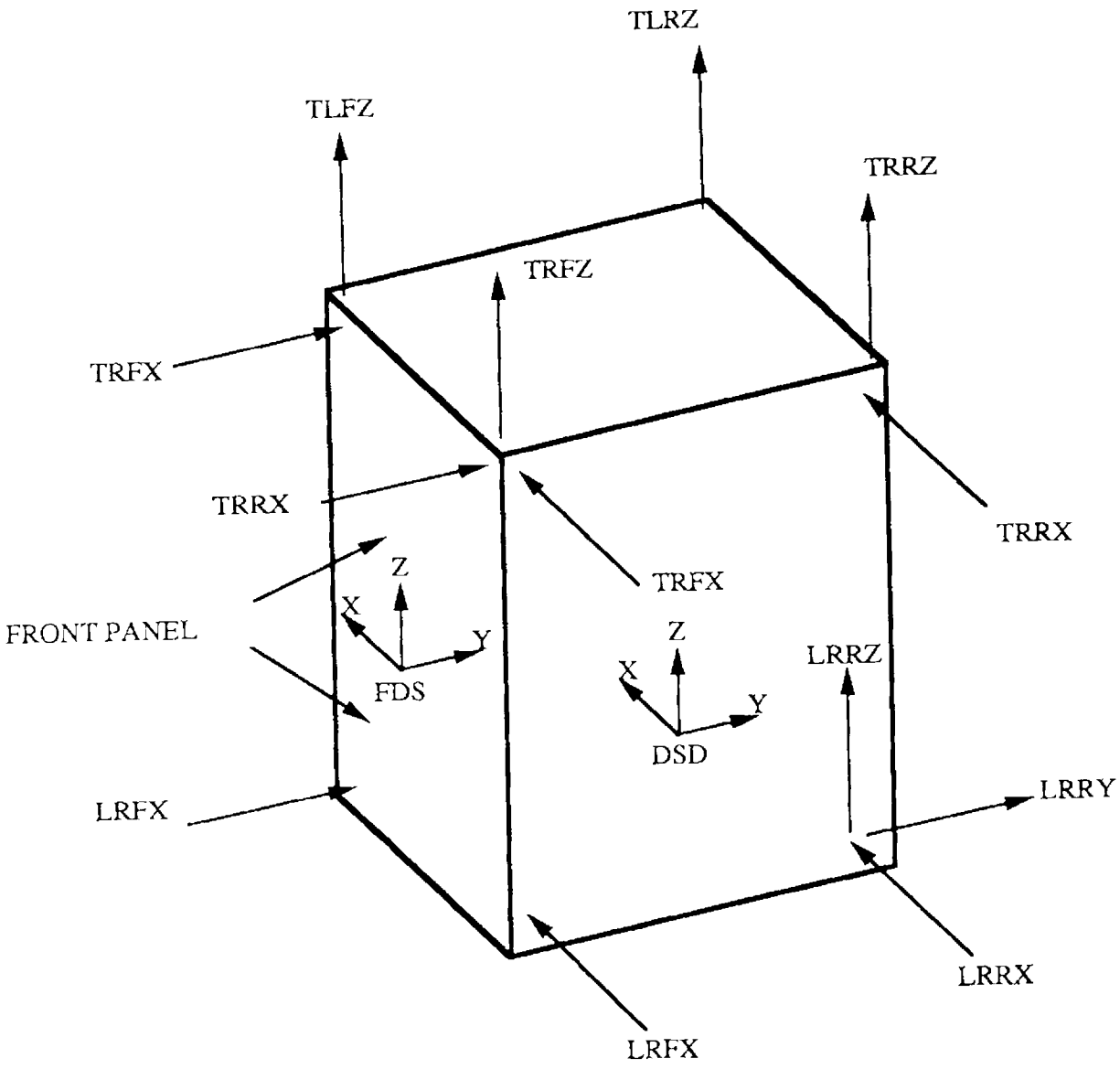


Fig. 2-4 Accelerometer Locations

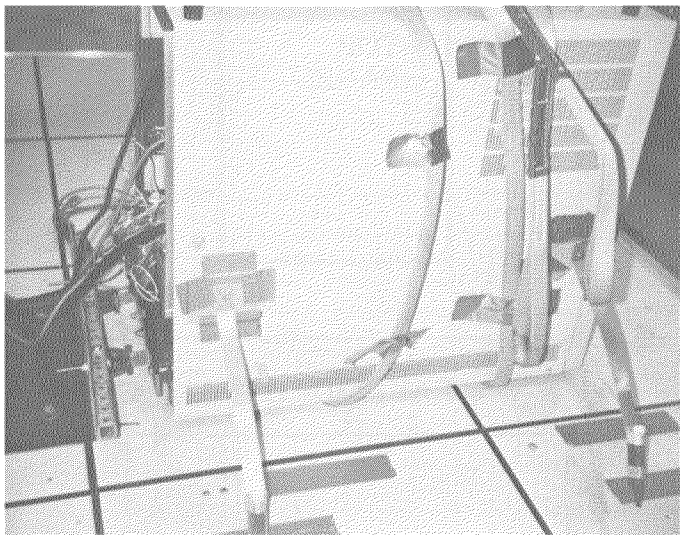


Fig. 2-5 Location of Markers

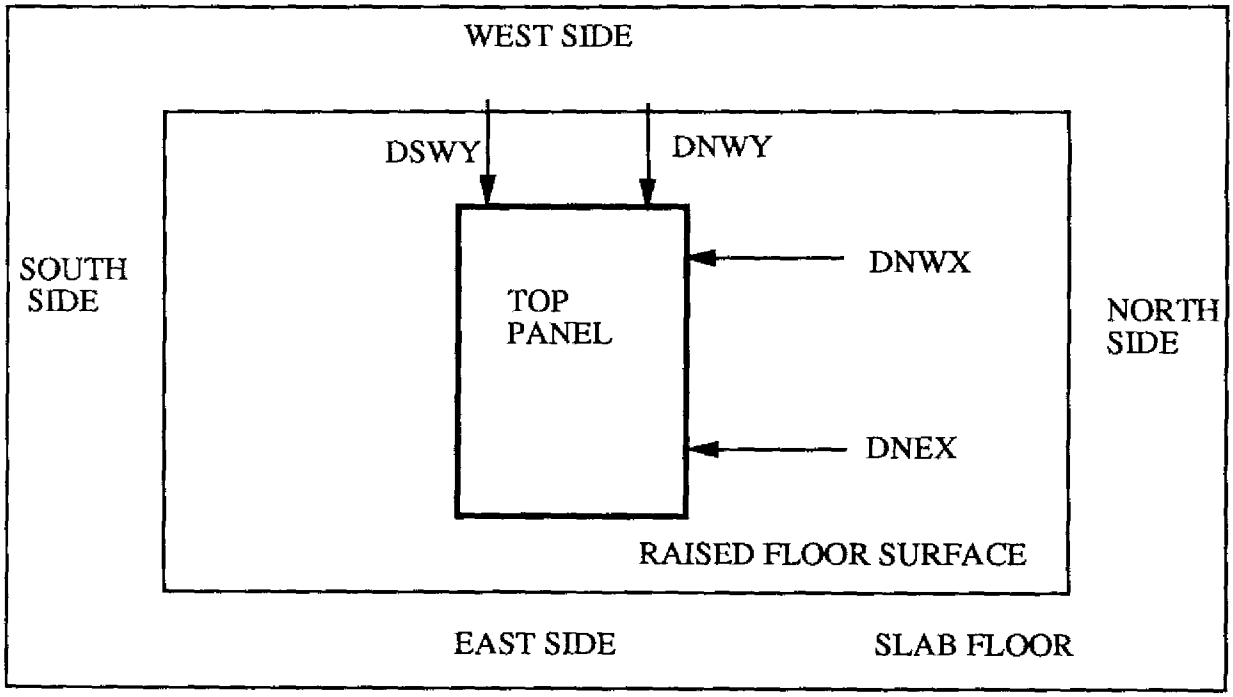


Fig. 2-6 Temposonic Transducer Locations

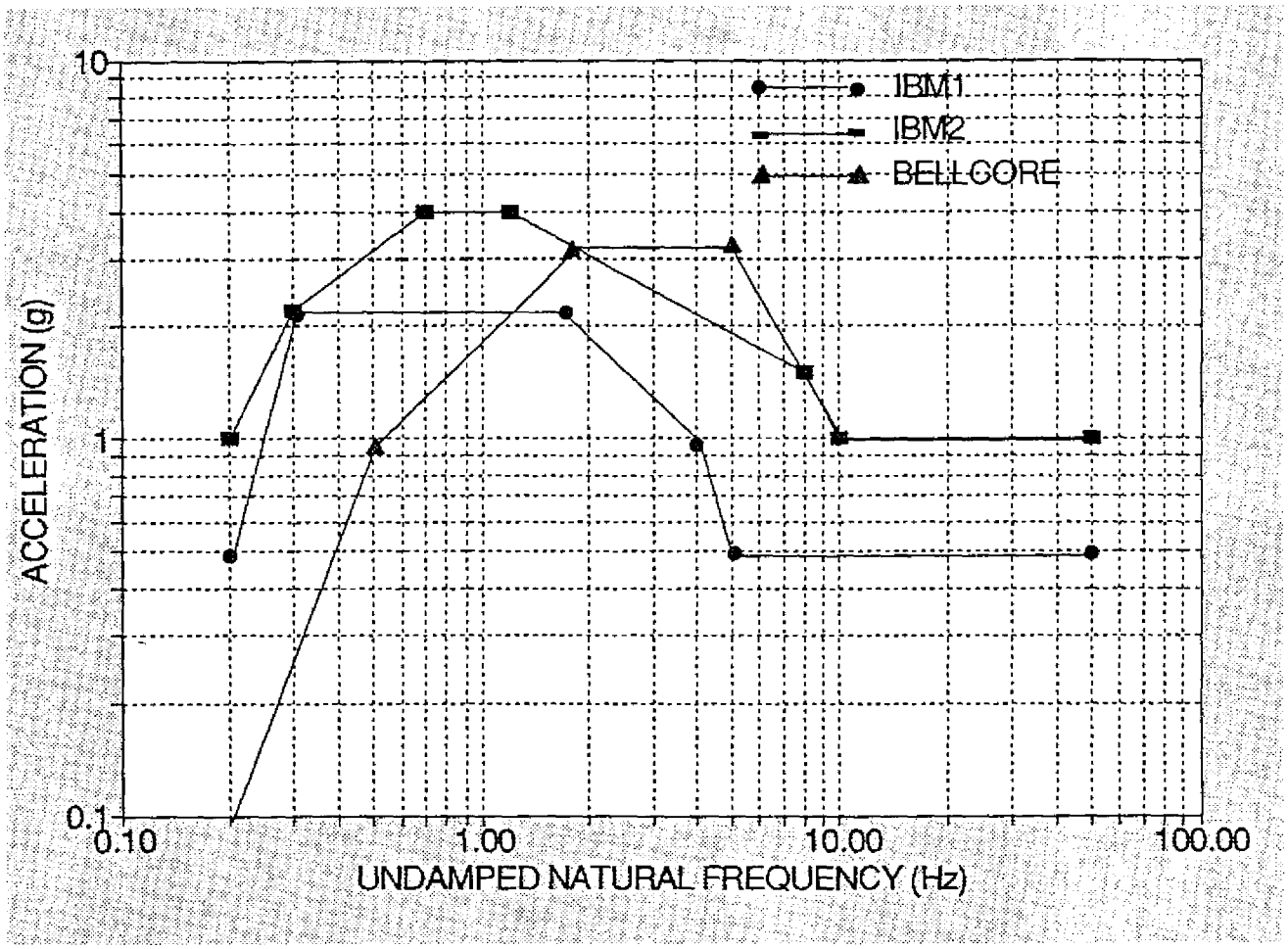


Fig. 2-7 Acceleration Response Spectra for IBM1, IBM2, and Bellcore Inputs

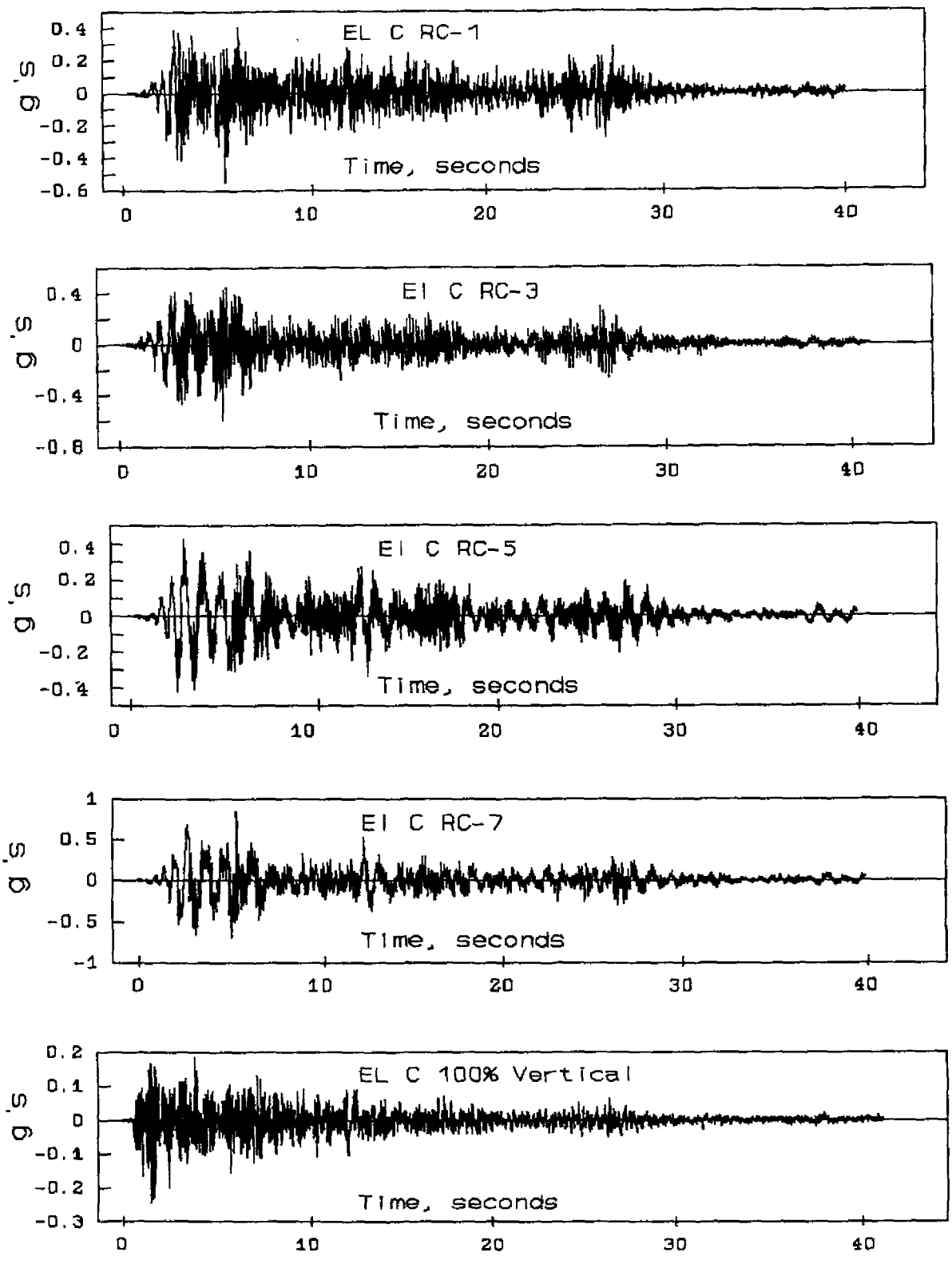


Fig. 2-8 Raised-floor Input Accelerations: El Centro Earthquake

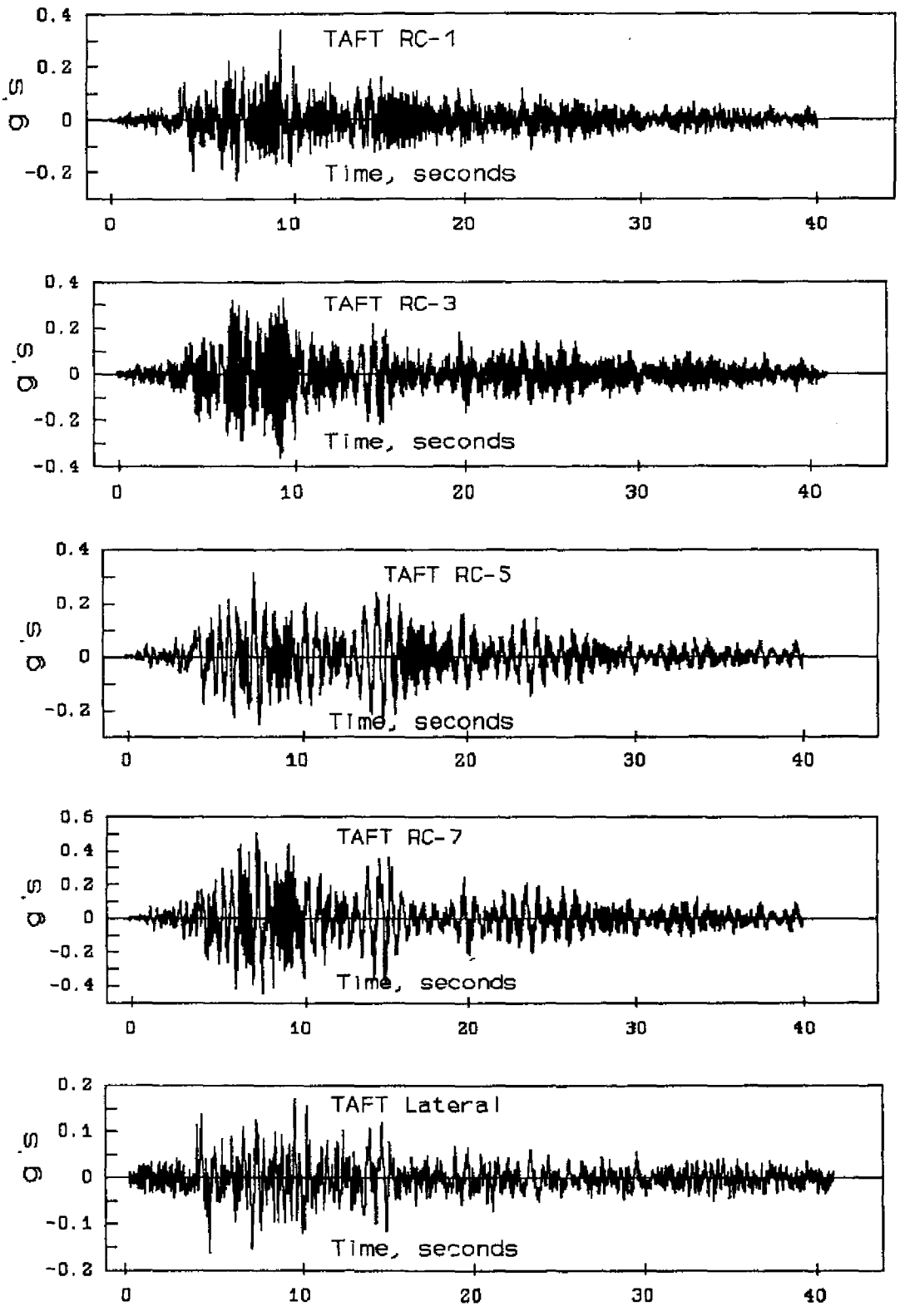


Fig. 2-9 Raised-floor Input Accelerations: Taft Earthquake

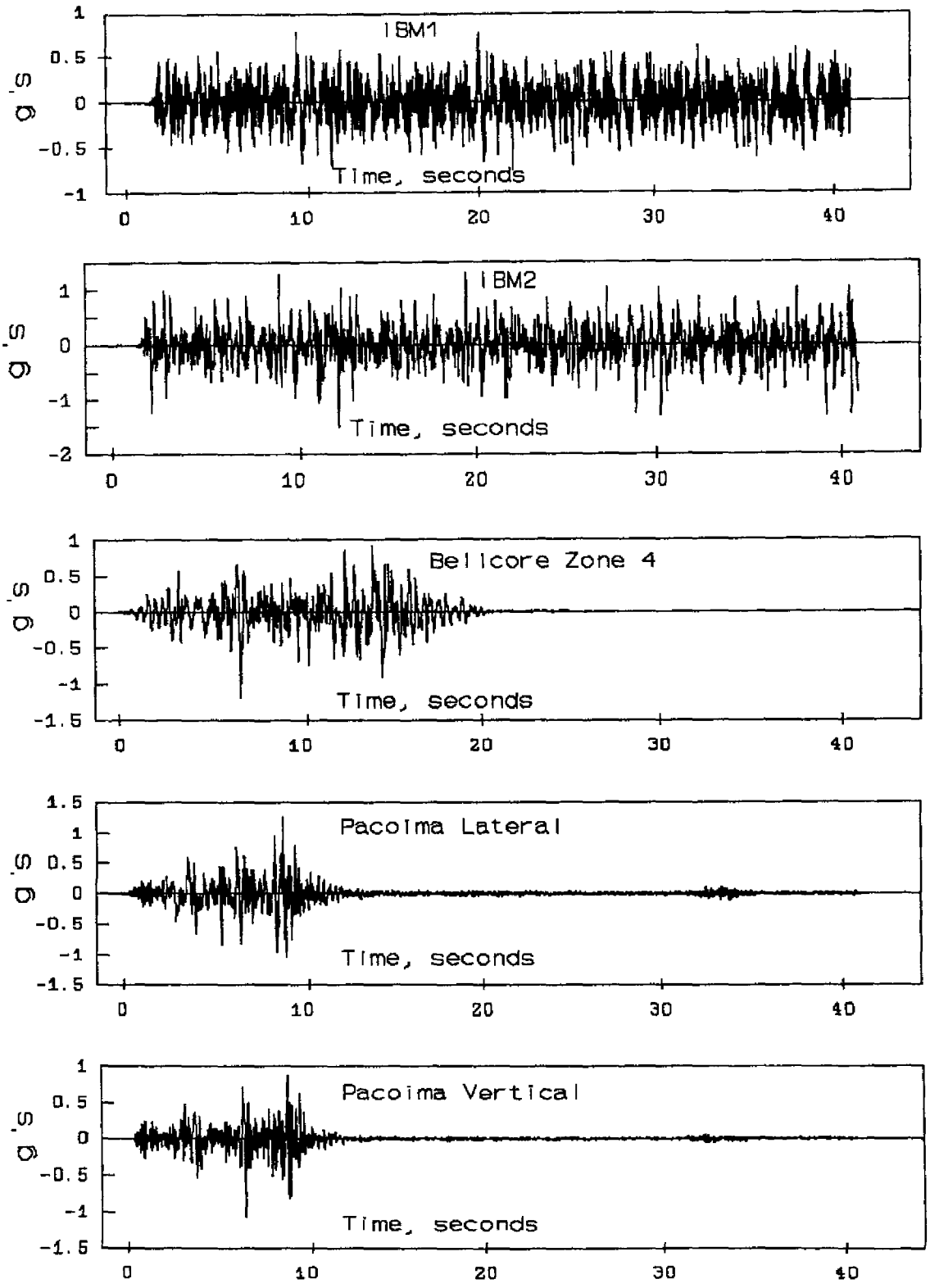


Fig. 2-10 Raised-floor Input Accelerations: IBM, Bellcore and Pacoima