National Strong-Motion Program of the U.S. Geological Survey

by

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ABSTRACT

The purpose of this paper is to provide current information related to the United States Geological Survey (USGS) National Strong Motion Program (NSMP). The significant part of the information provided can be found on the USGS Web Site: **agram.wr.usgs.gov (Figure 1).**

KEYWORDS: strong-motion, building, attenuation, spectra, web page, structural response, frequency

1. INTRODUCTION

The occurrence of earthquakes from coast to coast of the conterminous United States as well as in Hawaii, Alaska and Puerto Rico necessitates a well coordinated, cooperative and financially and organizationally stable National Strong Motion Program [NSMP]. The only organization that has the human resources to accomplish the objectives of such a program is the United States Geological Survey (USGS).

The NSMP is dedicated to investigating strong earthquake shaking at soil and rock sites throughout the United States, and its potential impact on engineered structures. These investigations of strong shaking are fundamental and are critically needed for support of seismological studies of source-site effects and, in particular, those engineering efforts aimed at establishment of rational zoning criteria and improvement of seismic design code provisions. The Program's consistency of strong-motion recording and long-term effectiveness are well-illustrated by selected accelerograms (Figure 2), which were recorded during significant U. S. earthquakes that occurred during the past sixty-two years.

The USGS National Strong Motion Program is coordinated in three general components:

A. Operations
B. Data Management
C. Research

The Program is cooperative in the sense that it has agreements with other federal and state agencies and other public and private institutions.

The program has a very significant research component that aims to complement and support mitigation efforts.

The purpose of this paper is to review the background of the USGS National Strong Motion Program (NSMP) and to discuss its current status as well as possible future improvements and developments. Most of

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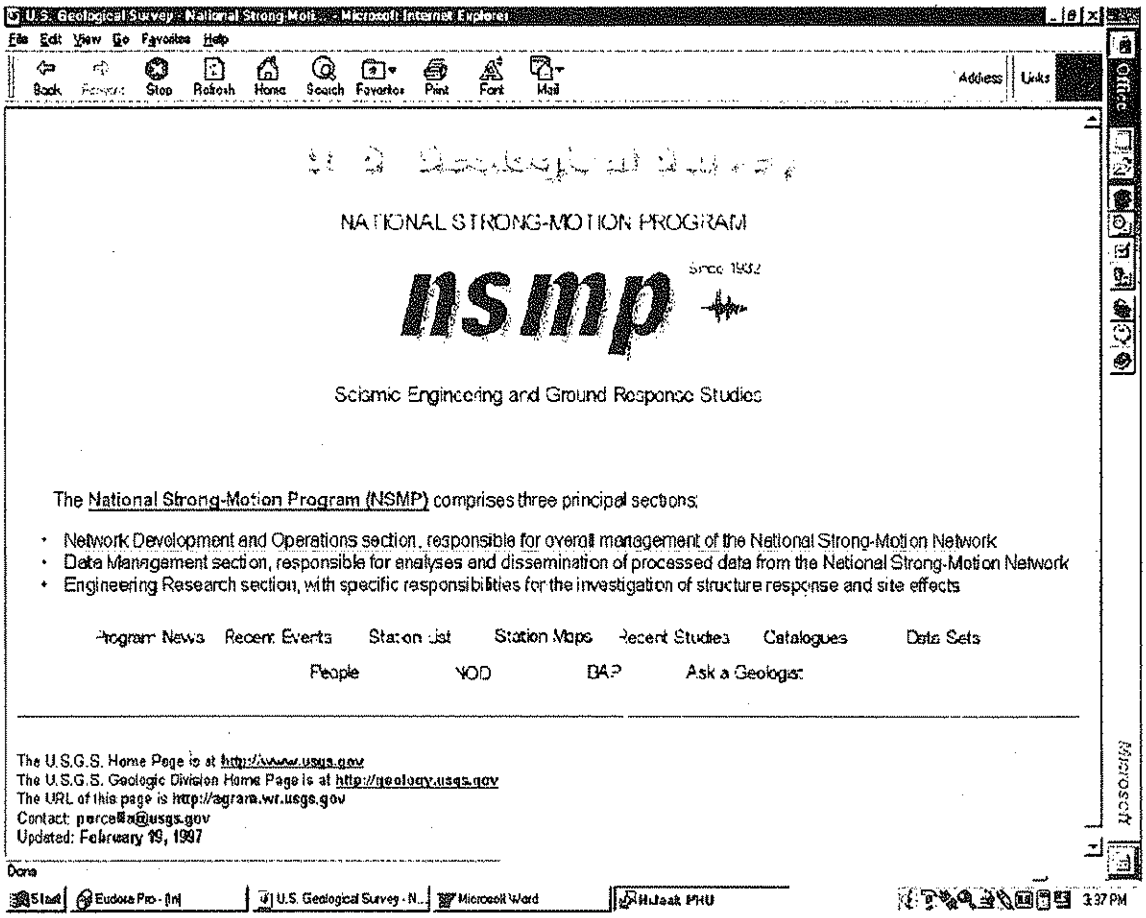


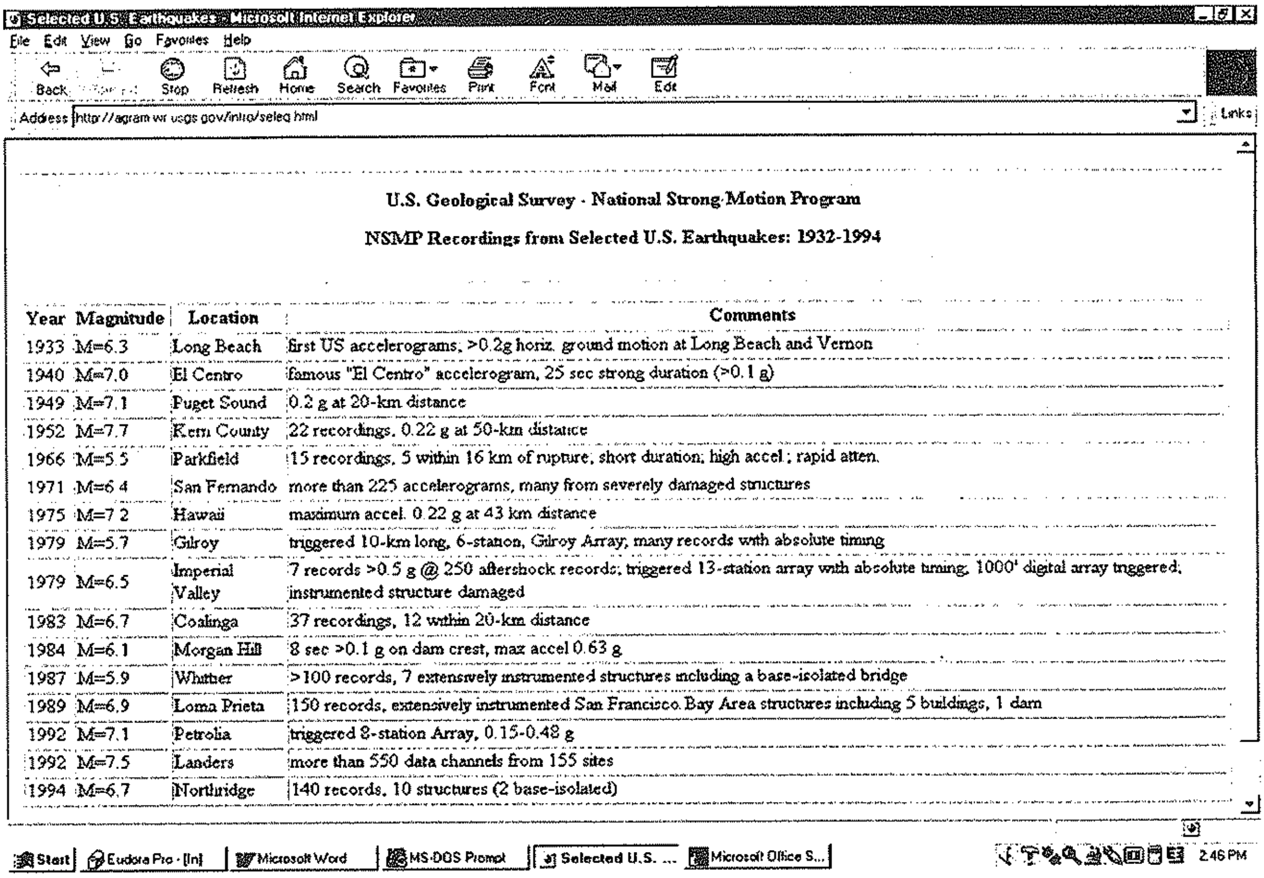
Figure 1. Introduction to the USGS-National Strong Motion Program **[http://agram.wr.usgs.gov] web page.**

the materials presented herein are directly quoted or derived from the web site of the USGS-NSMP **[http://agram.wr.usgs.gov].** The introduction to the web page is shown in Figure 1.

2. HISTORY

The history of strong-motion recording in the United States has roots in the World Engineering Congress that convened in Tokyo in 1929. American engineers returned from these meetings were convinced that there was an immediate need for the United States to develop a rugged seismograph able to record potentially damaging ground motions and to monitor the response of critical structures during strong local earthquakes. In 1931, U. S. Congress allocated additional funds to the Coast and Geodetic Survey for establishment of an engineering seismology program, including the development of a strong-motion seismograph (accelerograph), and the implementation and operation of a national strong-motion network.

The first U. S. accelerographs were installed in southern California in the summer of 1932; by 1972 the network included 575 accelerographs at permanent stations located throughout the United States and in Central and South America. Network responsibilities were transferred to the



U.S. Geological Survey - National Strong-Motion Program

NSMP Recordings from Selected U.S. Earthquakes: 1932-1994

Year	Magnitude	Location	Comments
1933	M=6.3	Long Beach	first US accelerograms, >0.2g horiz. ground motion at Long Beach and Vernon
1940	M=7.0	El Centro	famous "El Centro" accelerogram, 25 sec strong duration (>0.1 g)
1949	M=7.1	Puget Sound	0.2 g at 20-km distance
1952	M=7.7	Kern County	22 recordings, 0.22 g at 50-km distance
1966	M=5.5	Parkfield	15 recordings, 5 within 16 km of rupture, short duration, high accel.; rapid atten.
1971	M=6.4	San Fernando	more than 225 accelerograms, many from severely damaged structures
1975	M=7.2	Hawaii	maximum accel. 0.22 g at 43 km distance
1979	M=5.7	Gilroy	triggered 10-km long, 6-station, Gilroy Array; many records with absolute timing
1979	M=6.5	Imperial Valley	7 records >0.5 g @ 250 aftershock records; triggered 13-station array with absolute timing, 1000' digital array triggered; instrumented structure damaged
1983	M=6.7	Coalinga	37 recordings, 12 within 20-km distance
1984	M=6.1	Morgan Hill	8 sec >0.1 g on dam crest, max accel 0.63 g
1987	M=5.9	Whittier	>100 records, 7 extensively instrumented structures including a base-isolated bridge
1989	M=6.9	Loma Prieta	150 records, extensively instrumented San Francisco Bay Area structures including 5 buildings, 1 dam
1992	M=7.1	Petrolia	triggered 8-station Array, 0.15-0.48 g
1992	M=7.5	Landers	more than 550 data channels from 155 sites
1994	M=6.7	Northridge	140 records, 10 structures (2 base-isolated)

Figure 2. Selected Recordings of USGS-NSMP

National Oceanic and Atmospheric Administration's earthquake program in 1970; in 1973 (with National Science Foundation funding), the entire strong-motion program was absorbed by the Department of the Interior, U.S. Geological Survey, as part of the National Earthquake Hazards Reduction Program. **The National Strong-Motion Program currently operates nearly 900 strong-motion recorders at approximately 550 permanent stations located in 33 States and the Caribbean.**

3. COOPERATIVE PROGRAMS:

The U. S. Geological Survey's National Strong-Motion Program (NSMP) has evolved over more than six decades; the Program is primarily the result of cooperative efforts with many other Federal, state, and local agencies, private companies, and academic institutions. Key participants for whom the NSMP presently maintains instrumentation include the Army Corps of Engineers, the Department of Veterans Affairs, and the Metropolitan Water District of Southern California. Summary of participants in the USGS Cooperative Program is provided in Table 1.

4. MORE ABOUT THE WEB PAGE

4.1 DATA SETS

There is now considerable amount of the USGS data available to the user community

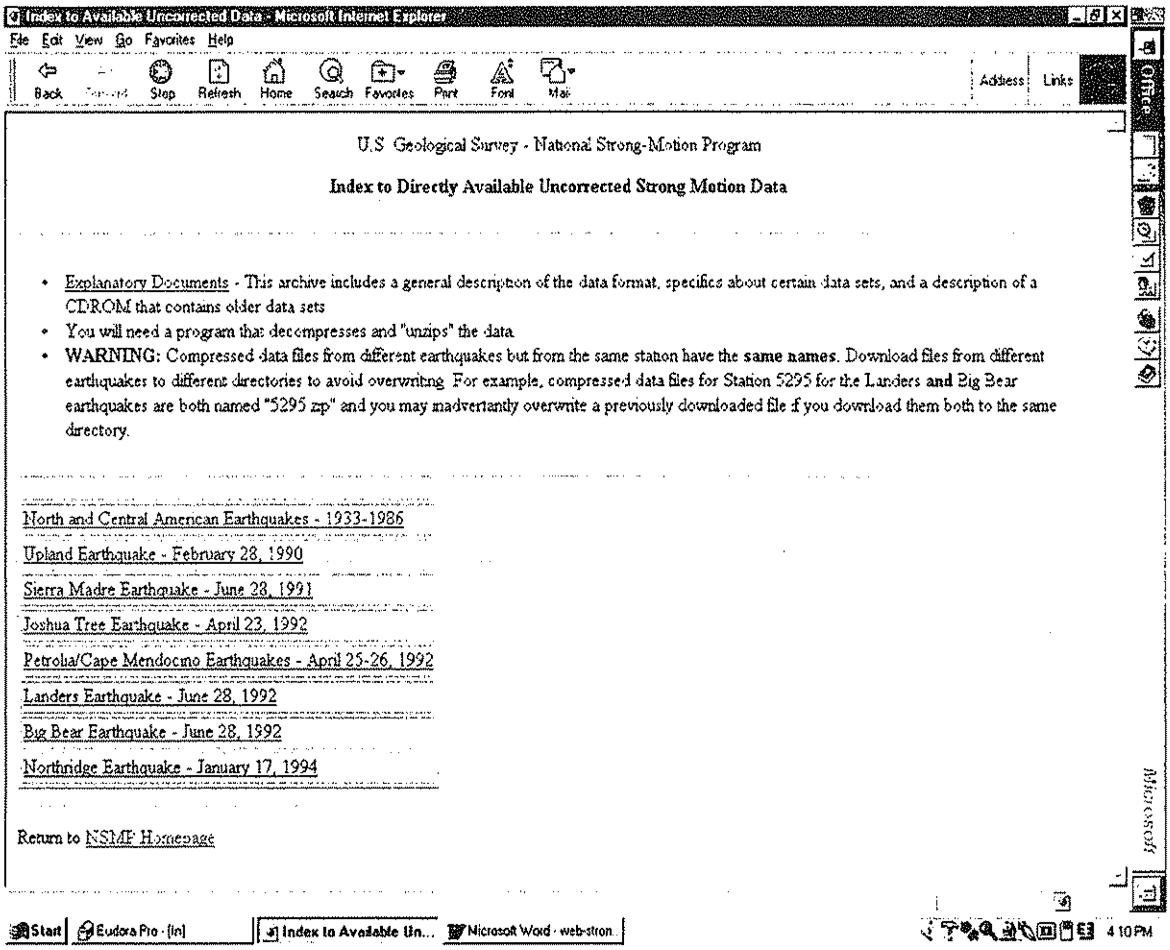


Figure 3. Web page describing the data sets available to user community

through the web. The descriptive information on the data sets is shown in Figure 3. The data can be directly unloaded. Also available on the web is the software BAP used for processing strong-motion data. This software can also be downloaded.

4.2 STATION MAPS AND LISTS

The locations of stations can be found readily on maps and in descriptive lists on the web page. The user has options for maps with faults and highways or 3-dimensional maps or topographical maps with faults for Northern and Southern California. A sample map is shown in Figure 4. A comprehensive descriptive list for all stations of NSMP is included separately. However, for Northern and Southern California, the user can click to any one of the stations and get the descriptive information for that station only. Figure 5 shows what a user can get if he/she clicks the Palo Alto VA Hospital station on the map in Figure 4.

5. RESEARCH COMPONENT

USGS research personnel conduct research using strong-motion data. The research topics encompass a wide variety of topics. Only two of them will be cited herein.

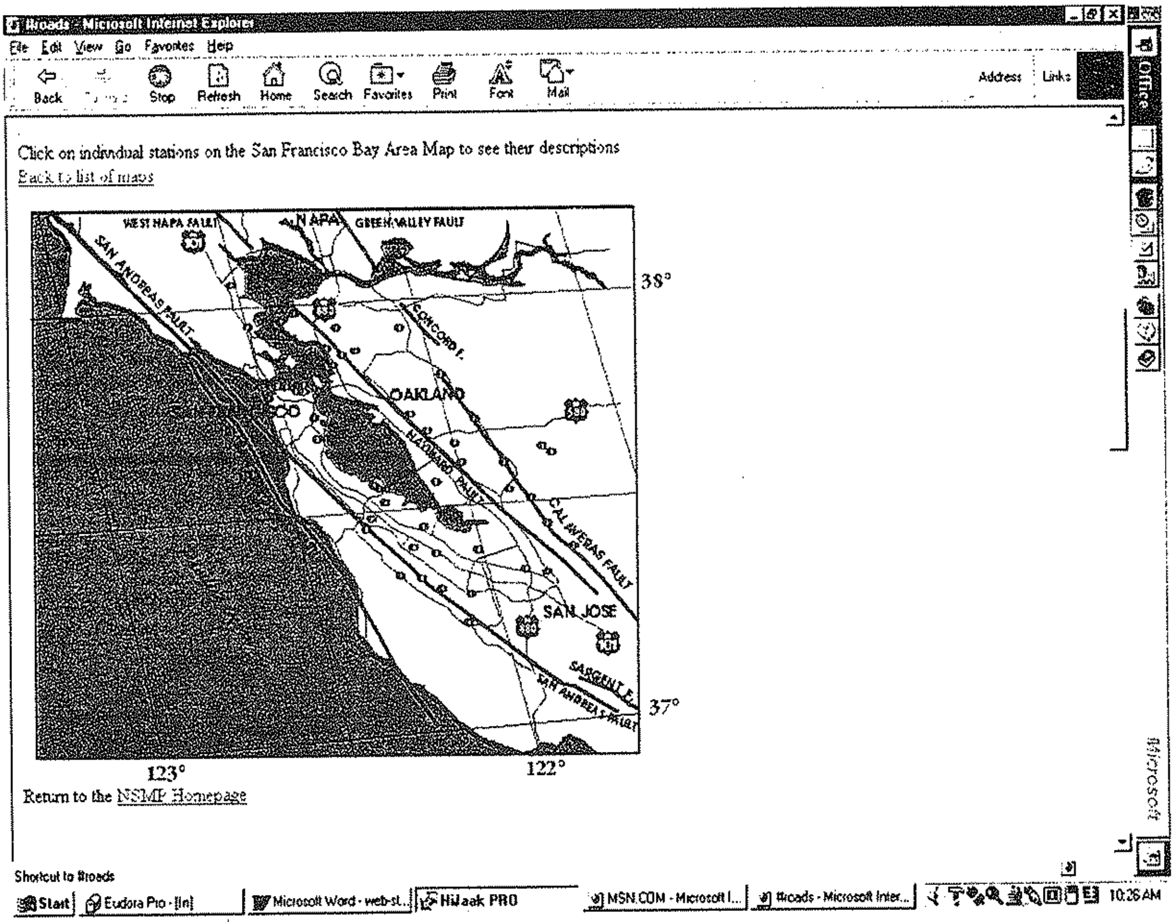


Figure 4. Sample station map on the USGS-NSMP web site.

5.1 Two Sample Research Topics of USGS-NSMP

5.1.1. Development of Attenuation Relationships

The attenuation relationships are developed by regression analyses of strong-motion data collected over many years mainly from Western United States. These relationships are used to predict peak accelerations at a site, for a specified site condition, magnitude and distance from a fault causing an earthquake. There are various definitions of the distance associated with attenuation curves (Joyner and Boore, 1996) . Figure 6 shows a sample attenuation curve (Boore, *personal communication*, 1997). In this particular figure, Boore compares Kobe (M=6.9) and Northridge (M=6.7) peak accelerations, recorded at Site Class C (V_s=180-360 m/s), with the attenuation curve for M=6.95 strike-slip earthquakes. These attenuation curves are used world-wide in various engineering projects for prediction of peak accelerations expected at a site for which a causative fault and associated earthquake magnitude is specified.

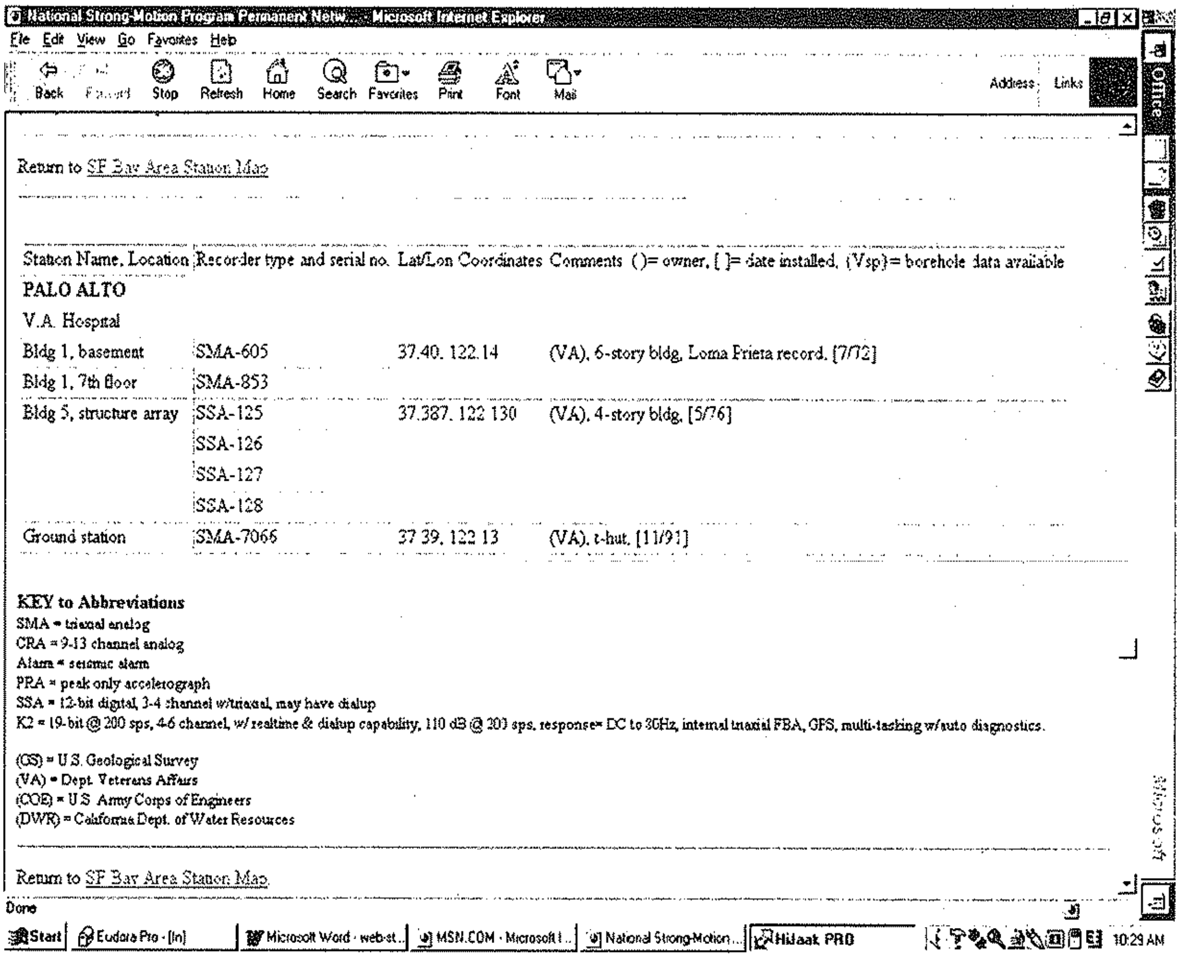


Figure 5. Descriptive information of one station identified by clicking on the map.

5.1.2. Instrumentation of Structures and Structural Response Studies

USGS-NSMP has instrumented structures throughout seismically active regions of the US. Current inventory of instrumented structures is provided in Table 2. One of the unique structures intrumented is the Pacific Park Plaza in Emeryville, Ca. Figure 7 shows Pacific Park Plaza (PPP) Building at Emeryville, Ca. The building was instrumented in 1985 with analog strong-motion recording system. PPP had 21 channels of accelerometers deployed throughout the superstructure. In addition, it had two free-field triaxial accelerographs as shown in the figure. The array recorded response of PPP and its associated free-field sites during the 17 October 1989 earthquake.

These structural response records are probably the most widely studied structural response data from the Loma Prieta earthquake (Aktan, etal., 1992, Anderson, Miranda, Bertero, 1991, Anderson and

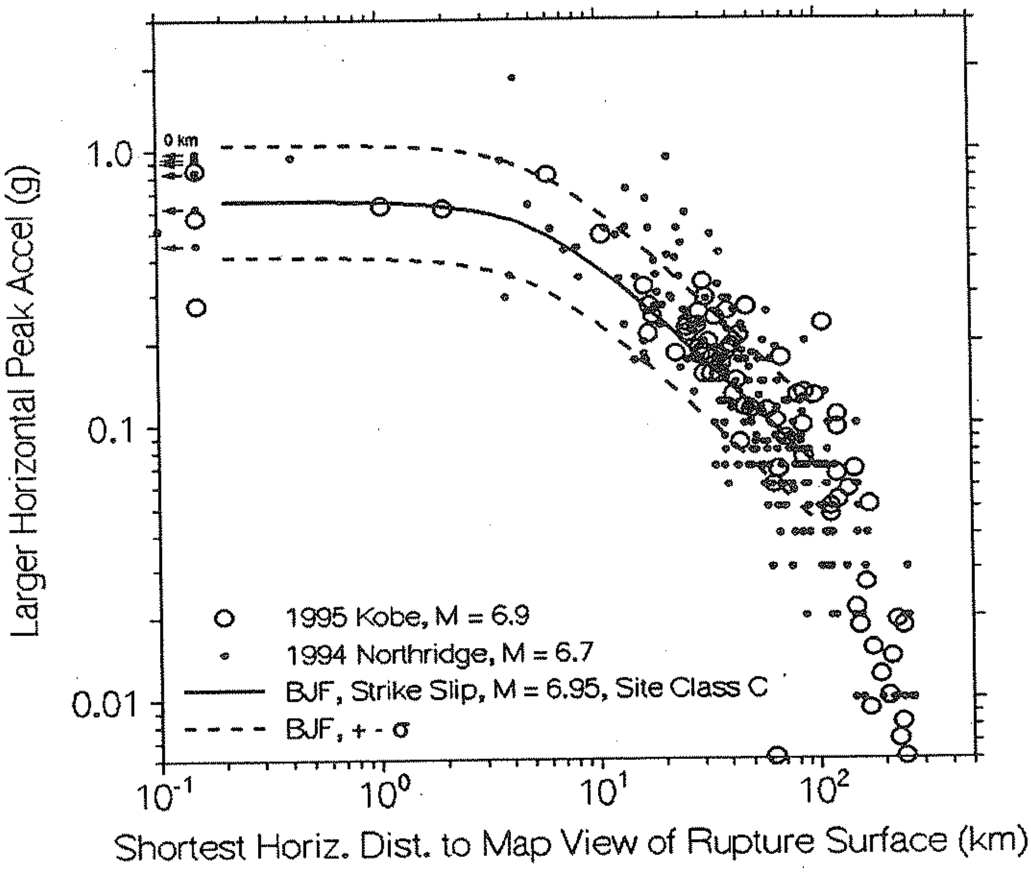


Figure 6. A Sample Attenuation Curve by Boore (*personal communication*, 1997)

Bertero, 1994, Çelebi, 1992, 1996, Çelebi and Safak, 1992, Kagawa etal., 1993,

Kagawa and Al-Khatib, 1993, Kambhatla etal., 1992 and Safak and Çelebi, 1992). Figure 8 shows the time-histories and response spectra of recorded acceleration responses at the roof, ground floor and south free-field (SFF) of the building as well as that at Yerba Buena Island (YBI), a rock site (with largest peak acceleration of 0.06 g). Both sites are approximately 100 km from the epicenter of the Loma Prieta earthquake. Response spectra of amplified motions (largest peak acceleration 0.26 g at the south free-field site [SFF]) are compared to the response spectra of Yerba Buena Island (YBI) in the figure.

Studies conducted using structural response data show that (a) the fundamental mode frequency (period) of the building is 0.38 Hz (2.63 s), (b) there is significant soil-structure interaction, (c) the critical damping percentages (12-15 %) determined using system identification techniques indicates that there is radiation damping, and (d) one wing of the building has significantly larger response as compared to the other two. For structures with wings, such as PPP, or unsymmetrical structures, the response can be significantly affected by the azimuthally variable ground motions from earthquakes with different epicenters. The free-field records have been used in assessing the amplified motions of the East San Francisco Bay and its effects on engineered structures such as the San Francisco Bay Bridge

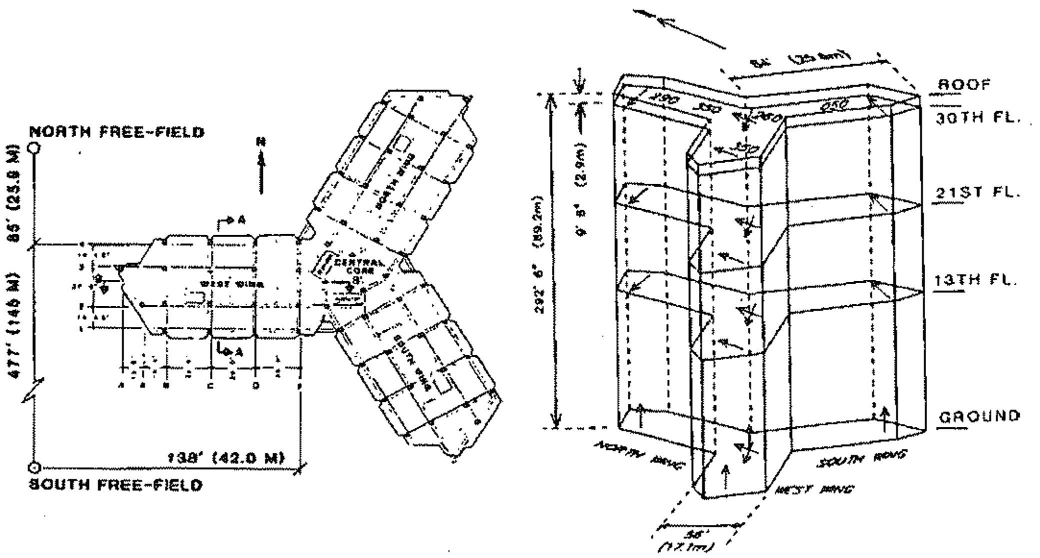


Figure 7. Plan view and three-dimensional schematic of PPP showing the location of accelerometers.

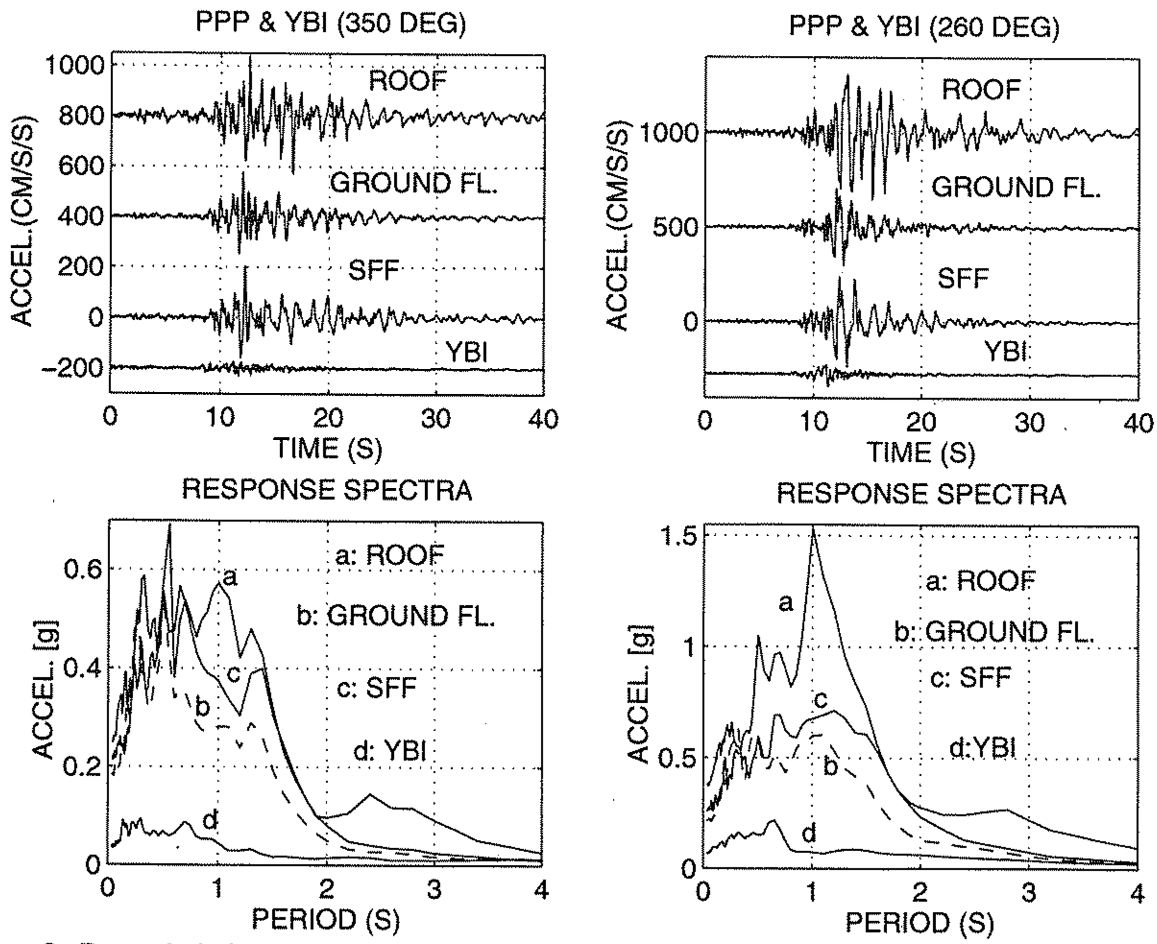


Figure 8. Recorded Ground Motions and Response Spectra of PPP, its free-field and Yerba Buena Island.

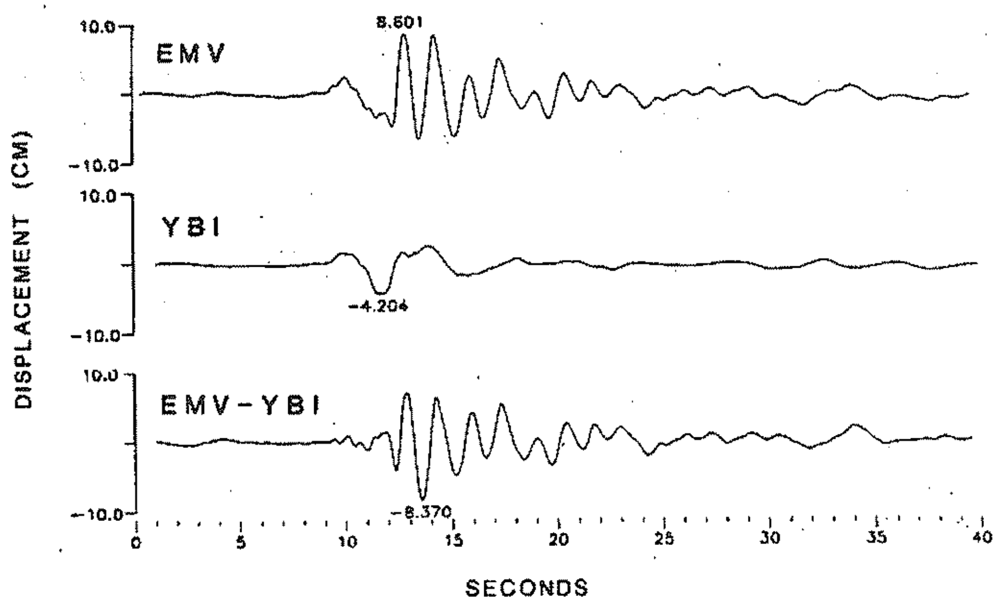


Figure 9. Displacements at Emeryville and Yerba Buena Island and Relative Displacement (from Hanks and Brady, 1991).

(Hanks and Brady, 1991). The south free-field [SFF] station shown in Figure 7 is also known as EMV[2] (designation for Emeryville). Figure 9 shows the displacements at EMV and YBI (Hanks and Brady, 1991). This figure depicts one of the possible reasons as to why one of the Bay Bridge spans between YBI and east end of Bay Bridge collapsed during the LPE. The approximate relative displacement of 8 cm between YBI and east end of Bay Bridge shows how much extension occurred between the two ends and possibly contributed to the collapse of the span.

In January 1997, a downhole accelerograph has been deployed (at 66 meters depth) at the location of the south free-field (SFF). Furthermore, the recording capability has been upgraded to a digital system. In future earthquakes, this site will produce very valuable data that will be available on the web site within a short time following the event.

7. LOOKING TO THE FUTURE

There is intensive effort to upgrade the strong-motion instruments from analog to digital. At the moment, approximately 15 % of the network is digital. In the near future, we expect to upgrade 100 % of the analog systems to digital systems.

Only a few of the special purpose experimental arrays that are in the development stage are cited below:

(a) We are developing a soil-structure interaction experiment for a building structure that will have, in addition to instruments within the building, special purpose instruments in the vicinity of the foundation, below the foundation, and on the surface near a building,

[2] In most studies, the site of south free-field (SFF) is referred to as the Emeryville site [EMV]. The data from this site is one of the most used ground motion records of the LPE strong-motion data set.

(b) Another experiment in the deployment stage is the drift experiment. Selective consecutive floors of two tall buildings are being instrumented in Los Angeles to collect data to specifically measure drift between several pairs of consecutive floors.

(c) Topographical effects have been observed during past earthquakes and their aftershocks. We are attempting to develop a topographical experiment array in an urban environment in the San Francisco Bay Area or Los Angeles.

CONCLUSIONS

The paper presents recent developments and factual information of the National Strong Motion Program of the U. S. Geological Survey. As in the past, plans are for USGS to play a leading national role in establishing and operating strong-motion networks, special purpose arrays, collection and dissemination of data and performing pertinent research for reduction of seismic hazards and improved public safety.

7. ACKNOWLEDGMENTS

This paper was prepared with the intention to provide current information of the USGS-NSMP. Information presented herein has been collected by many dedicated personnel of the NSMP. Ron Porcella is the current chief in charge of operations. Howard Bundock played a key role in initiation and updating the web site.

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Table 1. Participants of the USGS-NSMP Cooperative Program

OWNER/AGENCY	STATIONS	ACCELEROGRAPHS
Army Corps of Engineers	67	190
Property Owner (Code mandated)	31	35
California Department of Water Resources	4	7
Department of Veterans Affairs	59	77
General Services Administration	2	8
Hawaii State Civil Defense	5	5
Metropolitan Water District of Southern California	20	35
Oregon Department of Transportation	5	25
University of Puerto Rico	8	8
U.S. Department of Energy	1	6
U.S. Geological Survey	325	421
Utah Geological Survey	7	7
Washington, City of Aberdeen	1	3
Washington, Tacoma Public Utilities	1	3
Washington Dept.of Natural Resources	1	4
Washington Department of Transportation	3	6
TOTALS	540	840

Table 2. Structures Instrumented by USGS-NSMP

		NUMBER OF STRUCTURES	
		Extensively Instrumented (>8 channels)	Moderately Instrumented (4-8 channels)
Buildings			
	Alaska	3	
	California	20	6
	Hawaii	1	1
	Missouri	2	
	Puerto Rico	1	1
	South Carolina	1	1
	Tennessee	2	
	Utah	1	
	Washington	2	
Bridges			
	California	2	
	Oregon	9	
Dams			
	California	19	
	Idaho	2	
	Montana	1	
	New Mexico	1	
	Oregon	13	
	Utah	1	
	Washington	6	