CORRELATION BETWEEN RECORDED BUILDING DATA AND NON-STRUCTURAL DAMAGE DURING THE 1989 LOMA PRIETA EARTHQUAKE

by

Satwant S. Rihal

Architectural Engineering Department
Cal Poly State University
San Luis Obispo, California

Data Utilization Report CSMIP/94-04

California Strong Motion Instrumentation Program

April 1994

This study was conducted at the Cal Poly State University at San Luis Obispo and was supported by the Department of Conservation under Contract No. 1090-512.

California Department of Conservation
Division of Mines and Geology
Office of Strong Motion Studies
801 K Street, MS 13-35
Sacramento, California 95814-3531

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS
STATE GEOLOGIST

DISCLAIMER

The content of this report was developed under Contract No. 1090-512 from the Strong Motion Instrumentation Program in the Division of Mines and Geology of the California Department of Conservation. This report has not been edited to the standards of a formal publication. Any opinions, findings, conclusions or recommendations contained in this report are those of the authors, and should not be interpreted as representing the official policies, either expressed or implied, of the State of California.

PREFACE

The California Strong Motion Instrumentation Program (CSMIP) in the Division of Mines and Geology of the California Department of Conservation promotes and facilitates the improvement of seismic codes through the Data Interpretation Project. The objective of the this project is to increase the understanding of earthquake strong ground shaking and its effects on structures through interpretation and analysis studies of CSMIP and other applicable strong motion data. The ultimate goal is to accelerate the process by which lessons learned from earthquake data are incorporated into seismic code provisions and seismic design practices.

The specific objectives of the CSMIP Data Interpretation Project are to:

1. Understand the spatial variation and magnitude dependence of earthquake strong ground motion.

2. Understand the effects of earthquake motions on the response of geologic formations, buildings and lifeline structures.

3. Expedite the incorporation of knowledge of earthquake shaking into revision of seismic codes and practices.

4. Increase awareness within the seismological and earthquake engineering community about the effective usage of strong motion data.

5. Improve instrumentation methods and data processing techniques to maximize the usefulness of SMIP data. Develop data representations to increase the usefulness and the applicability to design engineers.

This report is the ninth in a series of CSMIP data utilization reports designed to transfer recent research findings on strong-motion data to practicing seismic design professionals and earth scientists. CSMIP extends its appreciation to the members of the Strong Motion Instrumentation Advisory Committee and its subcommittees for their recommendations regarding the Data Interpretation Research Project.

Moh J. Huang
CSMIP Data Interpretation
Project Manager

Anthony F. Shakal
CSMIP Program Manager

ABSTRACT

A study of non-structural damage observed in the instrumented Santa Clara County Government Center, during the Loma Prieta, California, earthquake of October 17, 1989, has been carried out, to correlate the recorded CSMIP response data with observed non-structural component damage. A methodology is presented to assess the performance and behavior of non-structural building components during earthquakes. One main objective of this seismic case-study was to investigate the relationship between seismic response parameters, e.g., peak response acceleration levels, frequency content and inter-story drift levels and corresponding non-structural damage observed during the Loma Prieta earthquake. Significant non-structural component damage was observed to have occurred particularly at the 7th and 11th floor levels. Comparison of the observed non-structural damage and peak recorded accelerations at the 7th floor (0.257g) and at the 12th floor (0.294g) shows the thresholds of response accelerations that produce non-structural component damage. It is suggested that one factor contributing to the extensive non-structural damage during the 1989 Loma Prieta earthquake may be the large number of floor acceleration cycles with amplitudes greater than 0.05g. A non-structural component damage index expressed as a percentage of components damaged is proposed as a means of characterizing observed non-structural component damage data.

APPLICATION TO CODES AND PRACTICES

Solution to most of the hazardous and expensive non-structural damage that occurred in this building lies outside the scope of most building code provisions. This points out the need for standards to mitigate damage to building contents. One example of application of the results is the threshold level of floor accelerations that caused damage to book shelving and filing cabinets. At the seventh floor level where extensive non-structural damage occurred, maximum recorded floor acceleration was 0.257g. Application of Uniform Building Code provisions for non-structural components (Table 23-P, 1991 Edition) showed that the typical filing cabinets satisfied these code requirements, but they still suffered damage.

ACKNOWLEDGEMENTS

This study is supported by a research grant from the Strong Motion Instrumentation Program of the California Department of Conservation. This support is gratefully acknowledged. The author would like to thank Dr. Moh Huang and Dr. Tony Shakal of the CSM1P for their encouragement, help and support. The valuable assistance of Mr. Wes Van Osdol of the County of Santa Clara, General Services Agency during this study is gratefully acknowledged. The author acknowledges the contribution of Robert Reitherman during the course of this investigation. The author acknowledges the valuable assistance of project research assistants Evelyn Pratt, John La Porta, Paul Philbaum, Mat Melcher and Tonya Emerson during the course of this research study. The contents of this report were developed under contract no. 1090-512 from the California Department of Conservation, Division of Mines and Geology, Strong Motion Instrumentation Program. However, those contents do not necessarily represent the policy of that agency nor endorsement by the State of California.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

An important aspect of the Loma Prieta, California, earthquake of October 17, 1989 was the widespread non-structural component damage observed and reported in a broad class of buildings during this earthquake. Such non-structural damage was distributed over the San Francisco Bay Area, including cities of Oakland, San Francisco, selected areas of peninsula cities and San Jose. Even three years after this major earthquake struck the San Francisco Bay area, no systematically collected statistics of non-structural component damage are available as yet [2][1]. Based on observed performance and behavior of building components during this earthquake, it is clear that the major consequences of the non-structural component damage were the significant losses caused by such damage including disruption of building functions as well as possible life-hazards in some cases. It is worth noting that as expected non-structural damage was observed mainly in modern multi-story buildings which otherwise behaved satisfactorily during the Loma Prieta, California Earthquake. A valuable and unique opportunity was provided by recorded data obtained from instrumented buildings, especially those that suffered non-structural damage during the Loma Prieta earthquake.

---

[1] Numbers in parenthesis refer to list of references on page 64

CHAPTER 2: SCOPE AND OBJECTIVES

The main objective of the project is to analyze recorded SMIP data and study the correlation between available recorded data and non-structural component damage in instrumented buildings during the Loma Prieta earthquake of October 17, 1989.

Further objectives are as follows:

1. To make a case-study of the seismic performance and behavior of an instrumented building which suffered non-structural component damage and make a comparison with its performance and behavior during the 1984 Morgan Mill and the 1986 Mt. Lewis earthquakes.

2. To develop a method for assessing the performance and behavior of non-structural building components during earthquakes.

CHAPTER 3: INSTRUMENTED BUILDING CASE-STUDY SANTA CLARA COUNTY GOVERNMENT CENTER IN SAN JOSE

After initial study it was decided to lead this research project with a case-study of the Santa Clara County Government Center in San Jose. This building has been the source of recorded data from two previous earthquakes in 1984 and 1986, and has been the subject of studies by other investigators [1] [6] [7]. The overall view of this case-study building is presented in Figures 1 and 2.

Figure 1: Santa Clara County Government Center - San Jose
Overall View from the South-West

Figure 2: Santa Clara County Government Center - San Jose
Overall View from the North-West

CHAPTER 4: DESCRIPTION OF BUILDING STRUCTURAL SYSTEM

This thirteen story building is essentially square in plan configuration. The structural system consists of moment-resisting frames at 26 ft. o.c. in both directions. Wings along the west and south sides of the building are used primarily for circulation, i.e., elevators and stairs as well as for mechanical systems. These wings are offset in plan, which is the only plan irregularity in the layout of the primary structural system. Furthermore, these wings extend one floor above the roof which is the main vertical irregularity in the building structural system. There is a non-structural irregularity on the southwest corner between the two wings discussed above. From the ground floor to the fifth floor there is a glass enclosed architectural space. The first five levels of this space is an atrium that frames into the floor slabs of the main building with steel pipes at the third and fourth levels. At the second floor is a link bridge from the new building to the circular auditorium, otherwise the space is open to the floor of the fifth level. The atrium is a frame of rectangular steel channels which supports the glass enclosure. The main foundation system consists of a solid mat foundation. The typical floor framing plan is presented in Figure 3. Typical moment-resistng-frame elevations are shown in Figures 4 and 5.

An unusual and unique irregularity was found in the structural framing system. The girders (W21x82) that are part of the E-W moment-resisting rigid frames are offset from the nominal floor diaphragm level by 3'-0″ as shown in Figure 6.

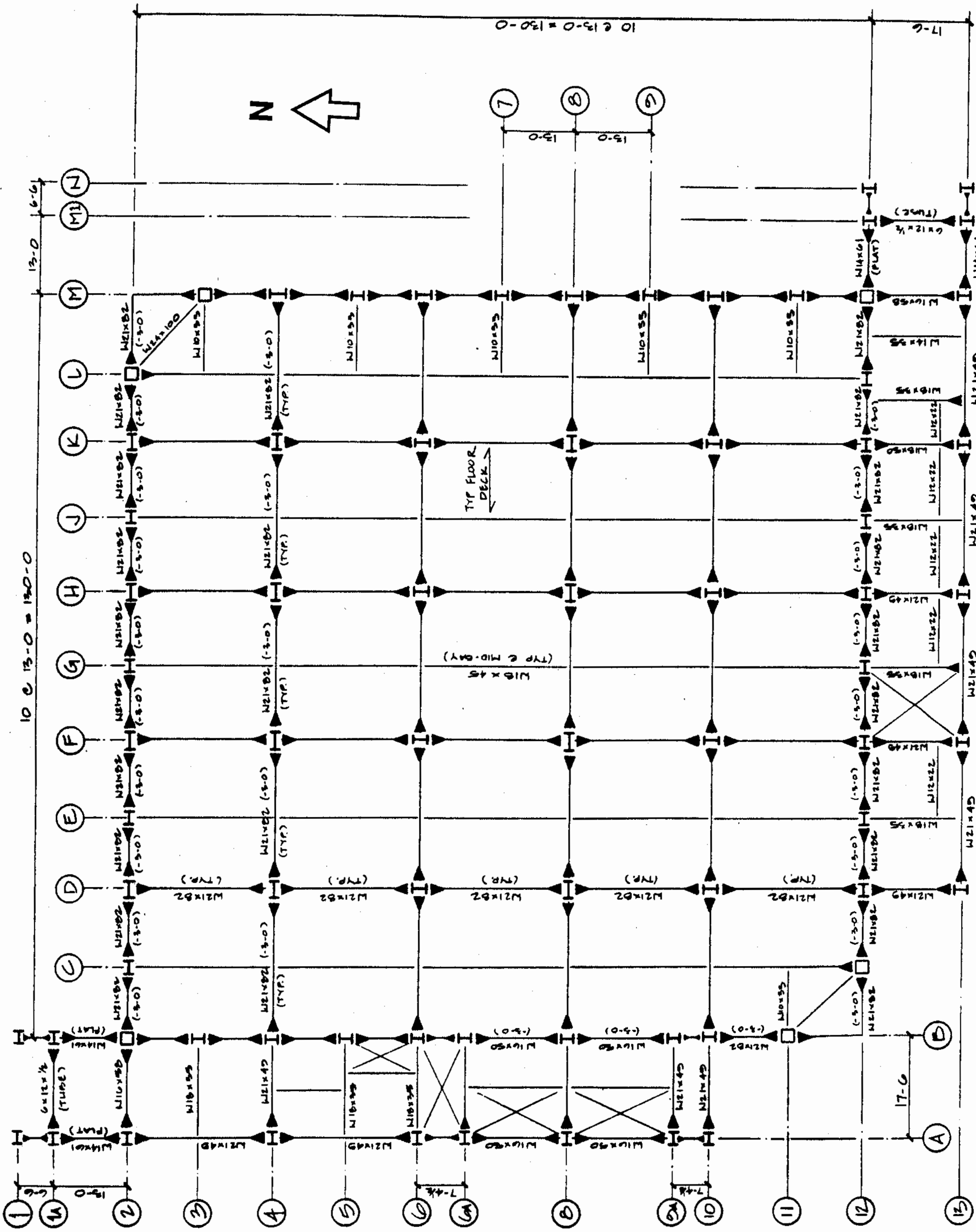


Figure 3: Santa Clara County Government Center - San Jose Framing Plan (Typical)

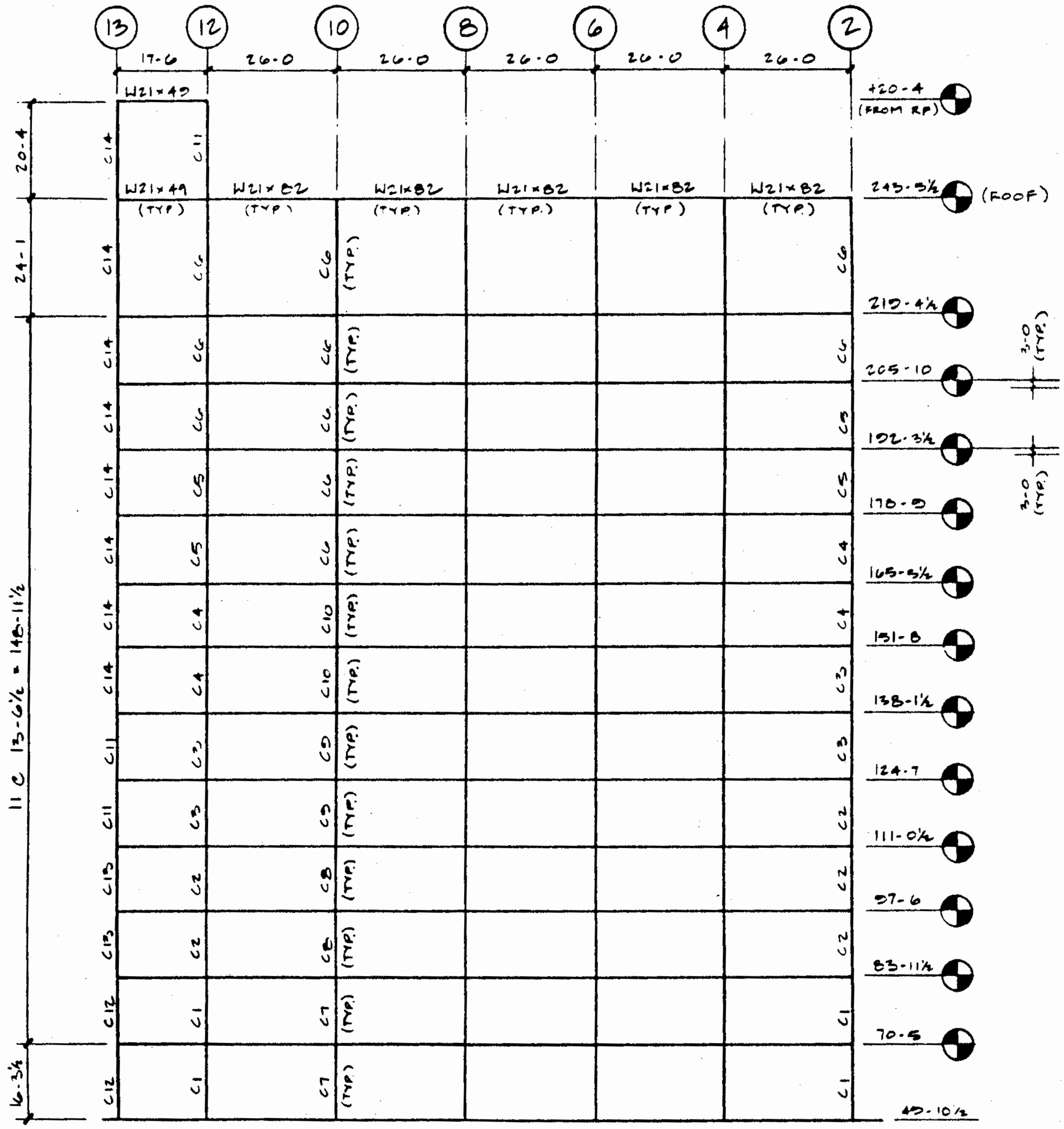


Figure 4: Santa Clara County Government Center - San Jose
Typical North-South Moment Resisting Frame

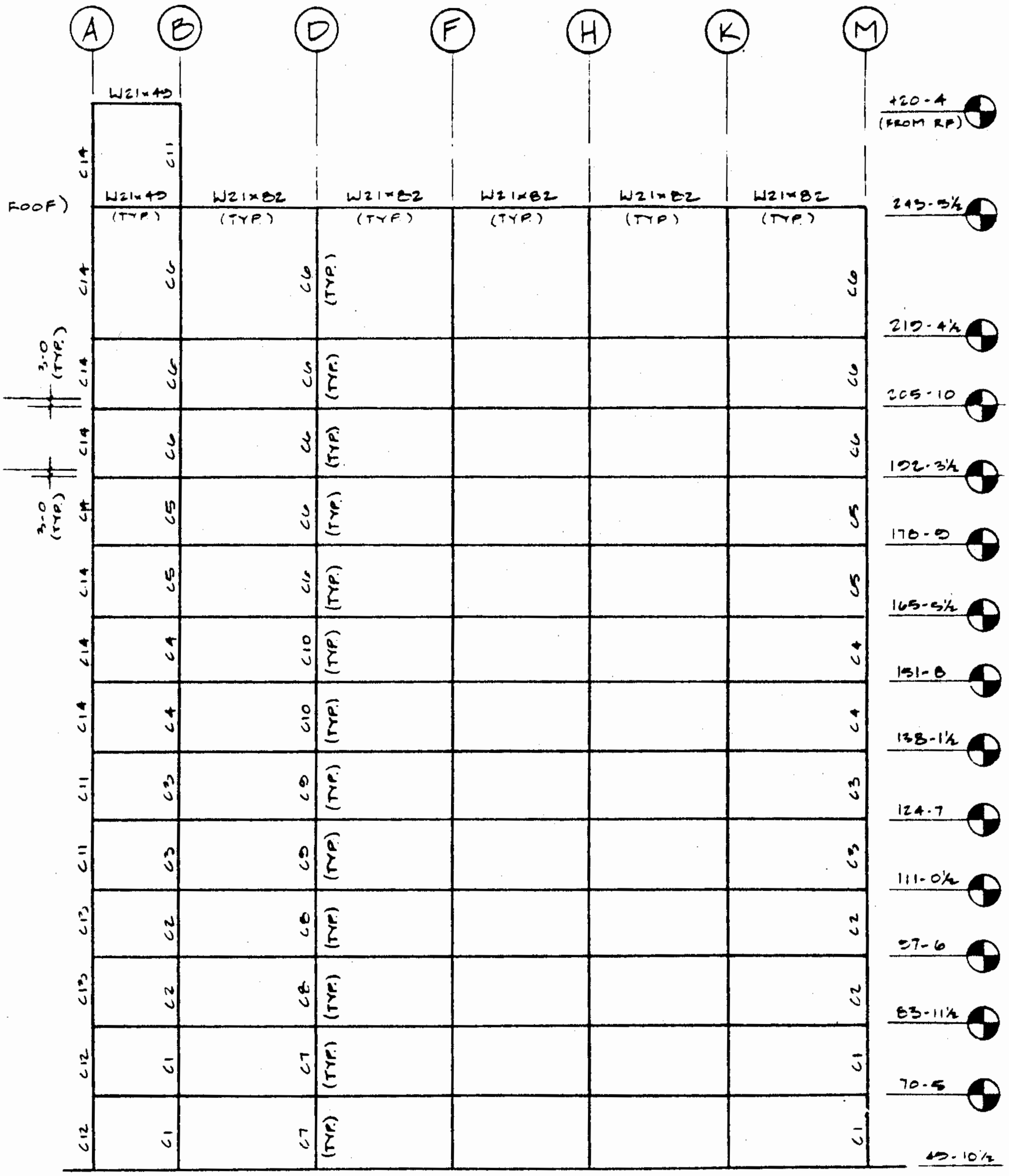


Figure 5: Santa Clara County Government Center - San Jose
Typical East-West Moment-Resisting Frame

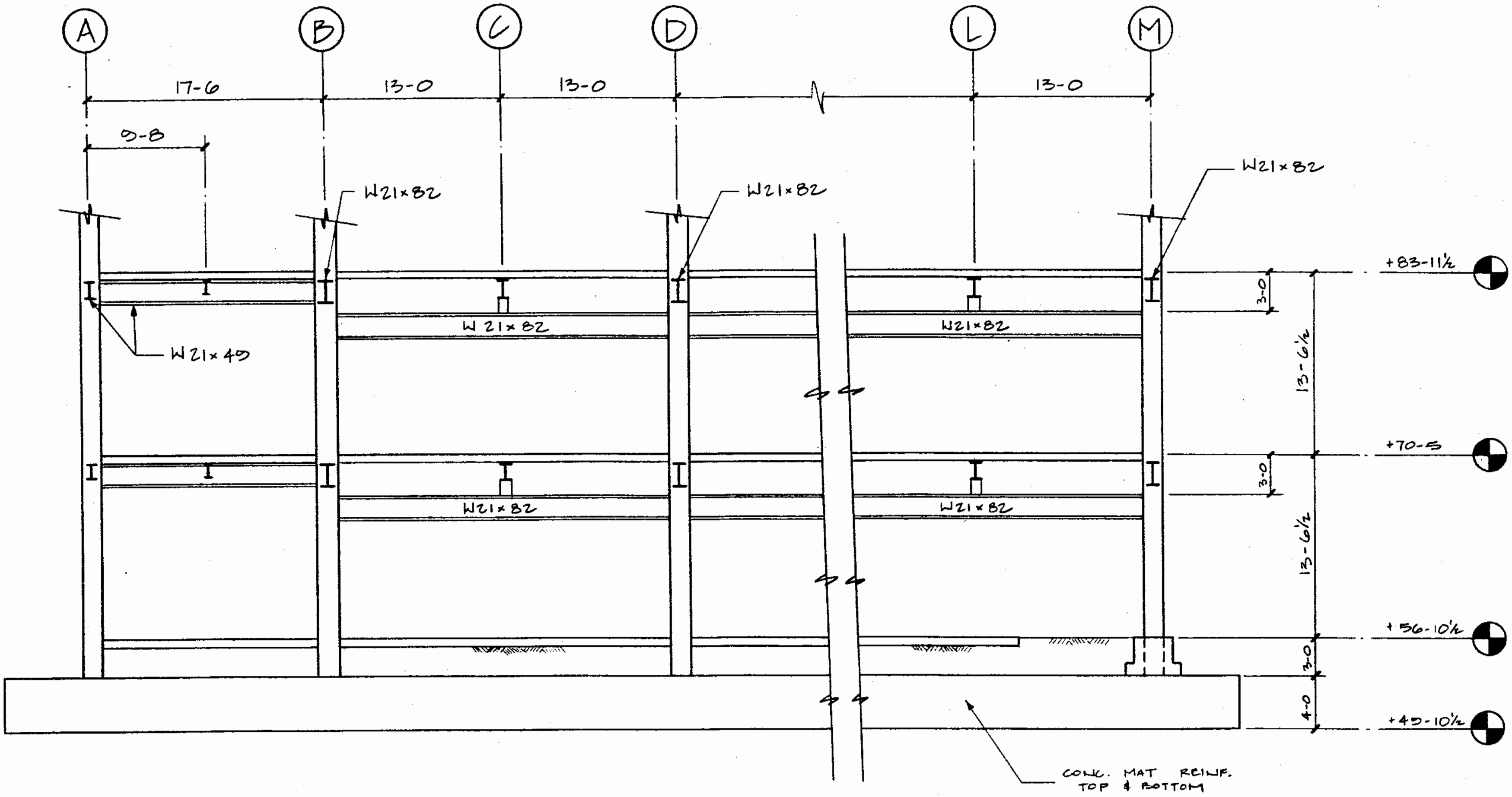


Figure 6: Santa Clara County Government Center - San Jose
Floor System - Details

CHAPTER 5: OBSERVED NON-STRUCTURAL DAMAGE

Loma-Prieta Earthquake of October 17, 1989

Non-structural building components are classified to include partitions, suspended ceilings, curtain walls, facades and cladding, and contents, e.g., filing cabinets, book shelves, computer equipment, office furniture, etc. Table 23-P of 1991 UBC [11] defines non-structural components that have to be braced, e.g., permanent floor-supported cabinets and book stacks more than 5 feet in height. The non-structural damage observed in the Santa Clara County Government Center falls mainly in the category of contents damage including damage to interior space-enclosure partial-height partitions. Most building contents are not regulated by building codes.

In general valuable non-structural damage data get lost soon after an earthquake due to the necessity to quickly repair such damage to bring building facilities back into operation. For this case-study, the Santa Clara County Government Center, a video tape documenting nonstructural damage observed soon after the Loma Prieta earthquake, was obtained [12] for study and analysis. A review of the video tape [12] of observed non-structural damage shows that there was substantial damage to contents in this building facility, mainly at the 7th, 9th, 10th and 11th floor levels with some non-structural damage also observed on the 6th and 8th floors.

According to Van Osdol, Loss Prevention Specialist, GSA, County of Santa Clara [12], the extent of non-structural component damage during the 1989 Loma Prieta earthquake was much greater than that during the 1984 Morgan Hill and 1986 Mt. Lewis earthquakes. The floor motions experienced were strong enough to cause extensive damage to lateral file cabinets (side opening) and similar non-structural components. It appears that long rows of such filing cabinets bolted end-to-end and not back-to-back overturned, creating very hazardous conditions for safe evacuation of building occupants, immediately after the Loma Prieta earthquake. None of the filing cabinets were attached to the floor. There were no latches on the drawers. One major factor that contributed to the overturning failure of lateral file cabinet systems was the sudden opening of an upper drawer which caused these components to overturn due to the adverse P-Δ effect. According to Van Osdol [12], those filing cabinets that were attached back-to-back and end-to-end including end units arranged normal to the row configuration and attached back to back, performed satisfactorily during the 1989 Loma Prieta earthquake.

A systematic classification of non-structural components, corresponding observed damage as well as its distribution across the height of the building is presented in Table I.

Typical and representative non-structural component damage observed at the 7th and 11th floor levels is graphically presented in Figure 7.

Morgan-Hill Earthquake of April 14, 1984

According to damage data provided by Van Osdol [12], the non-structural component damage observed in the Santa Clara County Government Center during the 1984 Morgan Hill earthquake was similar to that observed during the 1989 Loma Prieta earthquake. During the 1984 Morgan Hill earthquake such non-structural component damage was located on the 7th, 8th, 9th, 10th, and 11th floor levels. There was a lot of shelving damage in the library located on the 9th floor.

Mt. Lewis Earthquake of March 31, 1986

According to Van Osdol [12], the County of Santa Clara carried out some retrofitting of non-structural components, e.g. bolting filing-cabinet systems together after the 1984 Morgan Hill earthquake. The pattern of damage was similar to that observed during the 1984 Morgan Hill earthquake. After the 1986 Mt. Lewis earthquake, bracing was added for the 9th floor library shelving. During the 1989 Loma Prieta earthquake, there was no damage to this library shelving at the 9th floor.

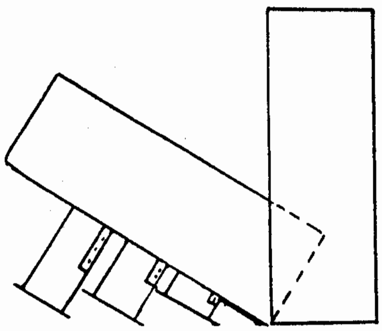
TABLE I

SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
1989 LOMA PRIETA EARTHQUAKE
CLASSIFICATION OF OBSERVED NON-STRUCTURAL DAMAGE

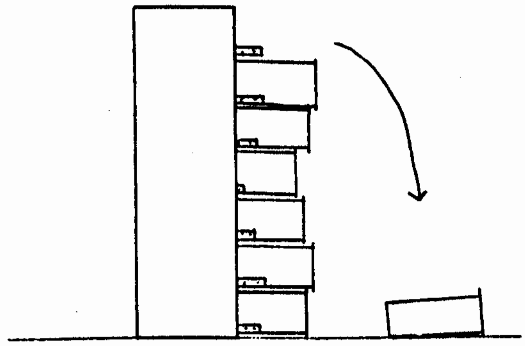
LEVEL	NON-STRUCTURAL COMPONENT	DESCRIPTION OF NON-STRUCTURAL DAMAGE										
		Toppled Forward	Toppled Backward	Opened	Moved Rel. to Original Position	Fell Down	Jumped Up	Torsion on Component	Chip-ped	Scat-tered	Warped	In Plane Buck-ling
7	File Cabinets	X	X	X	X			X				
7,11	Drawers in Desks			X	X	X		X				
7	Phone				X							
7,11	5+' Partitions	X	X		X	X						
7,11	6'Book-shelves	X	X		X	X						
7	Ceiling Plaster								X			
7	HP Computer	X			X			X				
7	Ceiling Molding				X	X						
7	Microfiche Files				X					X		
7	Desks				X							
7,11	Computer Screen		X		X			X				
7,11	Book-shelves				X							
7,11	General Supplies				X	X				X		
11	Laser Printer				X							

TABLE I
SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
1989 LOMA PRIETA EARTHQUAKE
CLASSIFICATION OF OBSERVED NON-STRUCTURAL DAMAGE
(Continued)

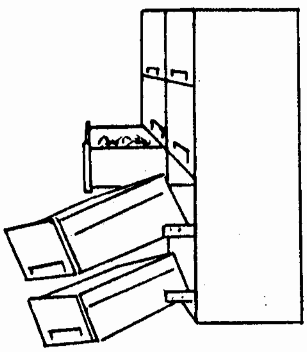
LEVEL	NON-STRUCTURAL COMPONENT	DESCRIPTION OF NON-STRUCTURAL DAMAGE										
		Toppled Forward	Toppled Backward	Opened	Moved Rel. to Original Position	Fell Down	Jumped Up	Torsion on Component	Chip-ped	Scat-tered	Warped	In Plane Buck-ling
11	Laser Ptr. Cart				x							
8,10, 11	Plant Pots Broken				x	x			x	x		
11	Bookshelves on wall				x							
9	Microwave		x		x	x						
9	Bookshelves Standing									x		
10	ComputerSys. on wheels				x							
5,7	Ceiling Moulding					x						
4	Ceiling Tile/Pipes					x						
4	Concrete Column							x	x	x		
4	Supporting Staircase											
4	Baseboard Molding				x						x	
7	Xerox Machine				x							
7	Air Condi-tion vents				x	x						
7	Bookshelves Library	x			x	x				x		x



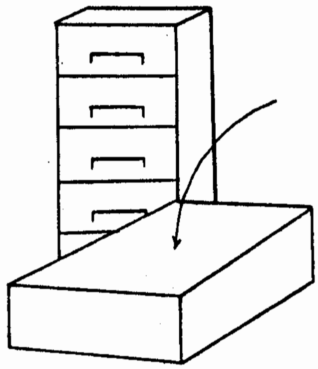
FLOOR 7 - File Cabinets Overturned



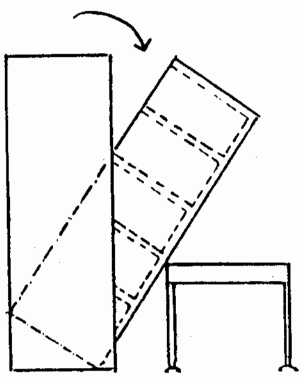
FLOOR 7 - Drawer Thrown From Cabinets



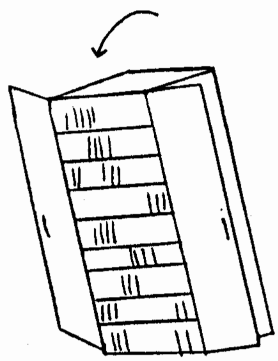
FLOOR 11 - Lower Drawers in the File Cabinets Opened and Twisted off Tracks



FLOOR 7 - File Cabinets Tipped Foreward with Drawers Closed



FLOOR 7 - Open Faced Bookshelves Tipped Backward



FLOOR 7 - Storage Cabinet Tilted Approx. 30° Doors Opened, Contents Strewn

Figure 7: Santa Clara County Government Center - San Jose
Representative Non-Structural Component Damage
1989 Loma Prieta Earthquake

CHAPTER 6: ANALYSIS OF RECORDED MOTIONS

The location and orientation of the twenty-two sensors in the Santa Clara County Government Center is presented in Figure 8.

The typical recorded and processed time-history data obtained from the strong motion instruments in the Santa Clara County Government Center, during the 1989 Loma Prieta; 1986 Mt. Lewis; and 1984 Morgan Hill earthquakes, as provided by the CSMIP program [3] [9] [10], is shown in Figures 9 and 10.

Representative floor acceleration response spectra obtained from each of the instrumented floors are presented in Figures 11, 12, and 13. These acceleration spectra graphs are based on Volume 3 data provided by CSMIP [3] [9] [10].

A comparison of the peak floor accelerations and peak floor displacements recorded during the 1989 Loma Prieta, 1986 Mt. Lewis and 1984 Morgan Hill earthquakes is presented in Table II.

An approximate analysis of recorded acceleration time-history data for channel 14 (7th floor) and channel 10 (12th floor) was made and resulting estimated building periods are presented in Table III.

San Jose - 13-story Government Office Bldg.

(CSMIP Station No. 57357)

SENSOR LOCATIONS

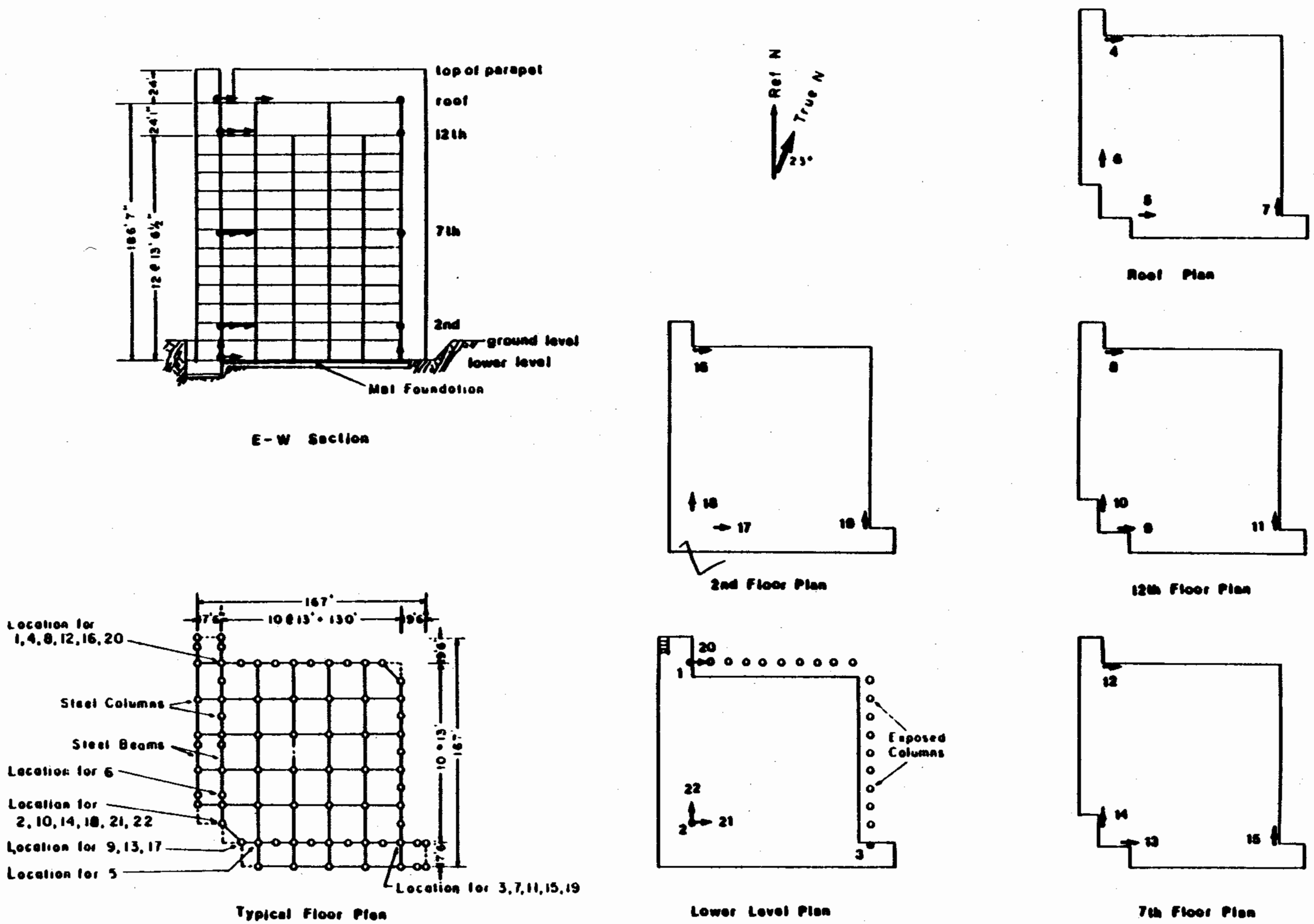


Figure 8: Santa Clara County Government Center - San Jose Sensor Layout, Location and Orientation (Source Ref. 9)

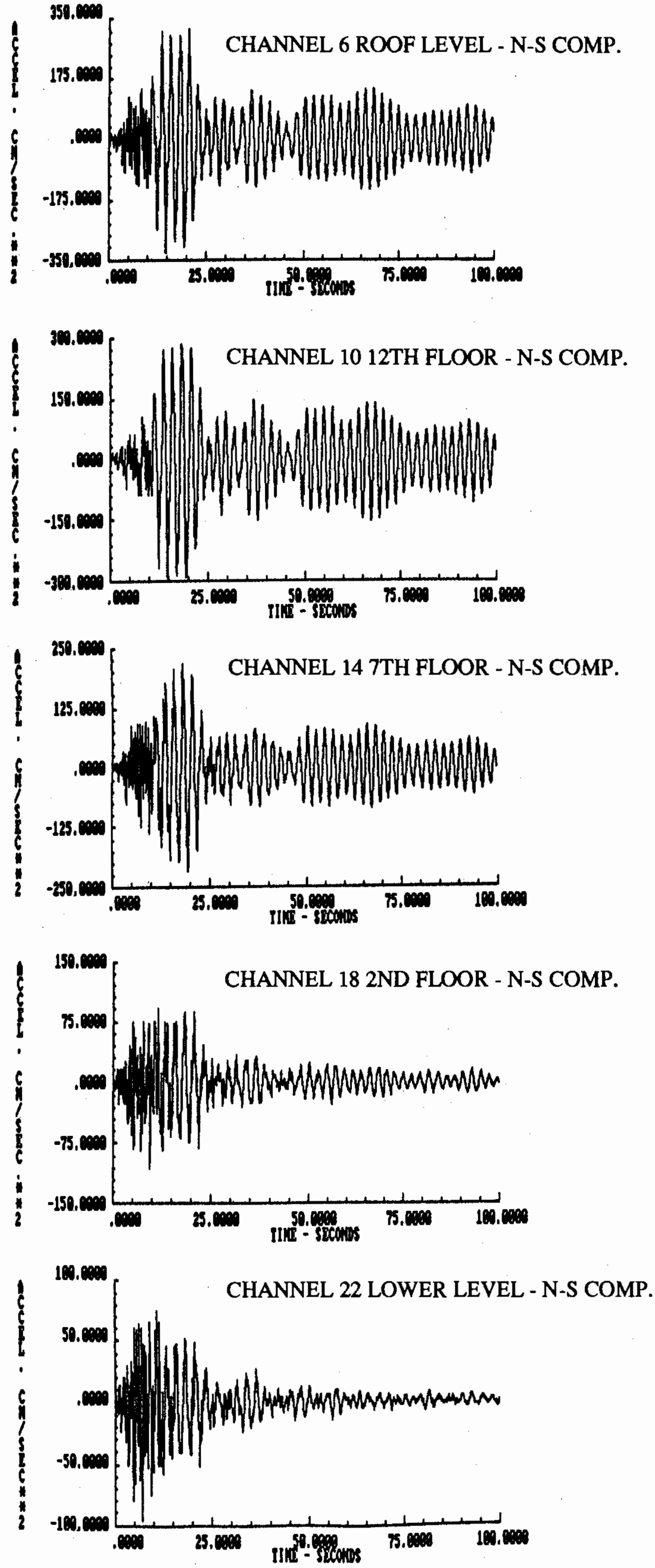


Figure 9: 1989 Loma Prieta Earthquake - Recorded Acceleration Time-History Data

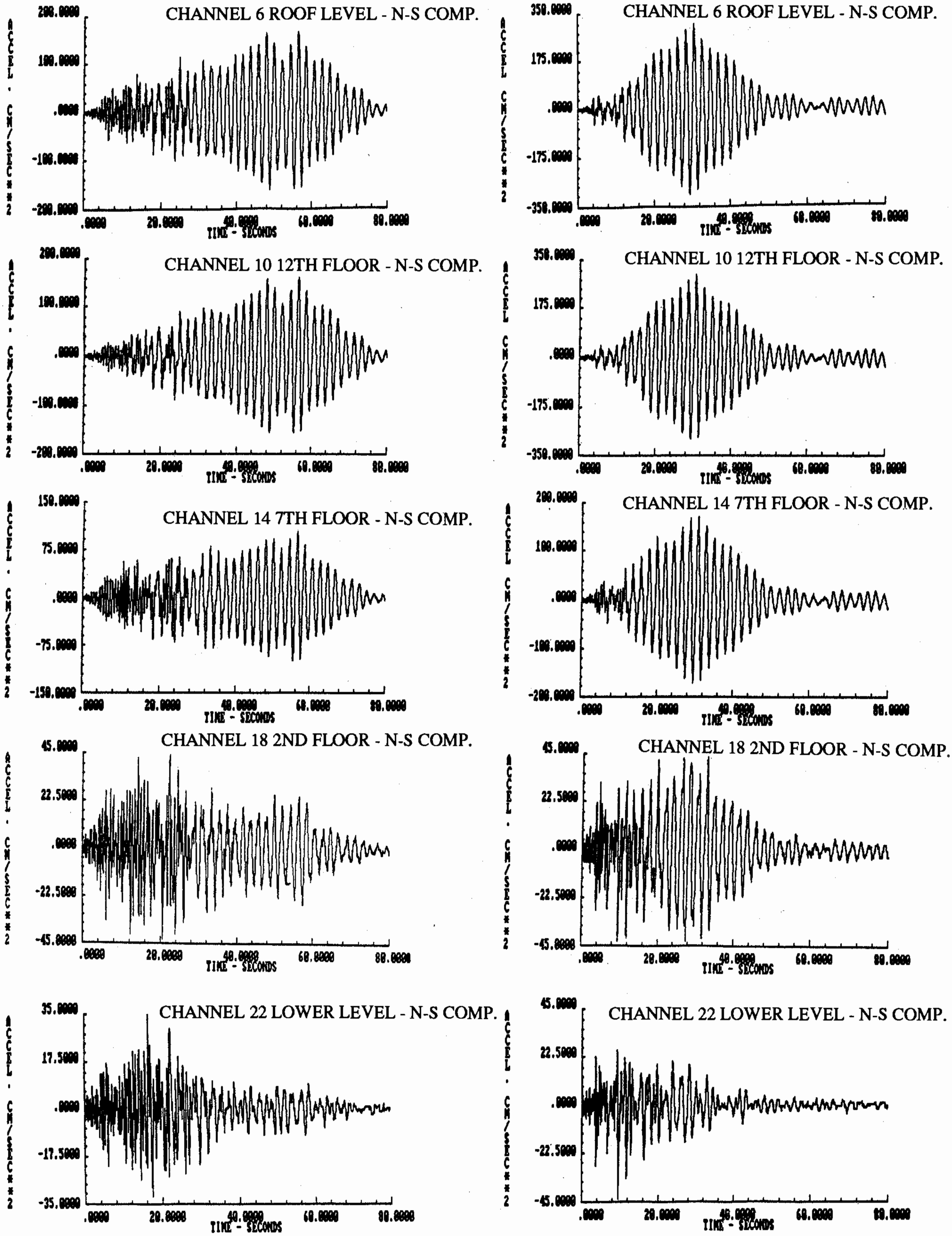


Figure 10: Recorded Acceleration Time-History Data
1984 Morgan Hill Earthquake (left) - 1986 Mt. Lewis Earthquake (Right)

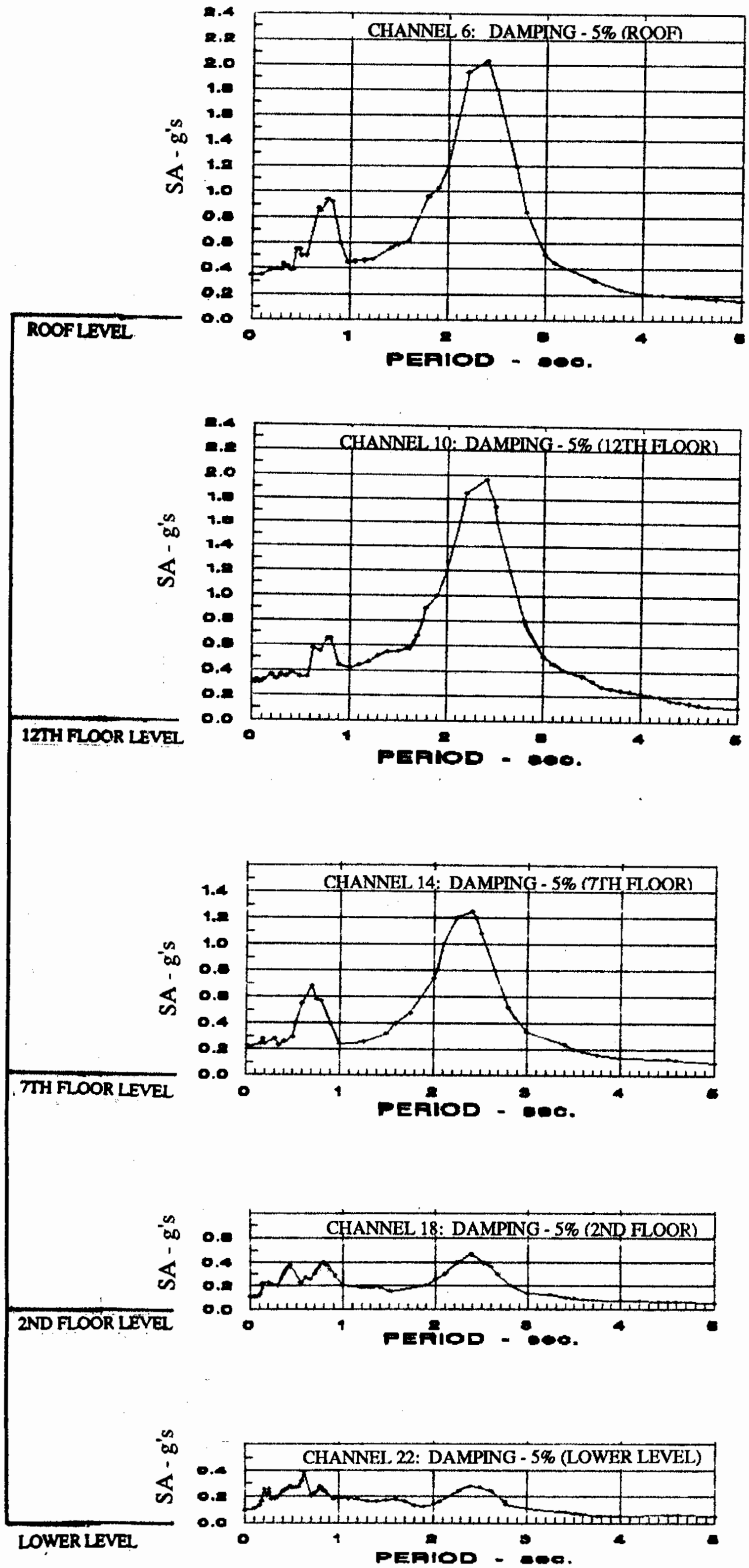


Figure 11: Recorded Floor Acceleration Response Spectra 1989 Loma Prieta Earthquake

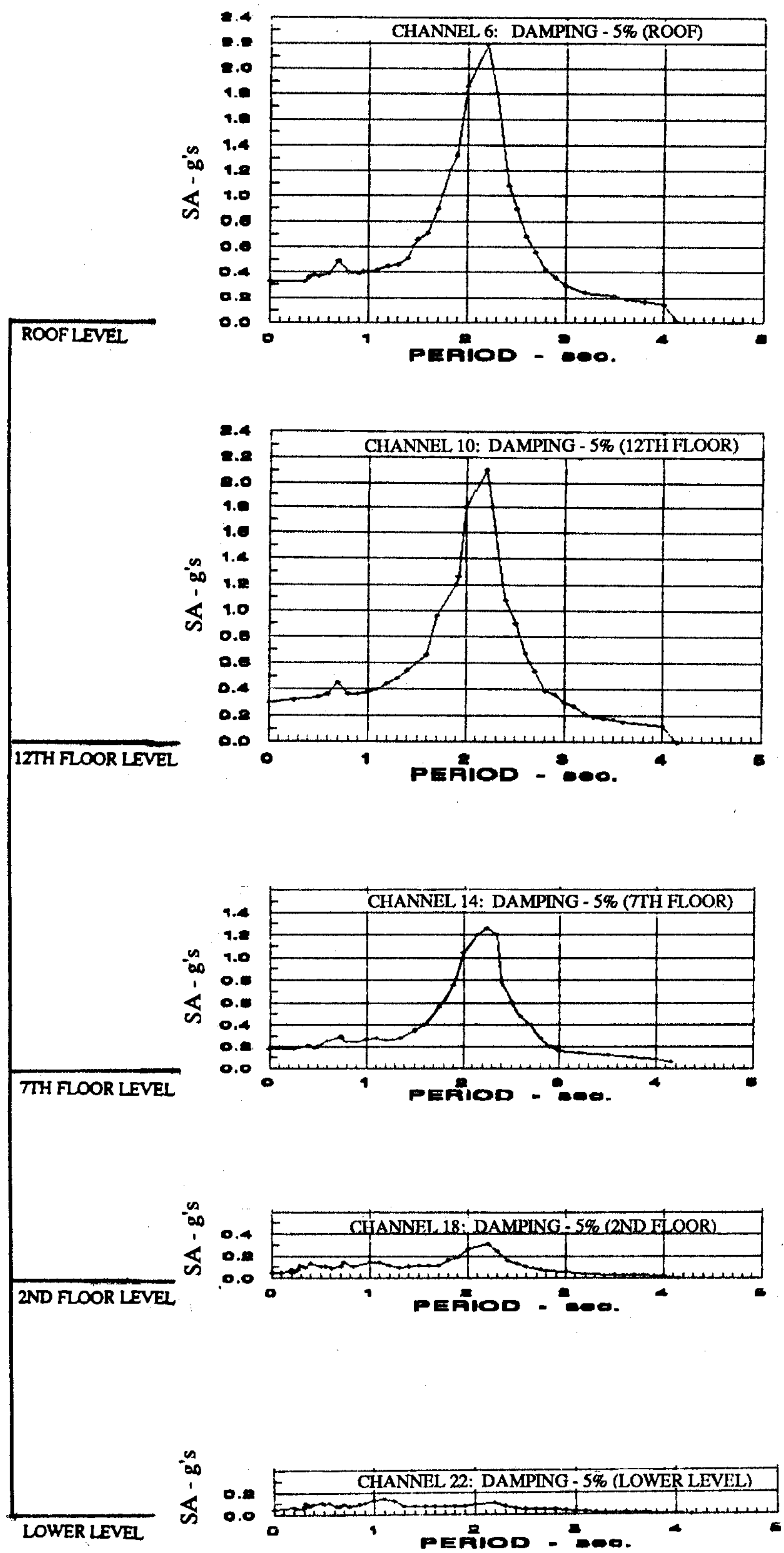


Figure 12: Recorded Floor Acceleration Response Spectra
1986 Mr. Lewis Earthquake

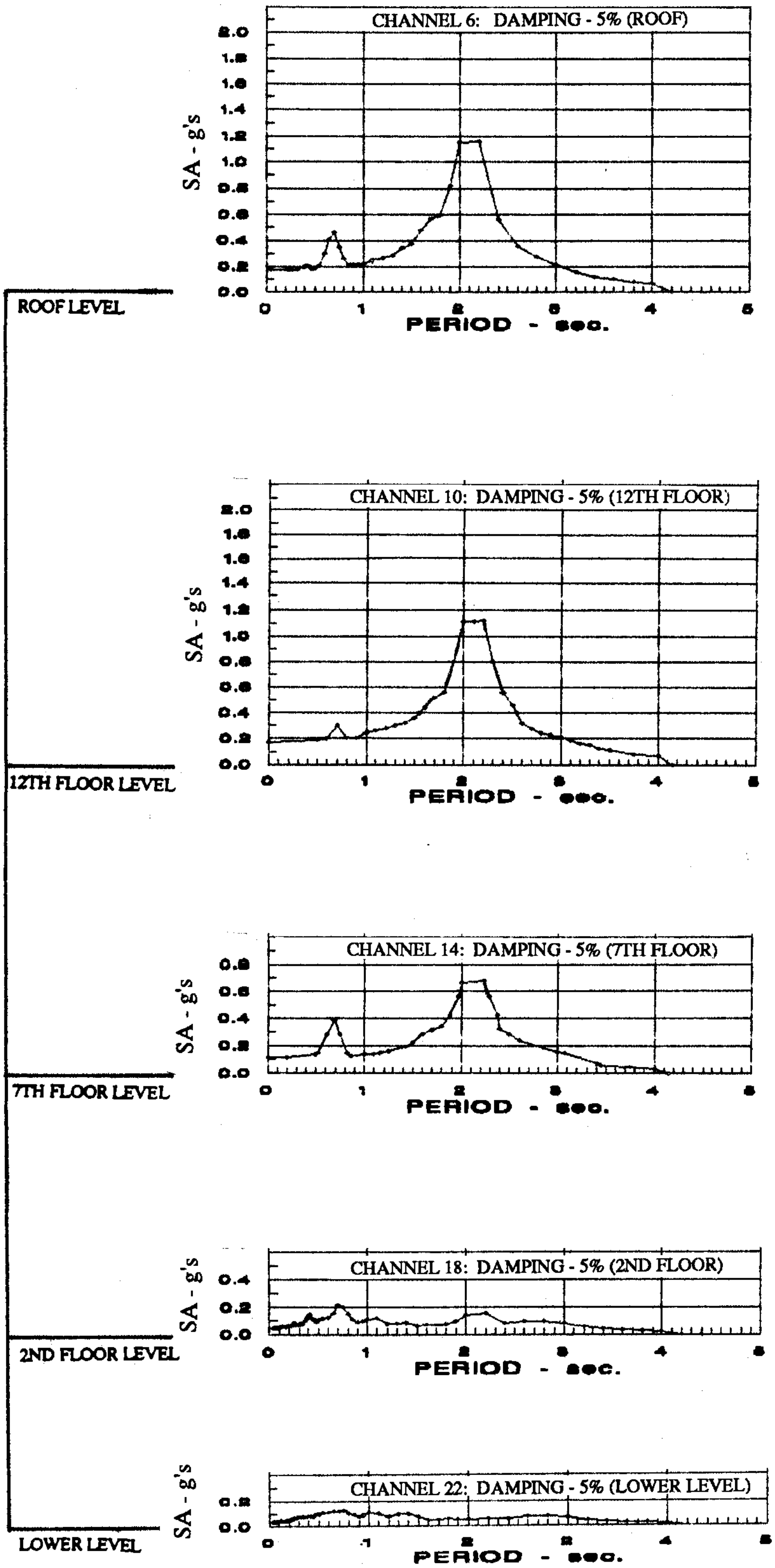


Figure 13: Recorded Floor Acceleration Response Spectra
1984 Morgan Hill Earthquake

TABLE II

SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
MAXIMUM RECORDED FLOOR ACCELERATIONS AND DISPLACEMENTS (ABSOLUTE)

			Loma Prieta EQ 17 Oct. 89		Mt. Lewis EQ 31 March 86		Morgan Hill EQ 14 April 84	
Location Level Corner	Direc-tion	Chan #	Max Accel (g)	Max Displ. (in.)	Max Accel (g)	Max Displ. (in.)	Max Accel (g)	Max Displ. (in.)
Lower NW	Up	1	0.104	1.59	-0.019	0.43	0.022	-0.36
Lower SW	Up	2	0.087	1.62	-0.017	0.40	0.020	-0.38
Lower SE	Up	3	0.104	1.61	-0.018	0.38	0.024	0.31
Roof NW	East	4	0.337	14.49	0.120	-4.84	-0.157	6.50
Roof SW	East	5	0.309	16.38	0.174	-6.02	0.173	7.68
Roof SW	North	6	-0.338	-17.44	0.317	13.31	0.170	-7.40
Roof SE	North	7	-0.325	-14.80	-0.223	9.25	0.164	-6.57
12th NW	East	8	0.266	13.27	0.107	-4.45	-0.140	5.75
12th SW	East	9	0.256	15.20	0.147	-5.47	0.157	7.05
12th SW	North	10	-0.294	-16.97	0.306	12.83	0.166	-7.20
12th SE	North	11	-0.259	-14.06	-0.210	8.78	0.148	-5.94
7th NW	East	12	0.257	10.12	-0.072	-2.90	-0.101	-3.82
7th SW	East	13	-0.251	11.18	0.079	3.17	-0.177	4.65
7th SW	North	14	0.222	-10.91	0.177	7.56	0.104	-4.37
7th SE	North	15	0.144	-7.20	-0.119	5.20	-0.093	-3.77
2nd NW	East	16	0.134	-6.10	0.045	-1.06	-0.057	1.37
2nd SW	East	17	0.131	-5.12	0.038	-1.29	-0.057	1.56
2nd SW	North	18	-0.106	-4.37	0.045	-1.98	0.046	-1.48
2nd SE	North	19	-0.098	-4.53	-0.041	-1.63	0.046	-1.53
Lower NW	East	20	-0.087	-3.75	-0.028	-0.88	0.039	0.87
Lower SW	East	21	0.084	-3.60	-0.028	-0.89	0.040	-0.90
Lower SW	North	22	-0.098	-2.79	-0.045	0.89	0.036	-1.25

TABLE III
SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
BUILDING PERIODS - ESTIMATED FROM RECORDED
ACCELERATION DATA

FLOOR LEVEL	SENSOR CHAN.		1989 LOMA PIETA EARTHQUAKE	1986 MT. LEWIS EARTHQUAKE	1984 MORGAN HILL EARTHQUAKE
	#	DIR			
7th	14	N-S	2.27 SEC.	2.16 SEC.	2.16 SEC.

CHAPTER 7: SUMMARY OF RECORDED RESPONSE DATA AND CHARACTERIZATION OF NON-STRUCTURAL COMPONENT DAMAGE

Non-structural component damage in buildings relates to acceleration as well as inter-story drift. A study of the observed non-structural damage data recorded on video tape showed that in general there was no damage observed below the fifth floor level. The majority of the non-structural component damage is concentrated at the 7th and 11th floor levels, with lesser damage observed at the 8th, 9th and 10th floor levels and some damage at 5th and 6th floor also.

Through consultation with Reitherman [8],it is suggested that characteristics of recorded floor motions that contribute to non-structural component damage are as follows:

1. Peak recorded amplitudes of floor accelerations, as well as displacements.
2. Frequency content of floor response accelerations.
3. Number of cycles of floor response accelerations with peak acceleration levels $\geq 0.05g$.
4. Duration of recorded floor accelerations, velocities and displacements.

Non-Structural Component Damage Index:

It is suggested that non-structural component damage expressed as a percentage of non-structural components damaged to not damaged at any given floor level could be used as one crude type of non-structural component damage index, as presented in

Table IV [8]. The next step is to develop a composite non-structural damage index taking into account the characteristics of recorded floor response motions outlined above.

Summaries of peak responses recorded at instrumented floor levels in the Santa Clara County Government Center during the 1989 Loma Prieta, California earthquake as well as the 1986 Mt. Lewis, and the 1984 Morgan Hill earthquakes are presented in Tables V, VI and VII.

The correlation between recorded response data and observed non-structural damge is shown by comparing the non-structural damage index (presented in Table IV) with the peak recorded floor accelerations as well as floor displacements (presented in Table V). It is found that the approximate percentage of bookcases and filing cabinets overturned was the highest (91% and 68% respectively) at the 11th floor level as compared to those that overturned at the 7th floor level (50% and 22% respectively). This appears to have occurred due to the higher level of floor accelerations at the upper floor levels, e.g., 12th floor which was 0.294g compared to a peak floor acceleration of 0.257g recorded at the 7th floor level.

TABLE IV
SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
NON-STRUCTURAL DAMAGE INDEX (EXPRESSED AS % OF COMPONENTS DAMAGED)

7TH FLOOR	TYPE OF DAMAGE				
NON-STRUCTURAL COMPONENT	NUMBER COUNTED	OVER-TURNED	BROKEN	SPILLED	MOVED
COMPUTERS	13	23%			
BOOKCASES	4	50%			
FILING CAB.	54	22%		26%	9%
DESKS	32	3%		56%	6%
PLANTS	1		100%		
BOOKSHELVES	1			100%	
MICROFICHE	4	25%		75%	
PARTITIONS		4 FELL			
TALL CABINETS	22	5%		41%	

8TH FLOOR	TYPE OF DAMAGE				
NON-STRUCTURAL COMPONENT	NUMBER COUNTED	OVER-TURNED	BROKEN	SPILLED	MOVED
COMPUTERS	3				
BOOKCASES					
FILING CAB.	39			56%	
DESKS					
PLANTS	1	100%			
BOOKSHELVES					
MICROFICHE					
PARTITIONS					
TALL CABINETS	2			50%	

9TH FLOOR	TYPE OF DAMAGE				
NON-STRUCTURAL COMPONENT	NUMBER COUNTED	OVER-TURNED	BROKEN	SPILLED	MOVED
COMPUTERS	6	11%			
BOOKCASES	21			52%	
FILING CAB.	35	6%		63%	
DESKS	10	10%		60%	
PLANTS	2		50%		
BOOKSHELVES					
MICROFICHE					
PARTITIONS					1 MOVED
TALL CABINETS	12	8%	83%		

TABLE IV (CONTINUED)

SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE

NON-STRUCTURAL DAMAGE INDEX (EXPRESSED AS % OF COMPONENTS DAMAGED)

10TH FLOOR	TYPE OF DAMAGE				
NON-STRUCTURAL COMPONENT	NUMBER COUNTED	OVER-TURNED	BROKEN	SPILLED	MOVED
COMPUTERS	3				
BOOKCASES	7	43%			
FILING CAB.	8	63%		37%	
DESKS	2	50%		50%	
PLANTS	3	67%			
BOOKSHELVES	1	100%			
MICROFICHE					
PARTITIONS		7 FELL			
TALL CABINETS	4				

11TH FLOOR	TYPE OF DAMAGE				
NON-STRUCTURAL COMPONENT	NUMBER COUNTED	OVER-TURNED	BROKEN	SPILLED	MOVED
COMPUTERS	8	25%			
BOOKCASES	11	91%		9%	
FILING CAB.	19	68%	32%		
DESKS	19	5%		58%	5%
PLANTS	2				
BOOKSHELVES					
MICROFICHE					
PARTITIONS		1 FELL			
TALL CABINETS	8			100%	

TABLE V
Santa Clara County Government Center - San Jose
Summary of Peak Recorded Motions/Damage Data by Levels
1989 Loma Prieta Earthquake

Level	East-West Component					North-South Component					Non-Struct. Damage Index**
	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T (sec)	No. of Cycles ≥ 0.05g *	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T, sec.	No. of cycles ≥ 0.05g *	
Lower	20	-0.087	-3.75	2.4	5	22	-0.098	-2.79	2.4	8	
2	16	0.134	-6.10	2.4	10	18	-0.106	-4.37	2.4	10	
7	12	0.257	10.12	2.4	35	14	0.220	-10.90	2.4	38	
12	8	0.266	13.26	2.2	40	10	-0.294	-16.97	2.4	41	
Roof	4	0.337	14.49	2.2	43	6	-0.338	-17.40	2.4	48	

* measured over 100 seconds
** TABLE IV.

TABLE VI
Santa Clara County Government Center - San Jose
Summary of Peak Recorded Motions/Damage Data by Levels
1984 Morgan Hill Earthquake

Level	East-West Component					North-South Component					Non-Struct. Damage Index**
	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T (sec)	No. of Cycles ≥ 0.05g *	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T, sec.	No. of cycles ≥ 0.05g *	
Lower	21	0.040	-0.90	2.2	0	22	0.035	-1.25	3	0	
2	17	-0.057	1.56	2.2	0	19	0.046	1.53	3	n/a	
7	13	-0.117	4.65	2.2	22	14	0.104	-4.37	2.2	22	
12	9	0.157	7.05	2.2	26	10	0.166	-7.20	2.3	24	
Roof	5	0.173	7.68	2.2	29	6	0.170	-7.40	2.2	36	

* measured over 80 seconds
** Table IV.

TABLE VII
Santa Clara County Government Center - San Jose
Summary of Peak Recorded Motions/Damage Data by Levels
1986 Mt. Lewis Earthquake

Level	East-West Component					North-South Component					Non-Struct. Damage Index**
	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T (sec)	No. of Cycles ≥ 0.05g *	Chan. No.	Peak Accel. (g)	Peak Displ. (in)	Peak Spectral Response @ T, sec.	No. of cycles ≥ 0.05g *	
Lower	20	-0.028	-0.88	n/a	0	22	-0.045	0.89	2.2	0	
2	16	0.045	-1.06	2.2	0	18	0.045	-1.98	2.2	0	
7	13	0.079	3.17	2.2	20	14	0.177	7.56	2.2	17	
12	9	0.147	-5.47	2.2	28	10	0.306	12.80	2.2	18	
Roof	5	0.174	-6.02	2.2	33	6	0.318	13.30	2.2	23	

* measured over 80 seconds
** Table IV.

CHAPTER 8: EVALUATION OF SEISMIC BEHAVIOR OF BUILDING SYSTEM

It was decided to evaluate the seismic behavior of the building system by carrying out a seismic analysis using the computer program ETABS [5]. The main objective of carrying out this seismic analysis is to estimate maximum probable inter-story drift levels using recorded spectrum data as input excitation at base of the building.

8.1 ETABS Seismic Analysis Model

Assumptions made in ETABS Modeling:

- 3 ft. offset of East-West wing story height was ignored. All story heights were defined by the "nominal floor line" defined on the structural working drawings.
- Splices of columns 4 ft. above floor level were ignored. The smaller section was extended to the floor below.
- Non-prismatic beams in perimeter moment resisting frames were adjusted to simulate prismatic beams. Weighted averages were taken of all relevant properties.
- Base fixity was assumed for the foundation. However, since column lines 6 and 10 extended below main foundation, very rigid columns were modeled under all other columns to create fixity.
- Connections assumed moment resisting are K1, K2, K3, K4, K9, K10, K11, K12, K13, K14, K18 as shown on structural working drawings.
- The elevator machine room's columns and beams had pinned end connections. These were therefore discounted from the

moment resisting model of the whole building.

- Floor diaphragms were assumed to be continuous, i.e., effect of openings was not taken into account.

A plan view of the input model of this case-study building, for seismic analysis using the computer program ETABS is presented in Figure 14. An Isometric View of the ETABS model for this case-study building is presented in Figure 15.

8.2 Assumed Dead Loads

Ground Floor - Elevator Floor	
Steel Deck (Robertson QL-99-I8)	
with Light-Weight Concrete Fill	49 psf
Structural Framing	9 psf
Partitions	20 psf
Ceiling	2 psf
Electrical and Mechanical	4 psf
Fireproofing	2 psf
Plumbing and Miscellaneous	5 psf
	95 psf
Elevator Mechanical Floor	
West Elevator Wing	80 psf
Elsewhere and South Wing	40 psf
Mechanical	
Shaded Areas:	200 psf
Others	75 psf
Roof and Penthouse	75 psf

Exterior Cladding

Steel-studs w/gypsum wall-board

and glass curtain wall @ 10 psf

tributary height 13'-6 1/2"

West Wall	135 plf
East Wall (add W4x13 and 2 ft. of steel deck floor)	250 plf
North Wall (add 2 ft. of steel deck floor)	235 plf
South Wall	235 plf

8.3 Input Earthquake Ground Motion

For seismic analysis, the earthquake response spectrum recorded at the lower level of the Santa Clara County Government Center was used as the input earthquake ground motion.

A graphical plot of this response sqectrum is presented in Figure 16.

8.4 Seismic Analysis Results using ETABS

Mode Shapes and Frequencies

The first 12 modal time periods and frequencies obtained are presented in Table VIII.

Plots of the first two translational modes in the E-W and N-S directions are presented in Figures 17, 18, 19, 20. A plot of the first torsional mode is presented in Figure 21.

Seismic Response Displacements

A comparison of the seismic response displacements obtained from ETABS for CQC Spectrum Loading in the N-S and E-W directions is presented in Table IX.

A comparison of response displacements obtained from seismic analysis using CQC Spectrum Loading, 1988 UBC loading as well as those obtained from recorded data are presented in Figures 22-25. It should be pointed out that the recorded response displacements are absolute displacements, whereas those obtained from seismic analysis are displacements relative to the base of the building.

Seismic Response Inter-story Drift-Ratios

A comparison of the seismic response inter-story drift ratios in the N-S and E-W directions obtained from the ETABS based seismic analysis for CQC Spectrum Loading and 1988 UBC Loading are presented graphically in Figures 26 and 27.

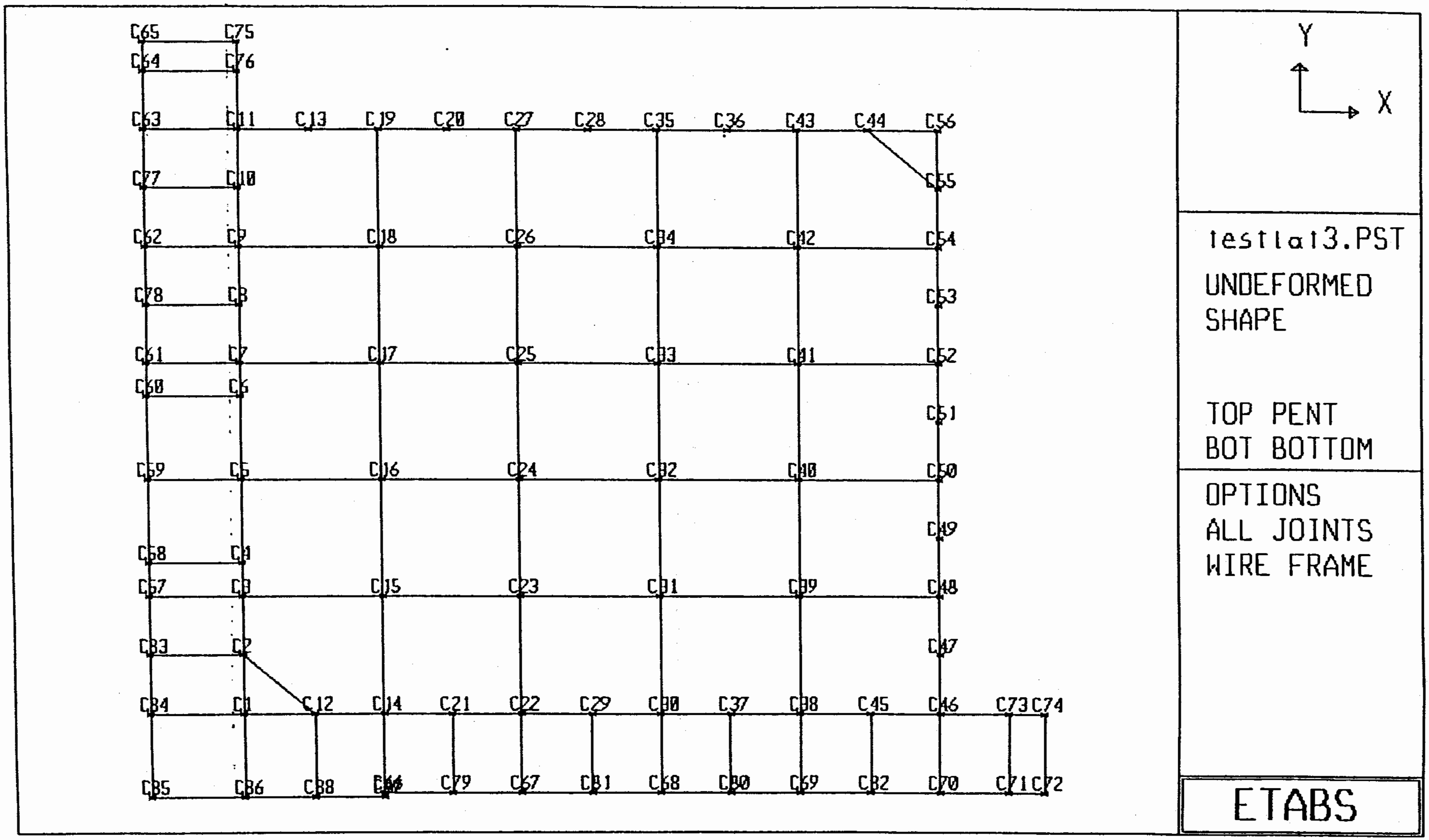


Figure 14: ETABS Seismic Analysis
Input Model - Plan View

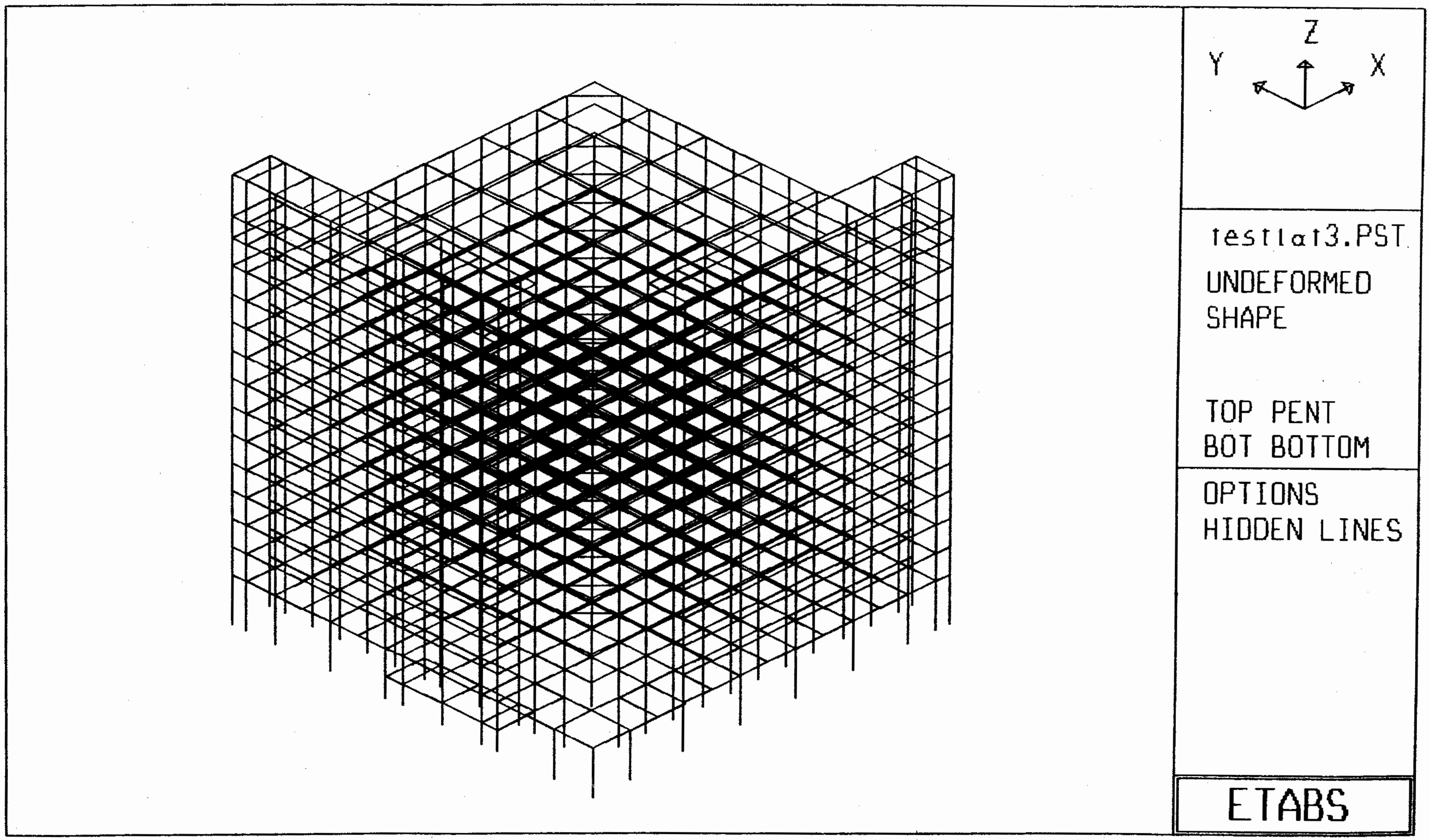


Figure 15: ETABS Seismic Analysis
Input Model - Isometric View

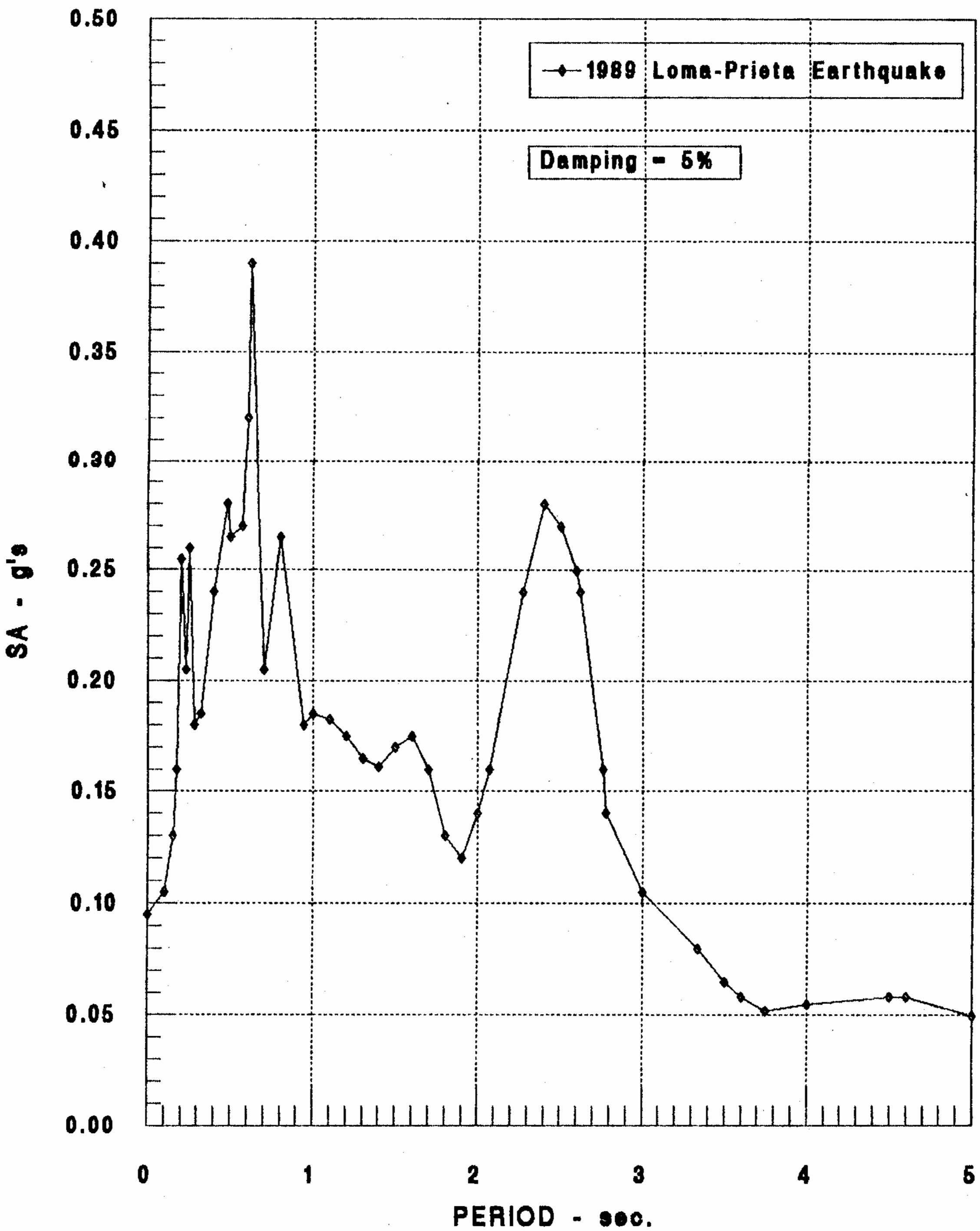


Figure 16: Earthquake Response Spectrum Lower Level - Channel No. 22 SW Corner in N-S Direction

TABLE VIII
SANTA CLARA COUNTY GOVERNMENT CENTER - SAN JOSE
MODAL TIME PERIODS AND FREQUENCIES

MODE NO.	PERIOD (SEC)	FREQUENCY (CYCLES/SEC)	DOMINANT DIRECTION		
			X-TRANSLATION	Y-TRANSLATION	Z-ROTATION
1	2.14547	.46610	■		
2	2.10116	.47593		■	
3	1.58903	.62931			■
4	.74951	1.33420	■		
5	.73048	1.36897		■	
6	.56790	1.76086			■
7	.45061	2.21922	■		
8	.43600	2.29360		■	
9	.34713	2.88074			■
10	.32756	3.05289	■		
11	.31841	3.14065		■	
12	.27215	3.67450	■		■

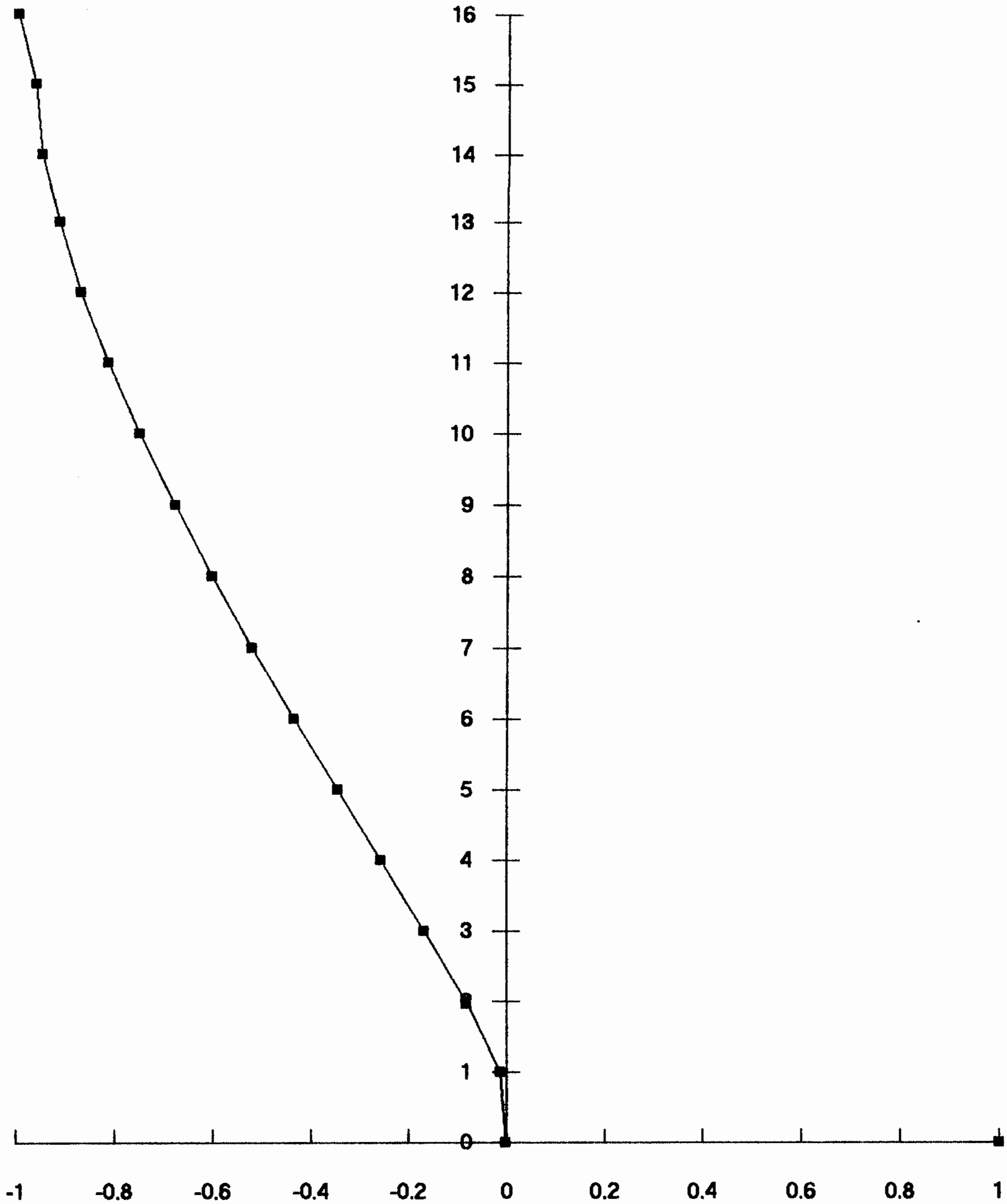


Figure 17: First Translational Mode - E-W
ETABS Seismic Analysis

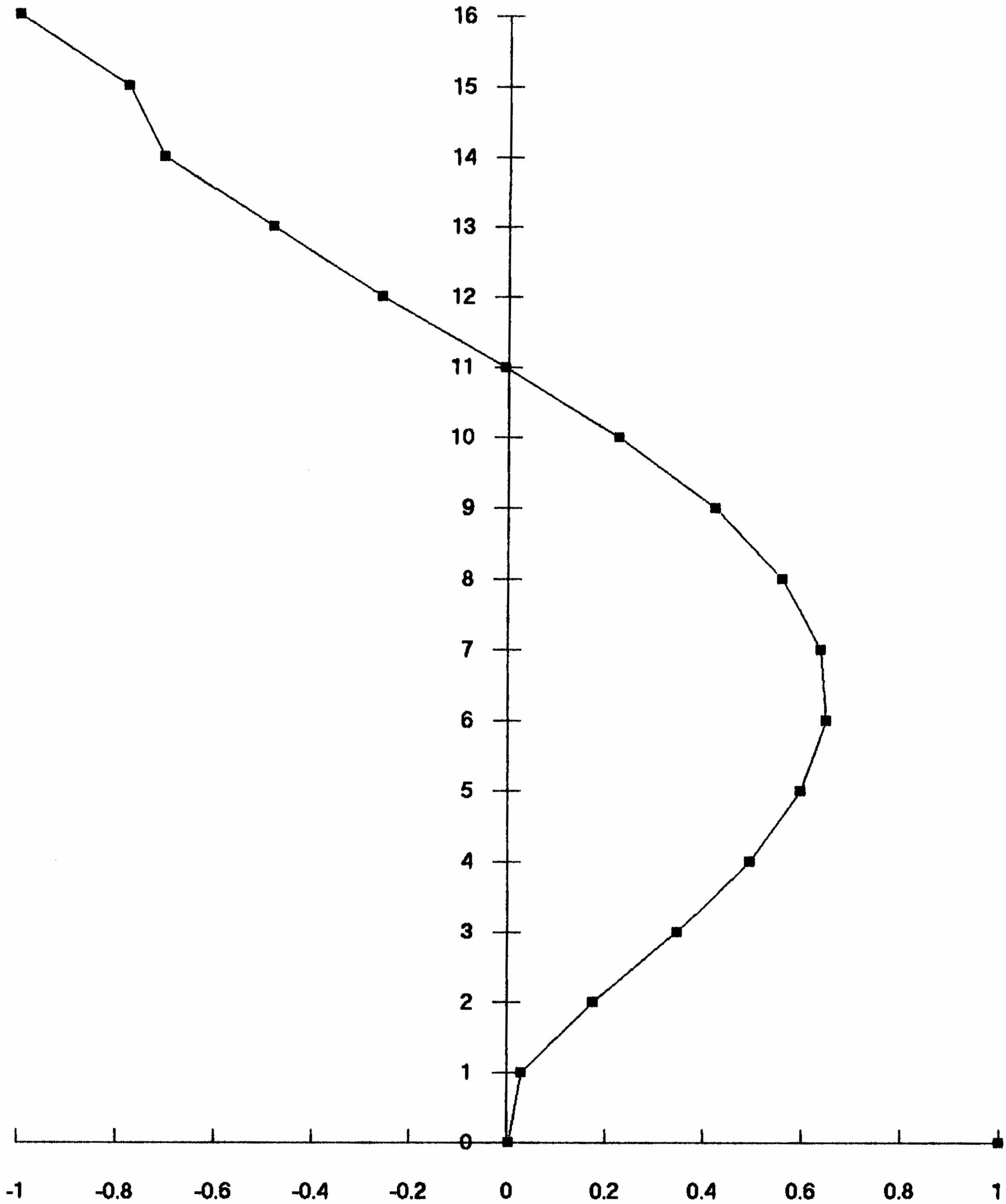


Figure 18: Second Translational Mode - E-W
ETABS Seismic Analysis

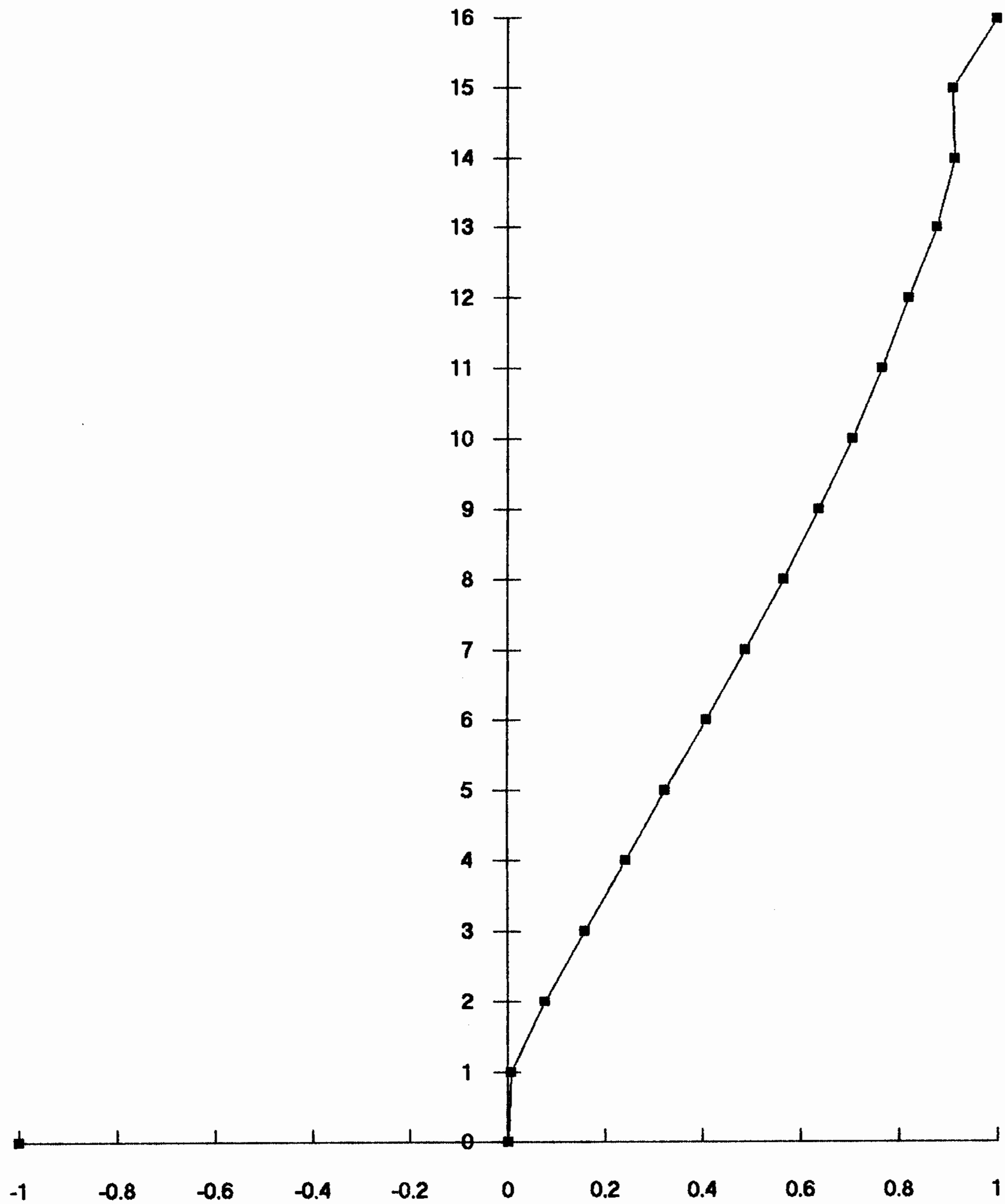


Figure 19: First Translational Mode - N-S
ETABS Seismic Analysis

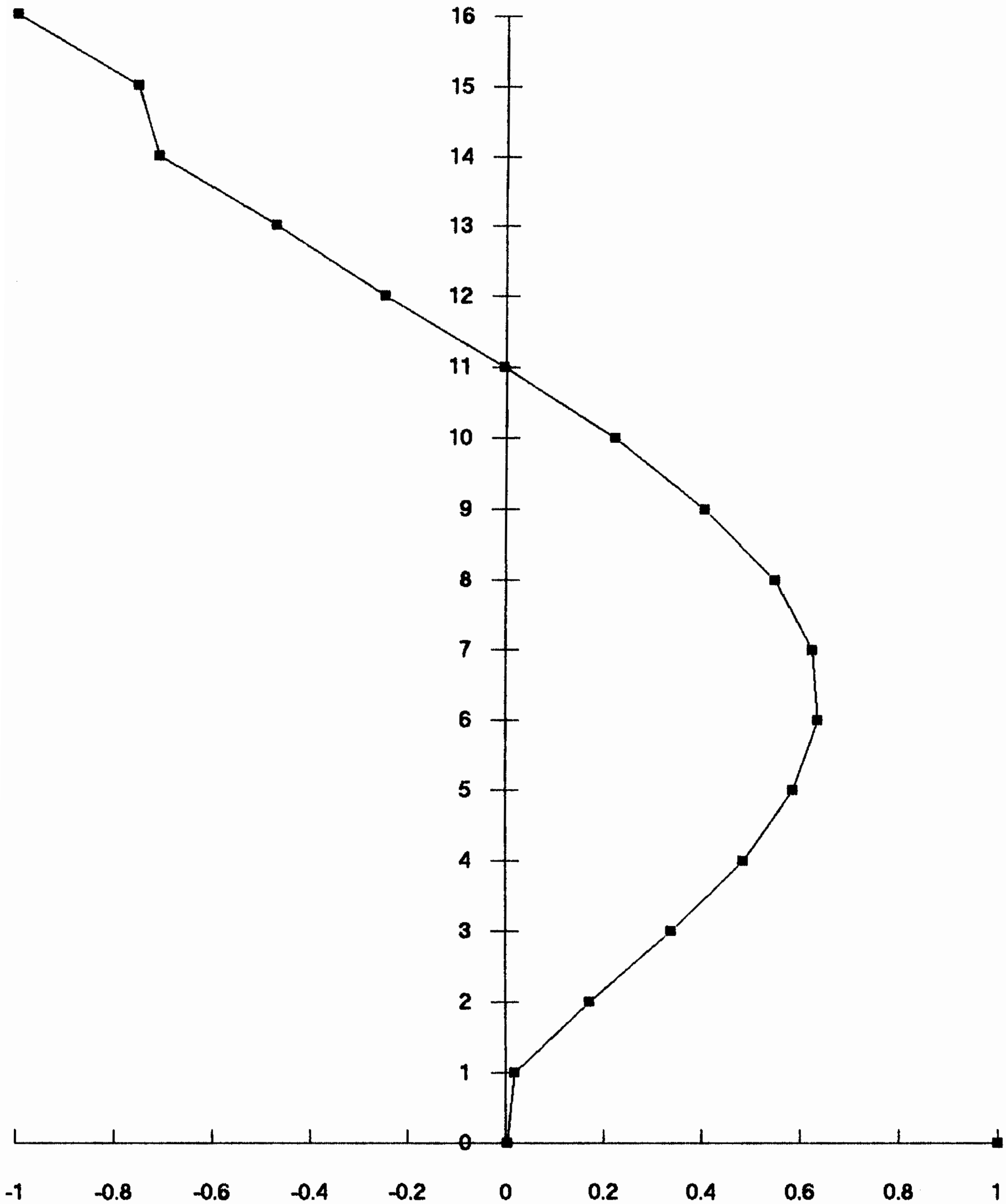


Figure 20: Second Translational Mode - N-S
ETABS Seismic Analysis

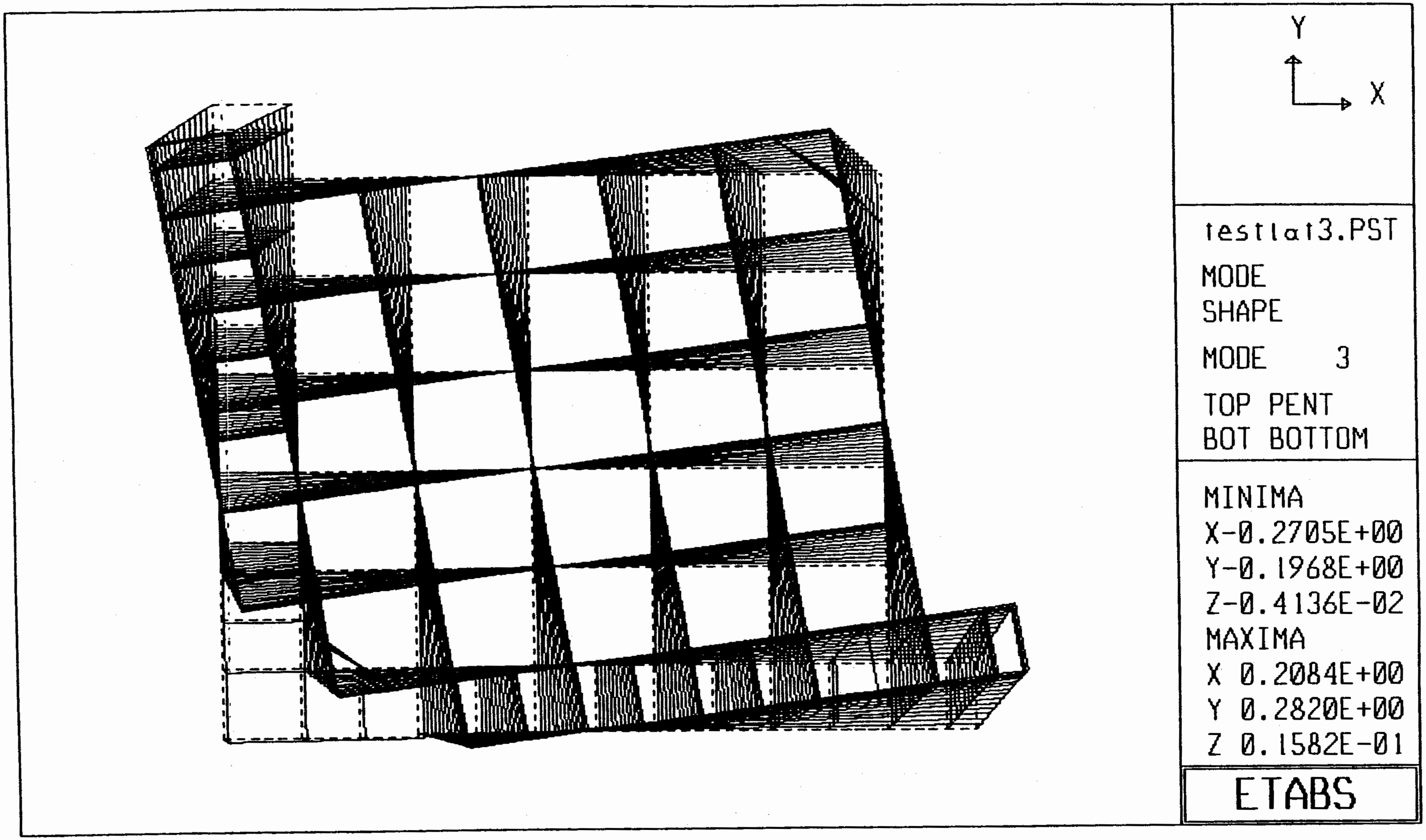


Figure 21: ETABS Seismic Analysis
First Torsional Mode

TABLE IX
Santa Clara County Government Center - San Jose
Response Spectrum Lateral Story Displacements

LEVEL	CQC SPECTRUM - LATERAL STORY DISPLACEMENTS (INCHES)	
	EAST-WEST	NORTH-SOUTH
PENTHOUSE	12.46	11.98
ROOF	12.08	11.57
ELEVATOR	11.92	11.43
MECHANICAL	11.45	10.93
ELEVENTH	10.91	10.38
TENTH	10.20	9.69
NINTH	9.41	8.91
EIGHTH	8.52	8.03
SEVENTH	7.58	7.13
SIXTH	6.56	6.15
FIFTH	5.49	5.14
FOURTH	4.39	4.09
THIRD	3.30	3.06
SECOND	2.17	1.99
GROUND	1.07	0.97
LOWER	0.09	0.09
BOTTOM	0.02	0.01

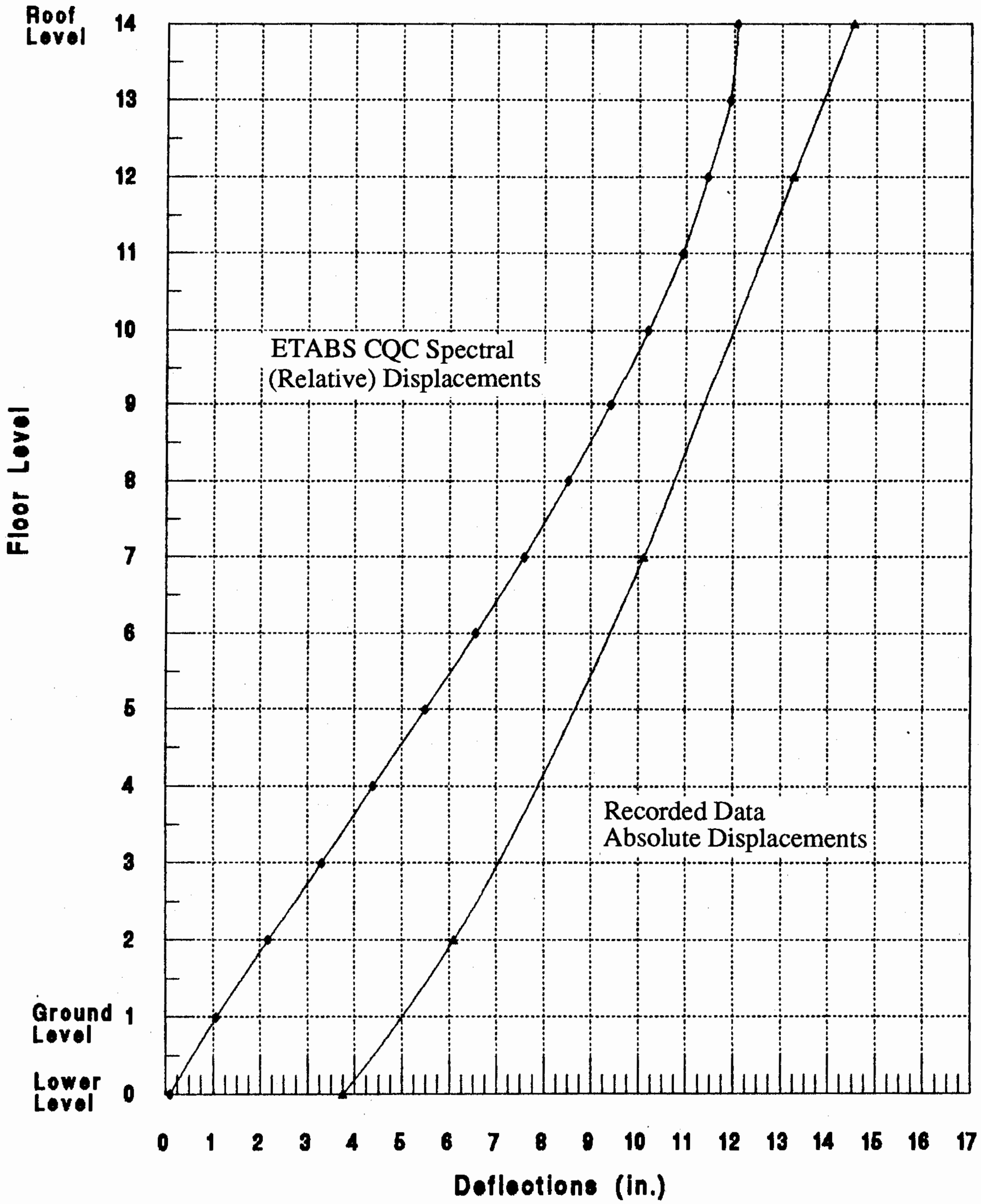


Figure 22: Recorded Displacements and Predicted Spectral Displacements vs. Floor Level
SW Corner: E-W Direction

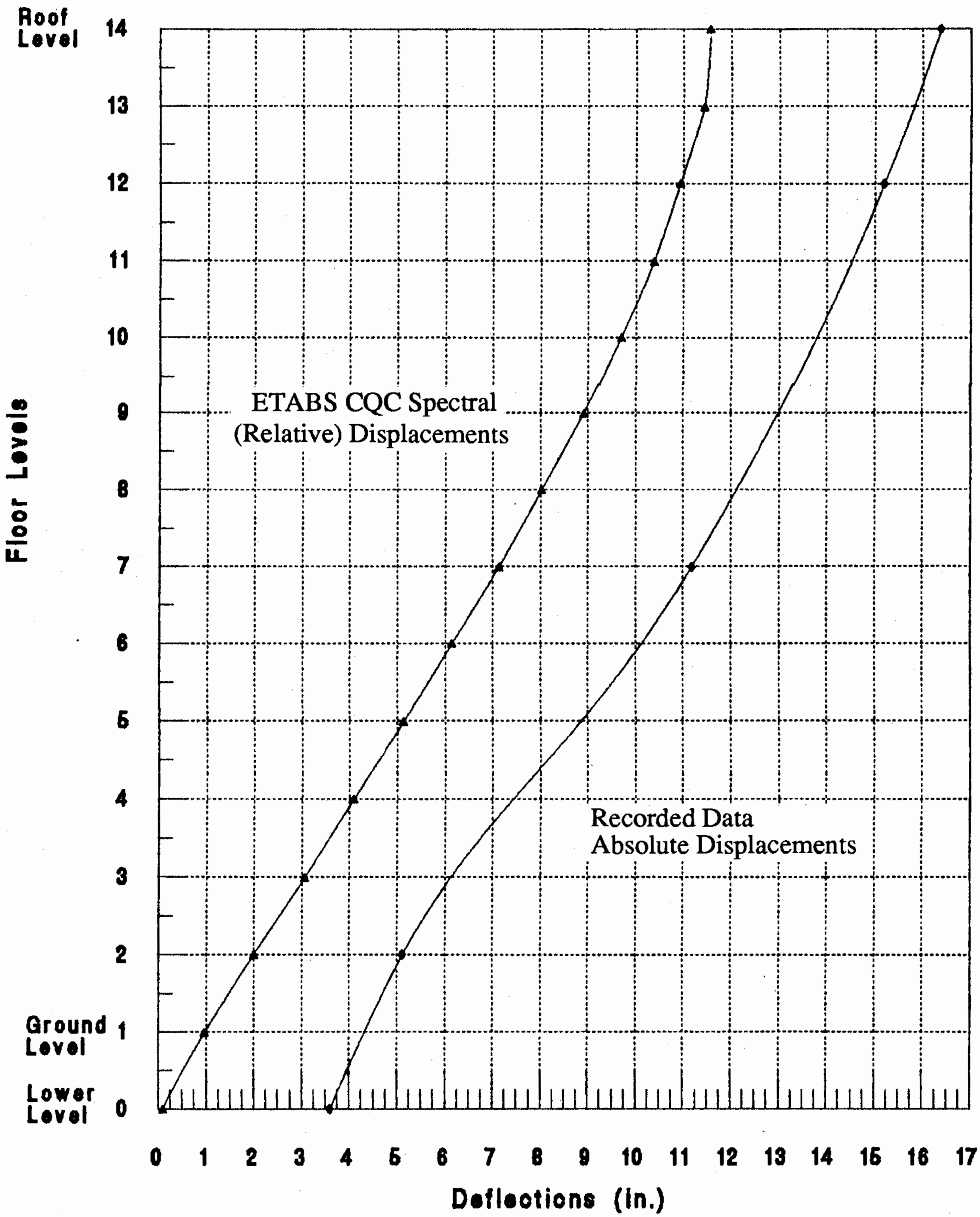


Figure 23: Recorded Displacements and Predicted Spectral Displacements vs. Floor Level
SW Corner: N-S Direction

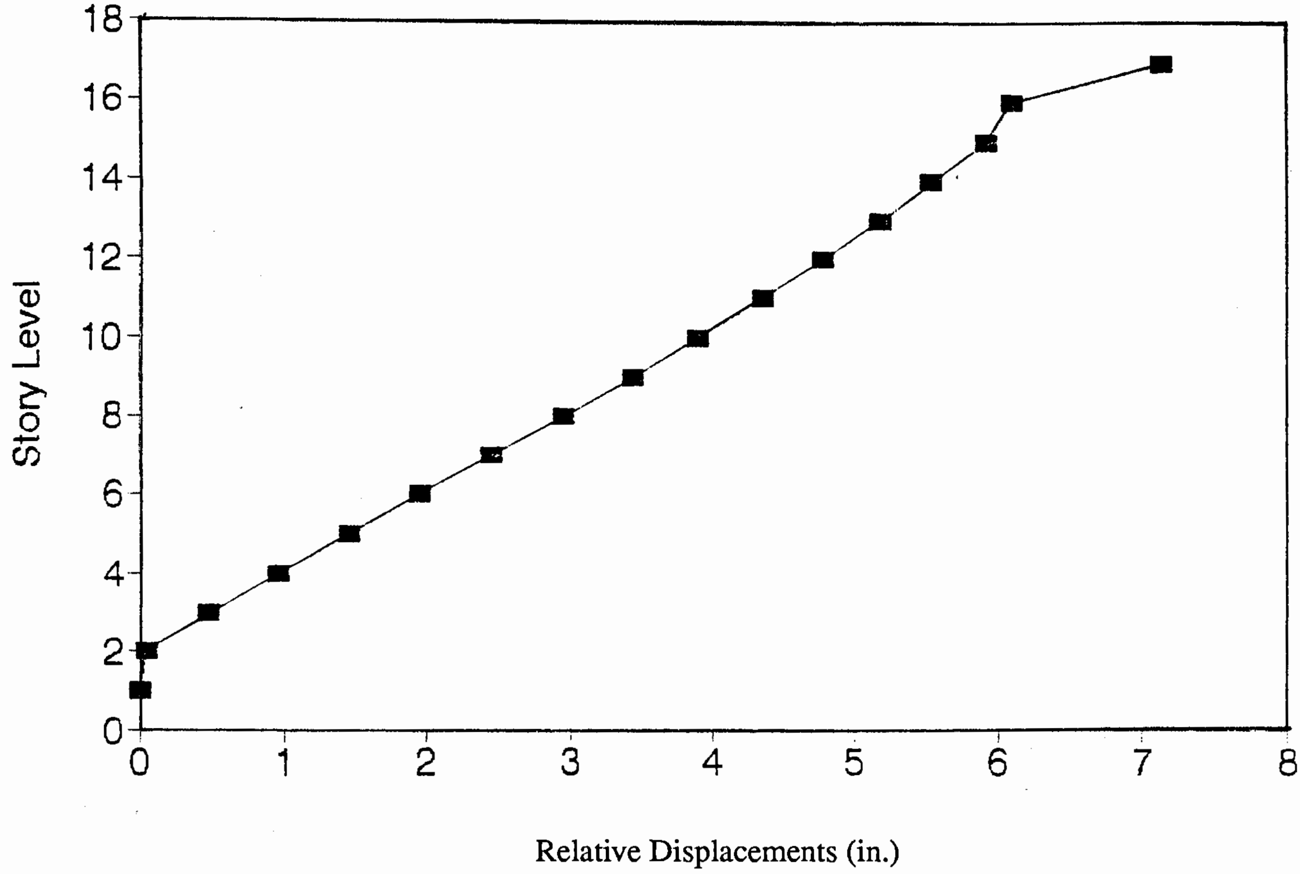


Figure 24: Relative Displacements vs. Story Level
88 UBC Seismic Forces: E-W

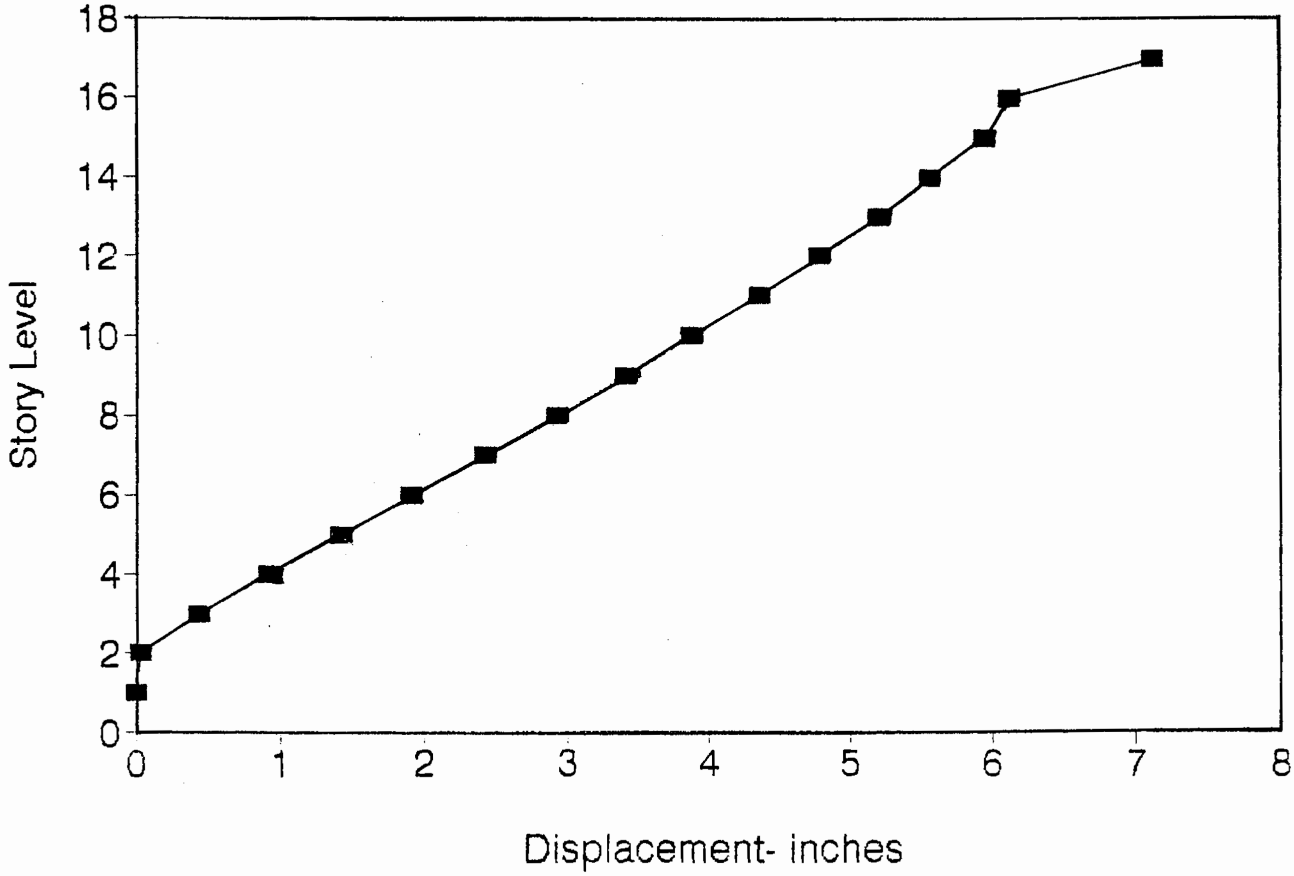


Figure 25: Relative Displacements vs. Story Level
88 UBC Seismic Forces: N-S

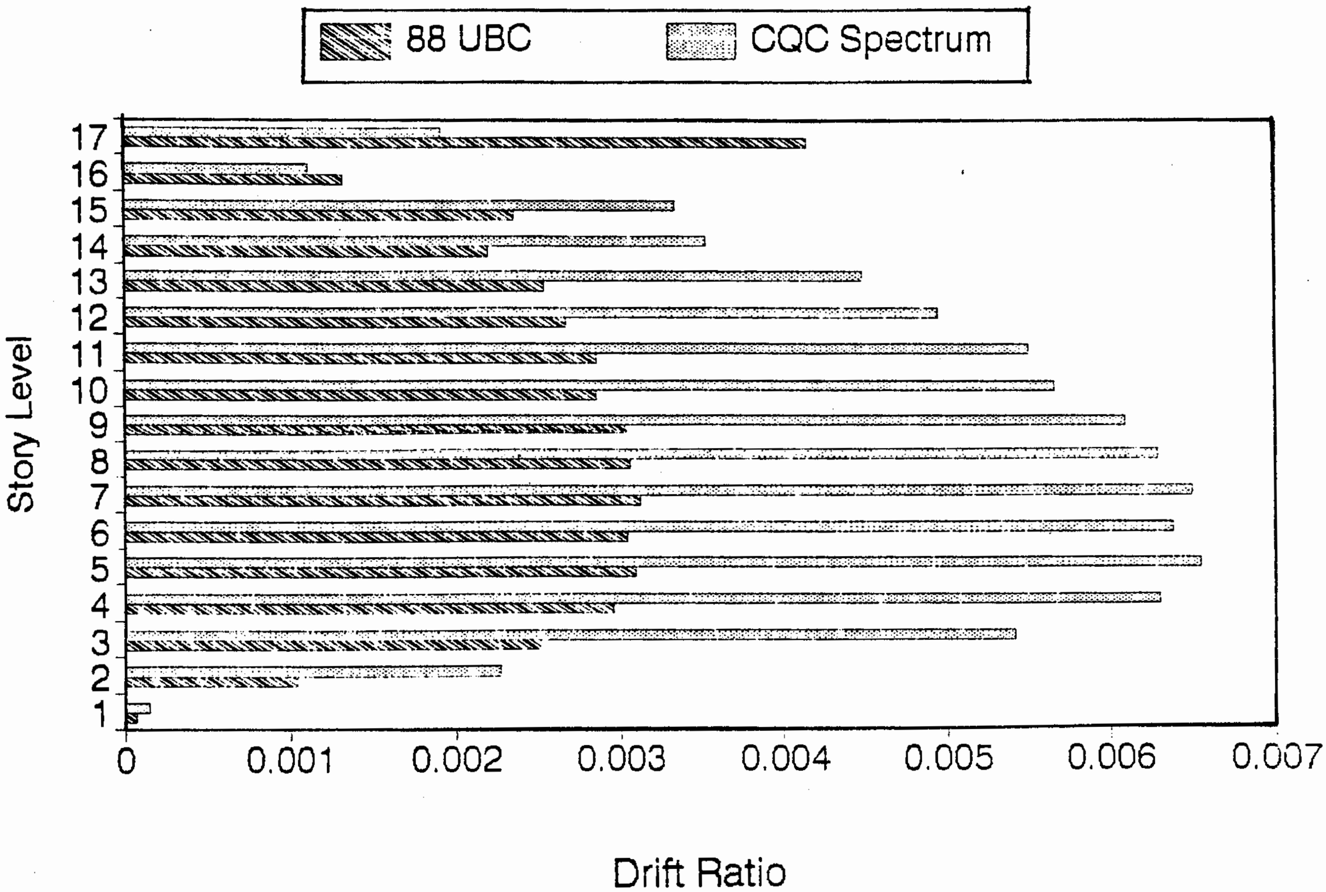


Figure 26: Inter-Story Drift Ratio vs. Story Level
88 UBC and CQC Spectrum: N-S

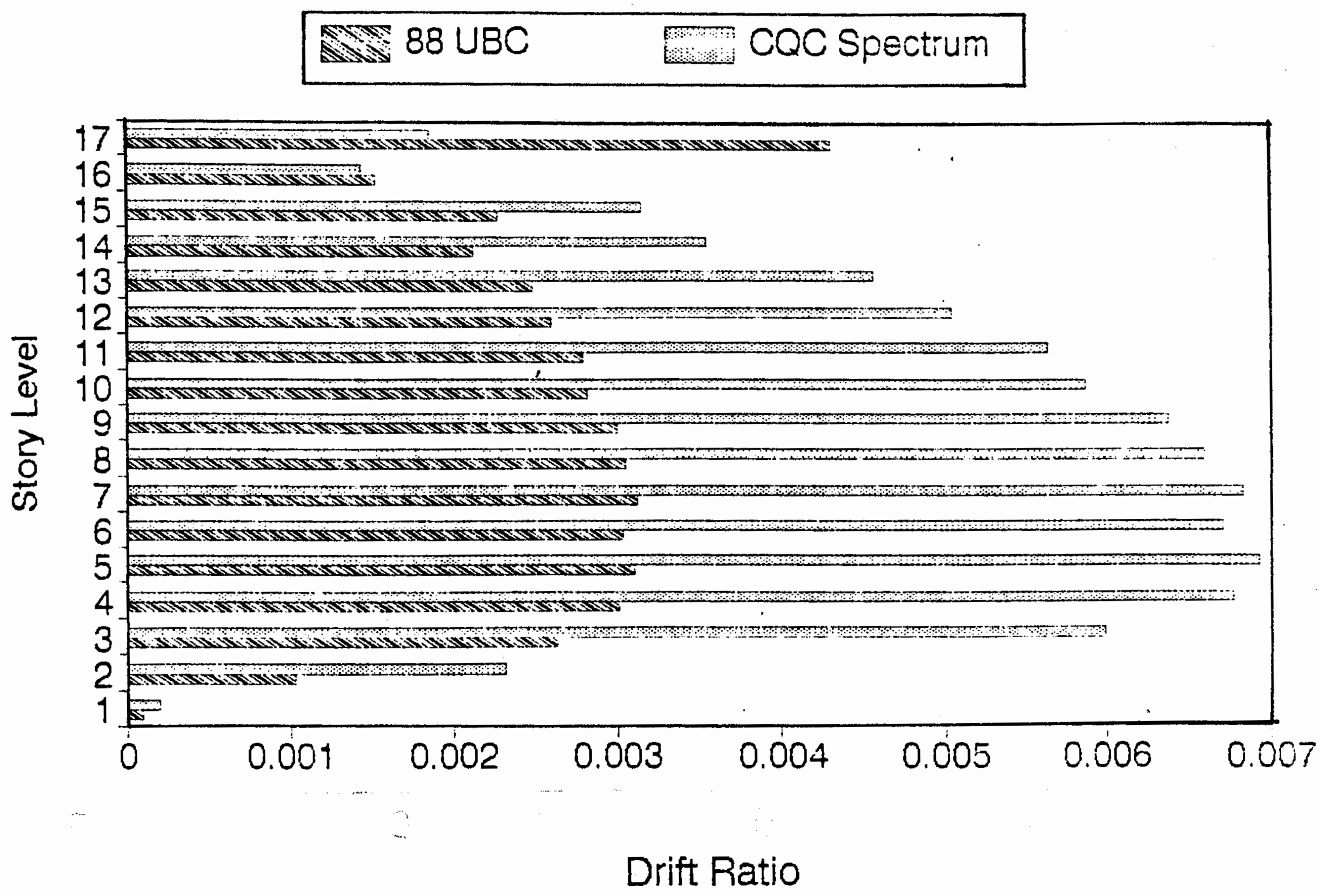


Figure 27: Inter-Story Drift Ratio vs. Story Level
88 UBC and CQC Spectrum: E-W

CHAPTER 9: ANALYSIS OF OBSERVED NON-STRUCTURAL DAMAGE AND RECORDED RESPONSE DATA

It is clear that the severity of the motions experienced by the Santa Clara County Government Center in San Jose, during the 1989 Loma Prieta earthquake resulted in much greater non-structural component damage than that observed during the 1986 Mt. Lewis earthquake and 1984 Morgan Hill earthquake.

A comparison of peak recorded motions at different levels in the Santa Clara County Government Center during the 1989 Loma Prieta earthquake and the 1986 Mt. Lewis and 1984 Morgan Hill earthquakes is graphically presented in Figures 28-31.

Significant non-structural damage was observed to have occurred particularly at the 7th and 11th floor levels especially during the 1989 Loma Prieta earthquake. At the 7th floor level the recorded peak accelerations and displacements during the 1989 Loma Prieta earthquake were apparently 2-3 times those recorded during the 1986 Mt. Lewis and 1984 Morgan Hill earthquakes.

Another important factor contributing to the extensive non-structural damage during the 1989 Loma Prieta earthquake, may be the relatively large number of floor acceleration cycles with amplitudes $\geq$ 0.05g, as shown in Tables V, VI, VII. These results show that typical number of floor acceleration cycles ($\geq$0.05g) were 38 (1989), 22 (1984), and 17 (1986).

In an attempt to further determine threshhold levels of nonstructural damage, recorded floor acceleration response spectra for the 7th floor and 12th floor (in E-W and N-S directions) were superimposed as shown in Figures 32-35. It is suggested that if the fundamental dynamic properties, e.g., period and damping etc., of the non-structural components can be estimated, then the responses of non-structural components to floor motion could be evaluated and correlated with observed non-structural component damage.

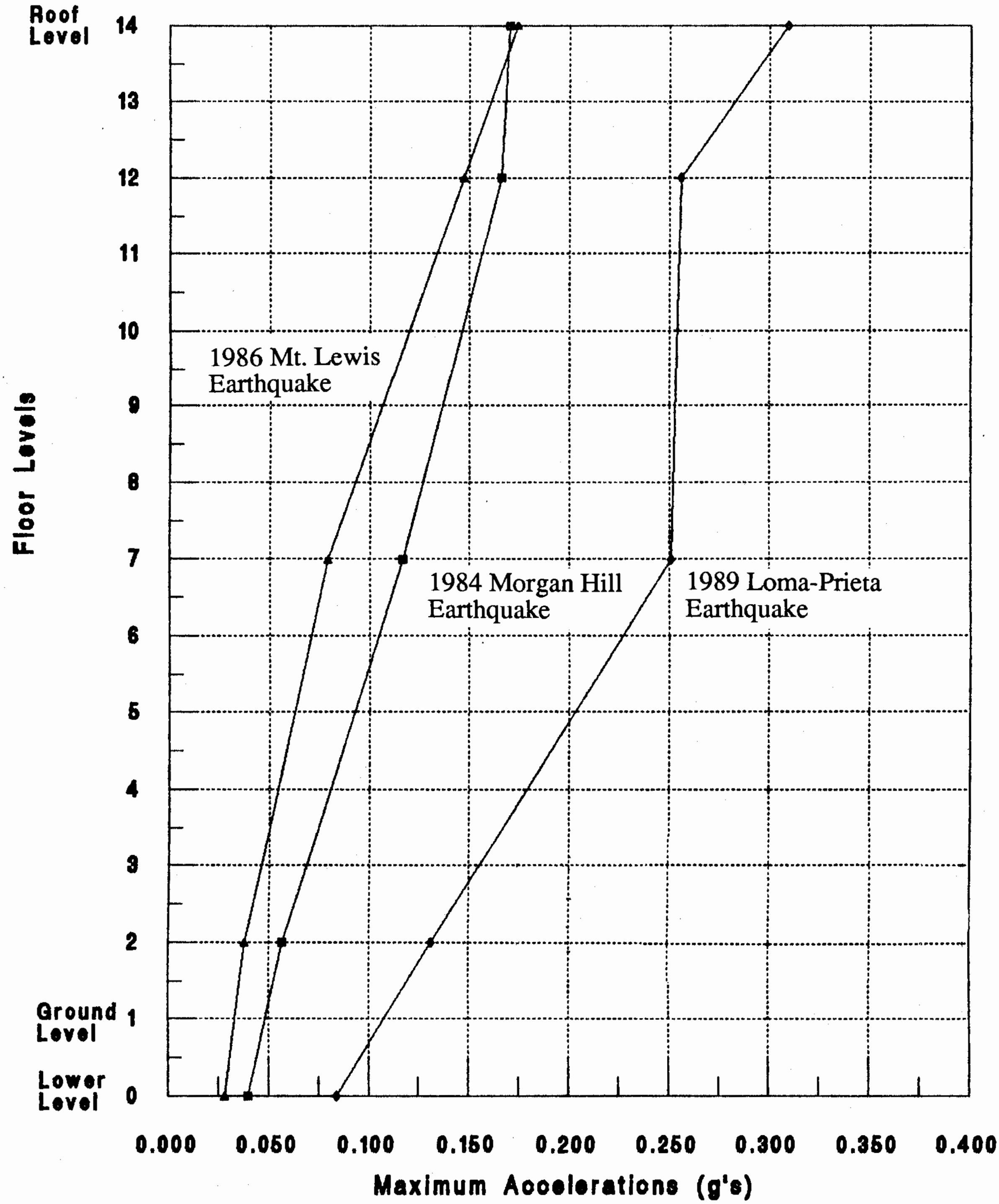


Figure 28: Maximum Recorded Accelerations vs. Floor Levels
SW Corner of Building in E-W Direction

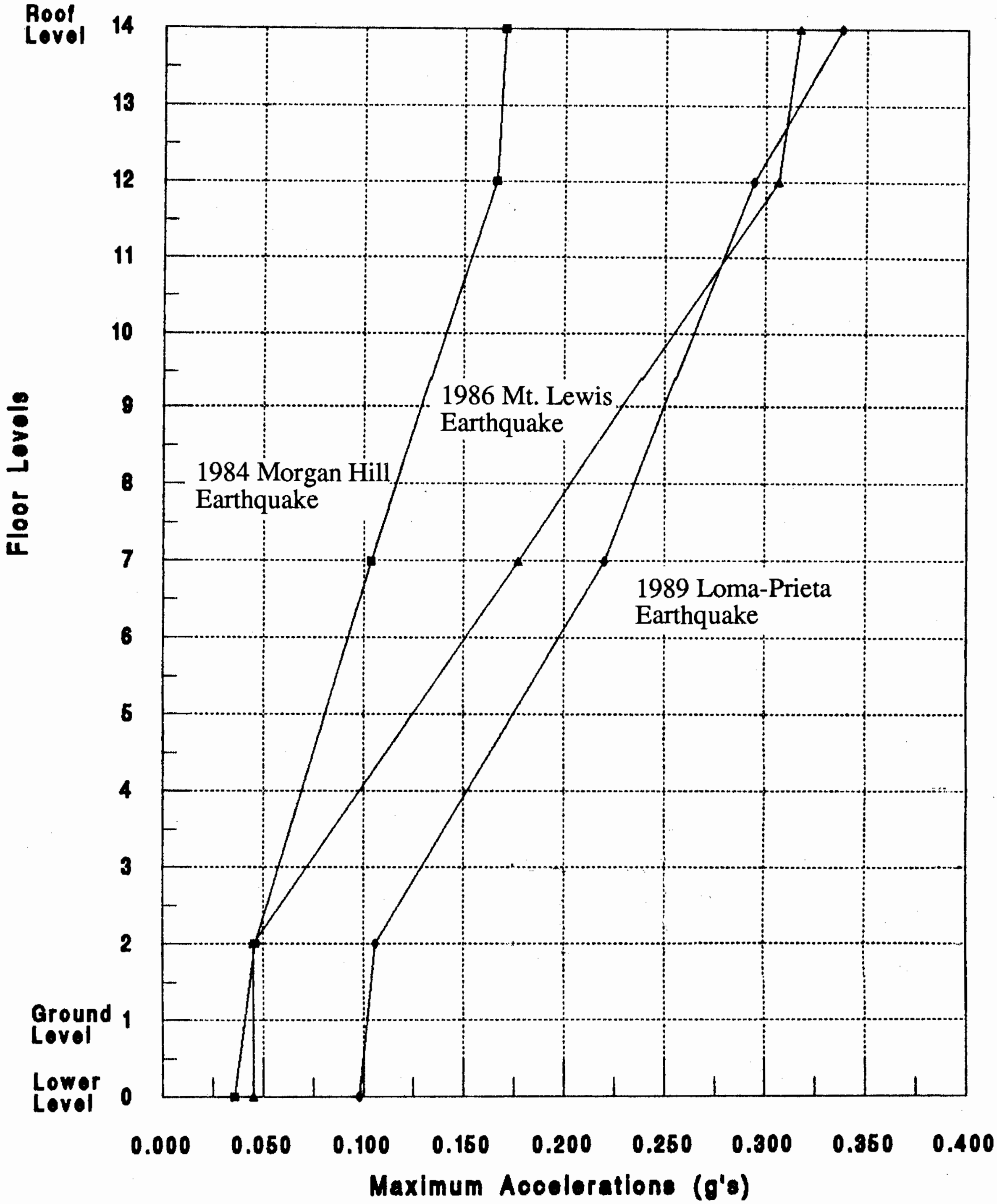


Figure 29: Maximum Recorded Accelerations vs. Floor Levels
SW Corner of Building in N-S Direction

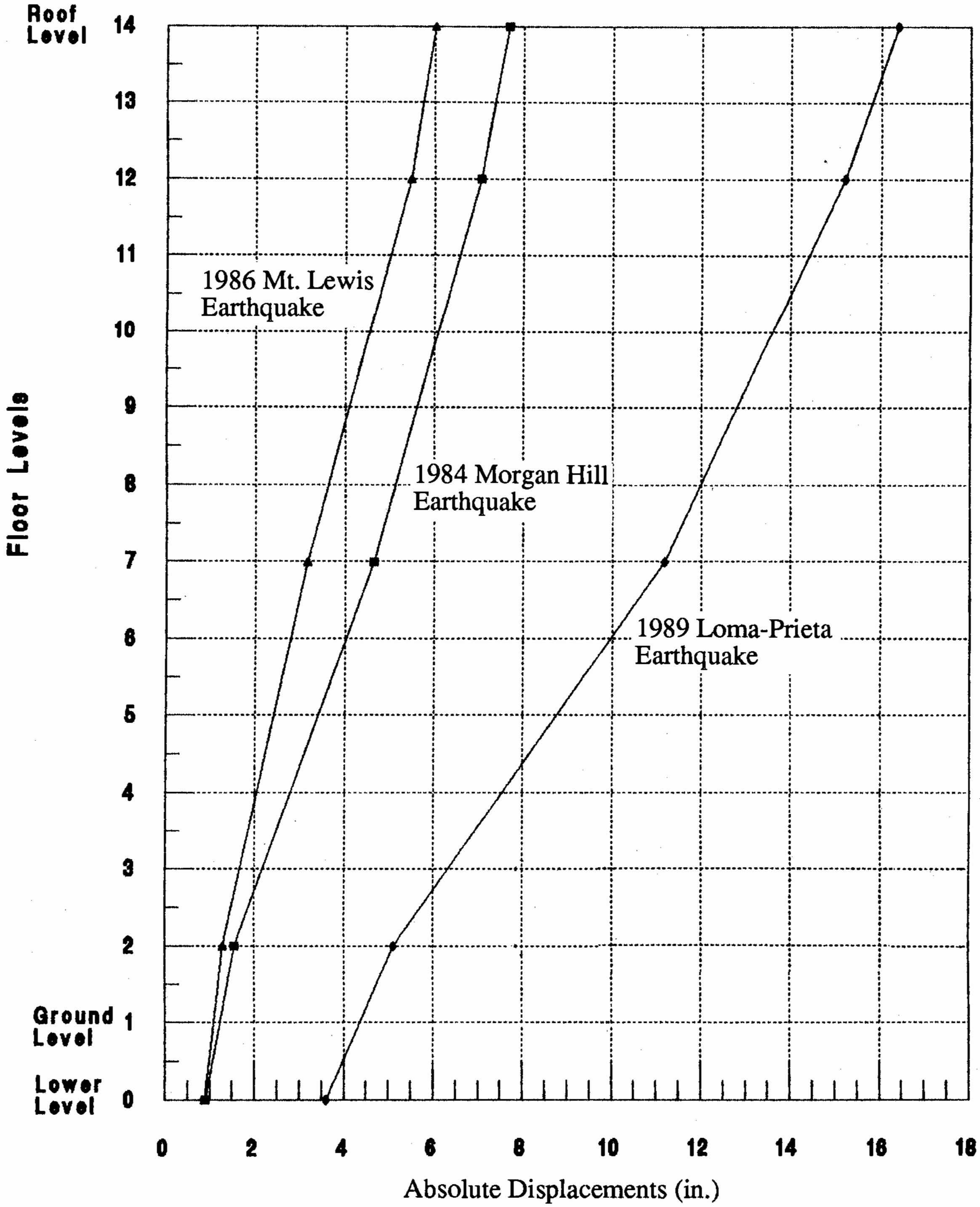


Figure 30: Maximum Recorded Displacements (Absolute) vs. Floor Levels
SW Corner: E-W Direction

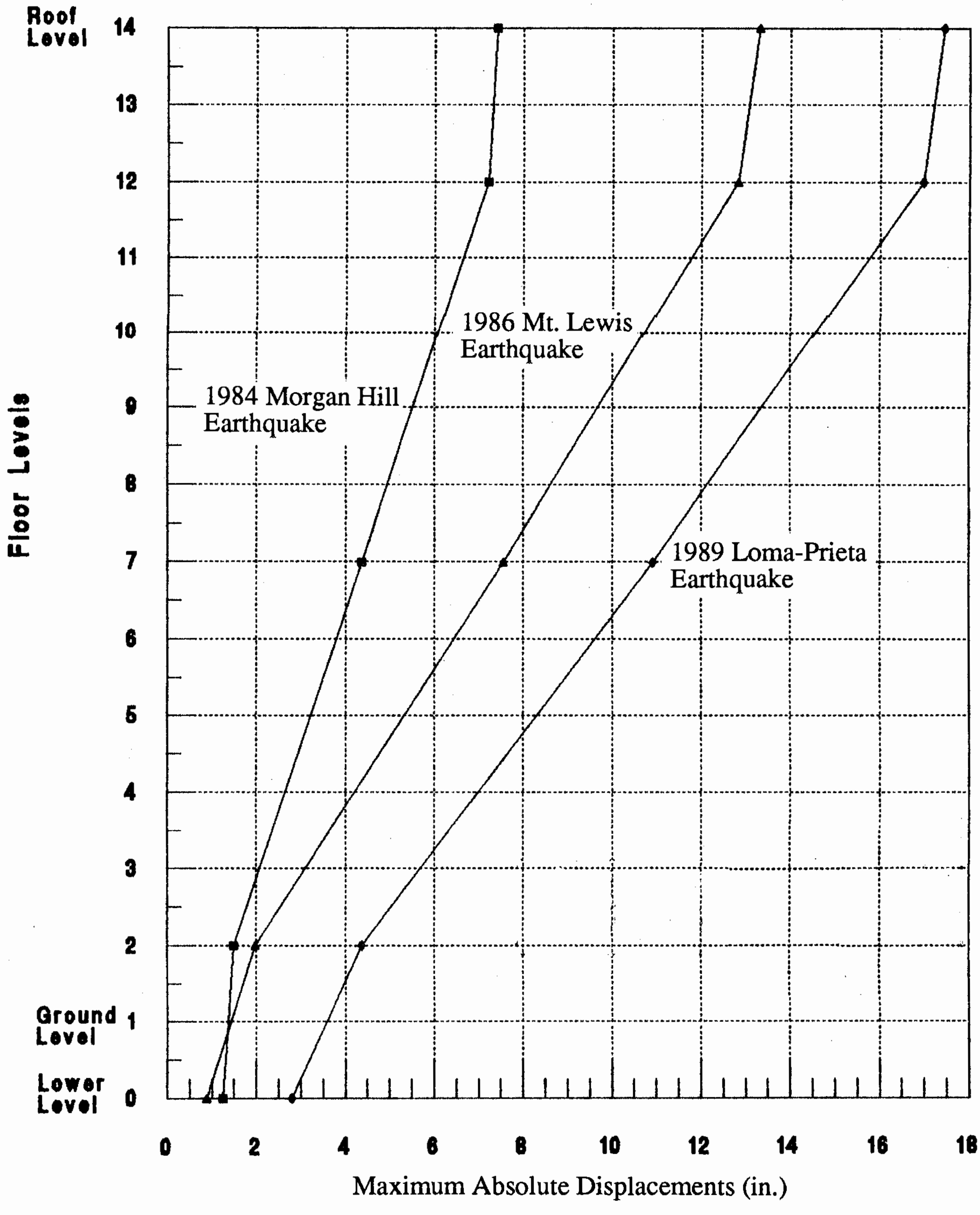


Figure 31: Maximum Recorded Displacements (Absolute) vs. Floor Levels
SW Corner: N-S Direction

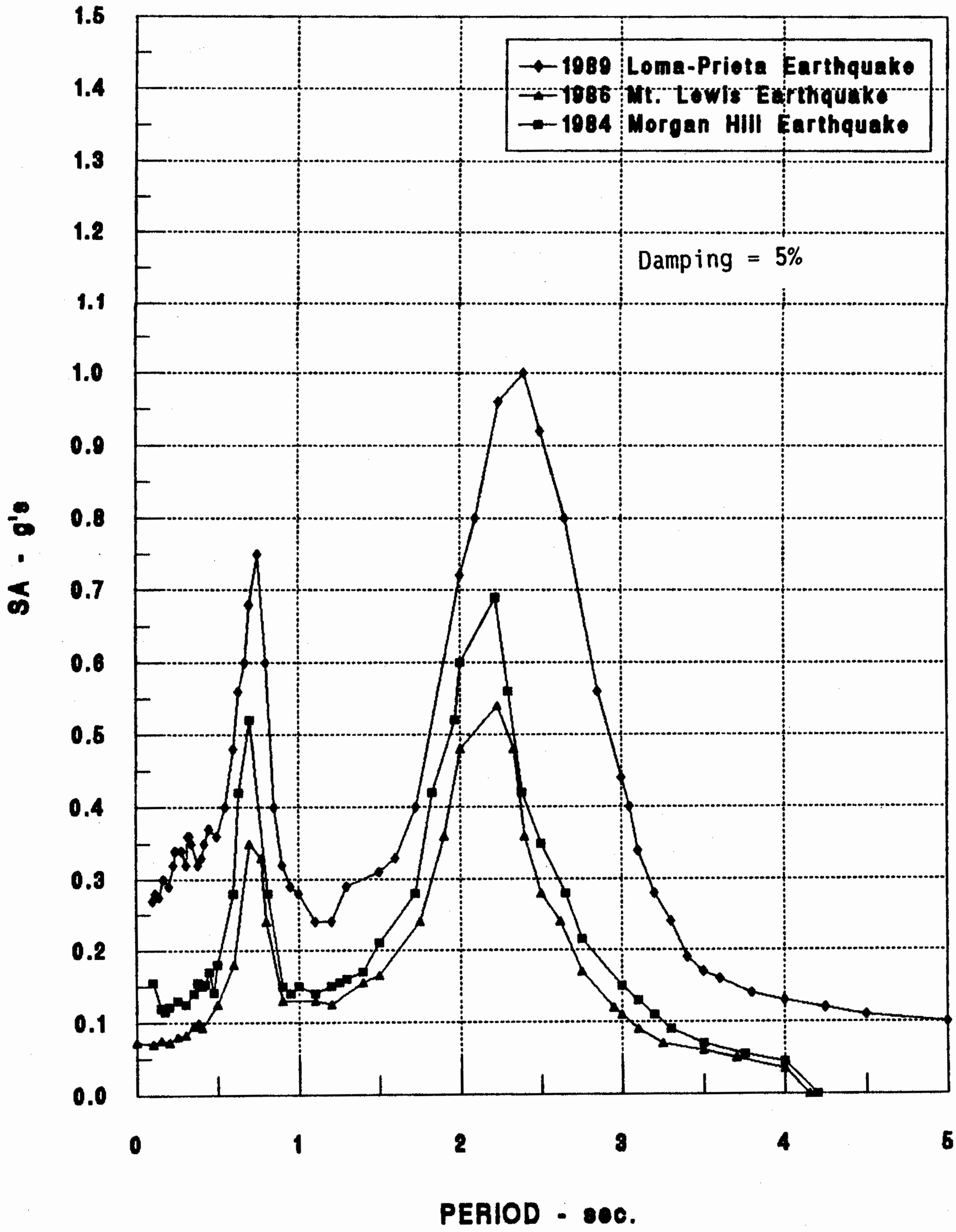


Figure 32: Earthquake Response Spectra - 7th Floor, E-W Direction
Chan. No. 13

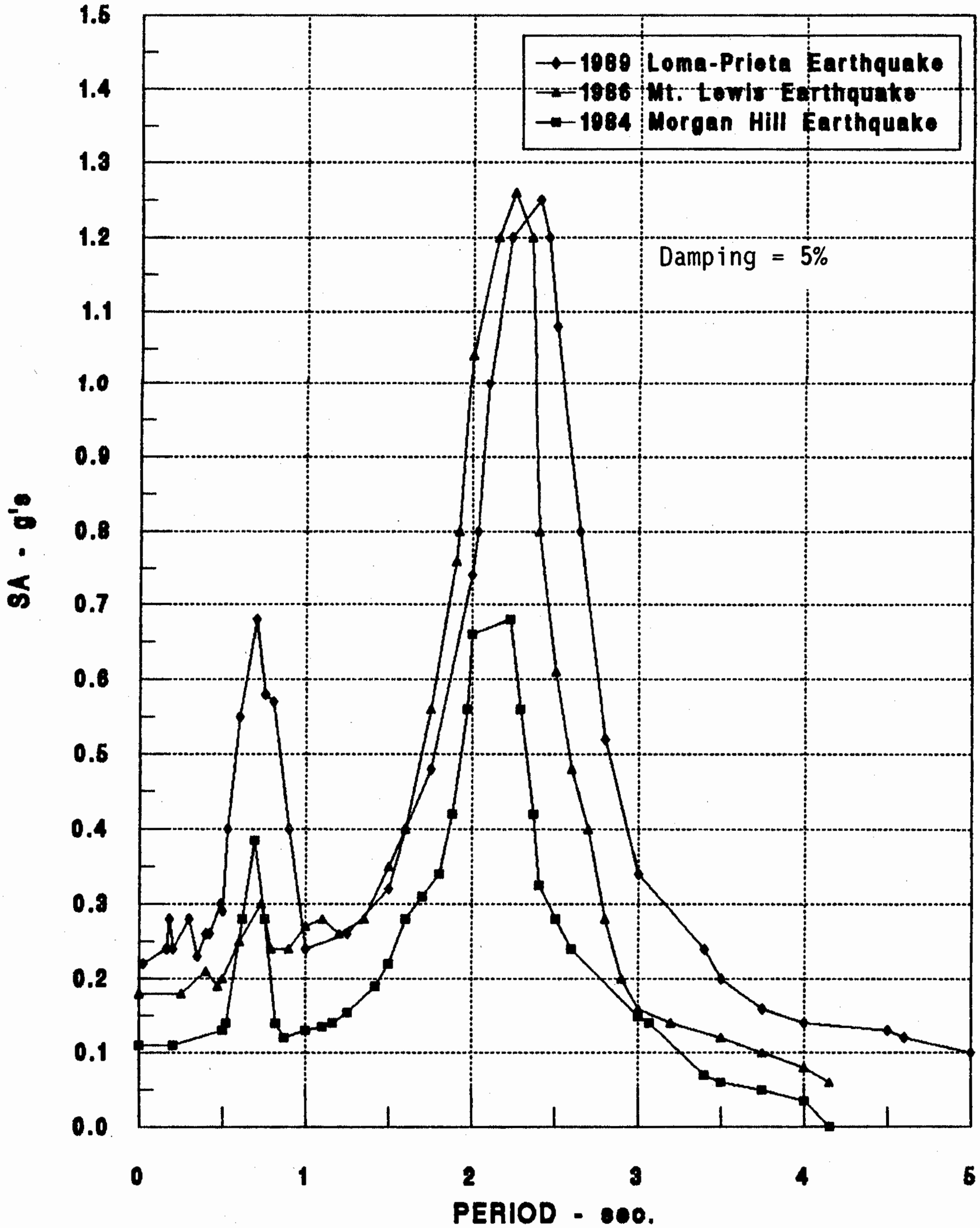


Figure 33: Earthquake Response Spectra - 7th Floor, N-S Direction
Chan. No. 14

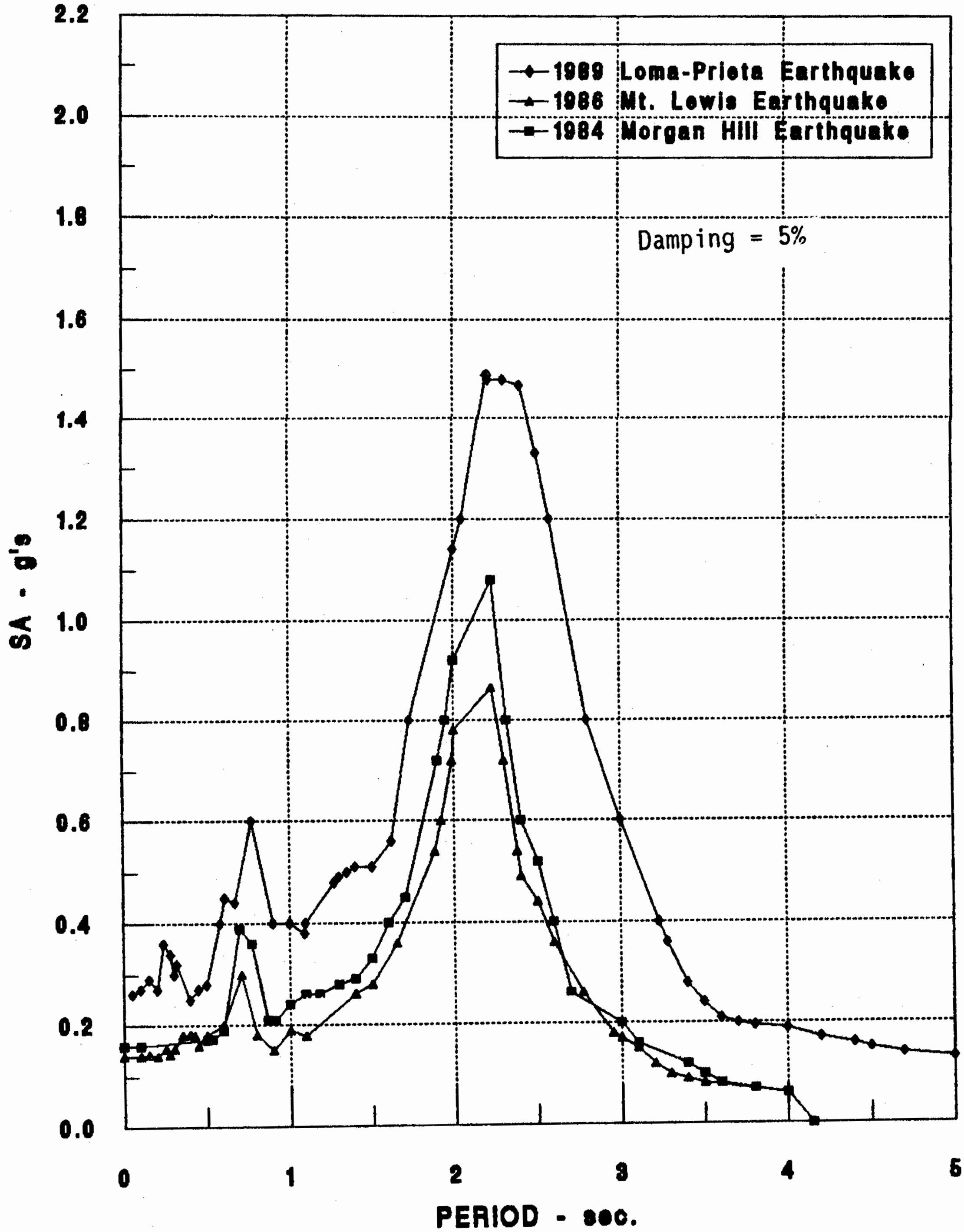


Figure 34: Earthquake Response Spectra - 12th Floor, E-W Direction
Chan No. 9

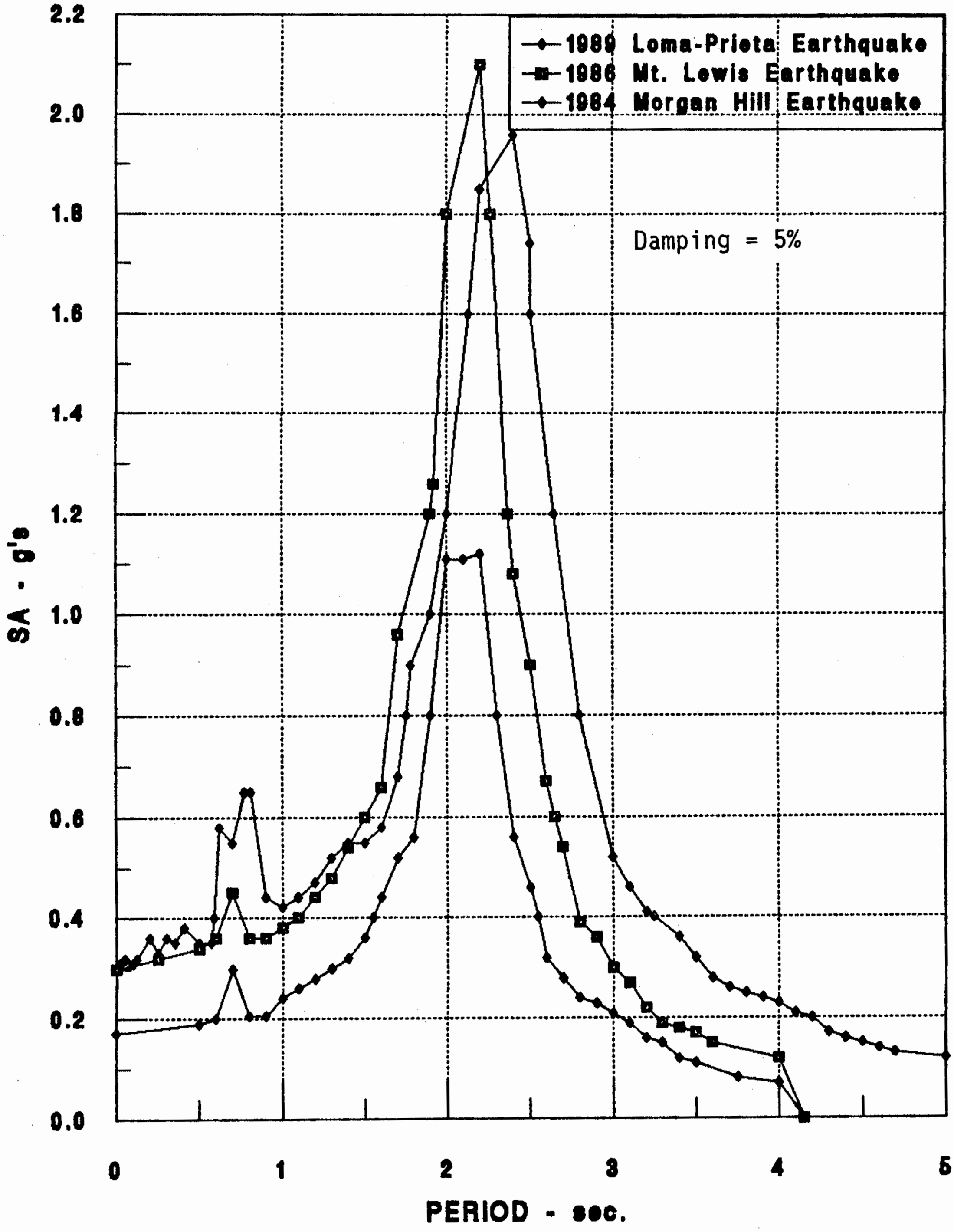


Figure 35: Earthquake Response Spectra - 12th Floor - N-S Direction
Chan. No. 10

CHAPTER 10: CONCLUSIONS

Discussion of Results and Conclusions

In view of the fact that only five floor levels were instrumented, recorded inter-story drift levels were not readily available. A study of the inter-story drifts obtained from seismic analysis using ETABS and CQC spectrum loading shows that analytically predicted inter-story drift index was of the order of 0.007. A study of observed component damage shows that despite the large displacements experienced by this case-study building, none of the observed non-structural component damage was caused by inter-story drift effects. It appears that the exterior glass curtain-wall system survived the 1989 Loma Prieta earthquake without any visible damage. None of the open office areas had any full-height non-structural partitions that could have been prone to earthquake damage due to the inter-story drift levels experienced by this building.

In conclusion, the important issues of correlation between recorded response data and non-structural component damage observed in the Santa Clara County Government Center are as follows:

Threshholds of response motions that produce non-structural component damage.

At the 7th floor level peak recorded acceleration was 0.257g and peak recorded absolute displacement was 10.12 inches in the E-W direction. At the 12th floor level peak recorded acceleration was 0.266g and peak recorded absolute displacement was 13.26

inches in the E-W direction. Significant non-structural component damage occurred at the 7th and 11th floor levels, especially during the 1989 Loma Prieta earthquake.

Non-structural components at the 7th floor level experienced 35 cycles of floor accelerations with amplitudes ≥0.05g. This may be one significant reason for the extensive nonstructural damage observed during the 1989 Loma Prieta earthquake.

Non-Structural Component Damage Index

A crude non-structural component damage index expressed as a percentage of components damaged was attempted based on a review of the video-tape of the observed non-structural damage, as presented in Table IV. Such an index, when improved by taking into account additional factors outlined above, could provide a means of characterizing observed non-structural component damage during earthquakes.

Frequency Response

The typical peak spectral response for almost all floors in this flexible high-rise was approximately 2.25 seconds. This explains why tall, heavy file cabinets sitting on carpet were able to rock and overturn, while nearby rigid objects, such as telephones or low center-of-gravity computers, were not jarred off desks. Some weakly or eccentrically snubbed rooftop mechanical equipment that performed well may have been slightly too rigid to experience strong response.

Design and installation features of non-structural components that accounted for most damage are relatively typical and widespread. Therefore widespread damage of this type can be expected in other earthquakes where motions of this level are experienced.

REFERENCES

1. Arnold, Chris, Occupant Behavior Related to Seismic Performance in a High-Rise Office Building, Proceedings, Third National Conference on Earthquake Engineering, Charleston, S.C. 1986.
2. Benuska, L., Editor, "Loma Prieta Earthquake Reconnaissance Report," Earthquake Spectrum, Supplement to Vol 6. Earthquake Engineering Research Institute, 1990.
3. CSMIP, "CSMIP Processed Strong-Motion Data from the Loma Prieta Earthquake of 17 October 1989," California Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies, Report No. OSMS 91-07, 1991.
4. EERI, Non-Structural Issues of Seismic Design and Construction, Publication no. 84-04, Earthquake Engineering Research Institute, Oakland, California, June, 1984.
5. ETABS (Version 5.30), Computers and Structures, Inc., Berkeley, California, 1991.
6. Mahin, S.A., Boroschek, R., and Zeris, C., Engineering Interpretation of the Responses of Three Instrumented Buildings in San Jose, SMIP 89 Seminar, California Department of Conservation, Division of Mines and Geology, Sacramento, California, May, 1989.
7. Naaseh, Simin., "The Morgan Hill Earthquake of April 24, 1984 Performance of Three Engineered Structures, Earthquake Spectra, Vol 1, No. 3, Earthquake Engineering Research Institute, May 1985.
8. Reitherman, Robert,The Reitherman Company, Half Moon Bay, CA.

Personal Communication, 1991, 1992, 1993.

9. Shakal, A., Huang, M., et al "Processed Data from the Strong-Motion Records of the Mogan Hill Earthquake of 24 April, 1984," Part II, Structural Response Records, California Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies, OSMS 85-05.

10. Shakal, A., Huang, M., et al., "CSMIP Strong-Motion Records from the Santa Cruz Mountains (Loma Prieta), California Earthquake of 17 October 1989" California Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies, Report OSMS 89-06, 1989.

11. UBC, 1988 and 1991 Editions, International Conference of Building Officials, Whittier, California.

12. Van Osdol, Wes., GSA, County of Santa Clara, Santa Clara, CA. Personal Communication, 1991, 1993.