# Baseline Water Supply and Demand Evaluation

# of

# Southern Nye County Nevada

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# BASELINE WATER SUPPLY AND DEMAND EVALUATION OF SOUTHERN NYE COUNTY, NEVADA

**Prepared for:**

**The Nye County Nuclear Waste Repository Office**

**Prepared by:**

**Thomas S Buqo**
**Consulting Hydrogeologist**
**P.O. Box 127**
**Blue Diamond, Nevada 89004**

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### INTRODUCTION

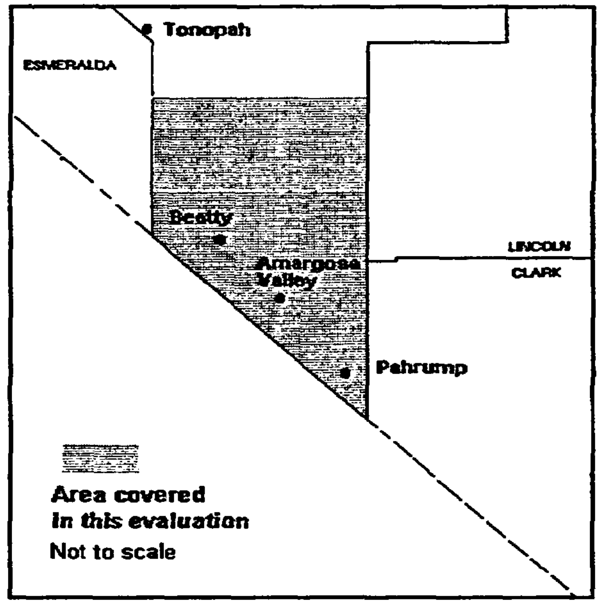
In the summer of 1996, the Nye County Nuclear Waste Repository Office noted the lack of a comprehensive baseline of information on the water resources of southern Nye County. This is the area that will be most impacted by the Yucca Mountain facility, as well as other federal actions. The rapid growth of southern Nye County has resulted in increased competition for water for municipal, quasi-municipal, and industrial purposes. To determine the existing hydrologic conditions and available water supplies, the Repository Office commissioned a special investigation. This report details the results of that investigation.

#### Background

Southern Nye County, Nevada is faced with a rapidly growing population and dwindling water supplies. Surface water sources have already been fully developed and all future water demands in this part of the county will have to be met through groundwater development. Although groundwater is physically available, there are a number of constraints on the development of new groundwater supplies.

Much of the area is controlled by either the U.S. Department of Energy, the U.S. Air Force, or the U.S. Department of the Interior. Large tracts of land have been reserved for federal use along with the vital groundwater resources under those lands. Additional water development on the Nevada Test Site is anticipated in support of the planned Yucca Mountain Repository and a proposed Solar Enterprise Zone. The development of groundwater for these projects will reduce the availability of groundwater to meet the future demands of the county, and could exacerbate an already critical water supply problem.

In the Beatty area, high fluoride concentrations limit the locations for development. Little water is available in Oasis Valley for development and the Beatty Water and Sanitation District has been forced to look to Amargosa Valley and Sarcobatus Flat as potential new sources of water. In the Amargosa Valley area, water right speculators are threatening existing water supplies with forfeiture with the intent of transferring water to metropolitan Las Vegas. Many water right holders have been forced to take measures to protect their water rights. As a result, the total water use in Amargosa Valley has more than doubled since 1991. In the Pahrump area, numerous water supply systems compete for the water needed to meet the needs of this rapidly growing community. The National Park Service has adopted a policy of evaluating all new water right applications within the Death Valley flow system and protesting any applications that they feel may affect Devil's Hole or springs in Death Valley. Each of these factors pose additional constraints on future water development in southern Nye County.




Future water demands can best be met through proper planning and the coordination of efforts at the community and county levels. The first step in this planning is the development of a comprehensive baseline of information on the existing water supply systems, the current demand for water and the projected future demand, and the major issues related to water development. This report provides a baseline on the supply of, and demand for, the precious water resources of the southern part of the county.

**Purpose and Scope**

The purpose of this evaluation is to provide baseline information on the hydrologic conditions and water supplies of southern Nye County. The collection of information for this baseline focused on establishing answers to the following water-resources related questions:

- What are the sources of water that are available in this part of the county?

- How much water is available?

- Who is currently using the water, where are they using it, and at what rate?

- How much water will be needed to meet the future demand in the area?

- Who is competing for the remaining water resources?

- What constrains future water resource development in the region?

To provide answers to these questions, a detailed investigation of the southern part of the county was conducted. The scope of this investigation included the review of all available published and unpublished data, the evaluation of the general hydrologic characteristics of the region, and the definition of historic, present, and future water demand and use patterns. The information that was compiled from various state and federal agencies was tabulated and summarized and is presented in this baseline in tables, graphs, and charts.

**Report Organization**

A considerable volume of technical literature has been prepared that relates to the water resources of the region. A summary of the many previous investigations of the area is provided in the next section. Summary data from these and other sources are presented in tables and figures in the next sections, which summarize the census data and method used to project future water demand and the general hydrologic conditions of the region. Additional data lists are provided in the appendices to this report. Separate sections are presented on the water supply and demand of the Beatty, Amargosa Valley, and Pahrump areas. This section is followed by the conclusions and recommendations and a list of the references that were cited. Maps of key hydrologic parameters were also prepared and are available as the Plates to this report. These plates are located in the pocket at the back of the report and show the locations of water rights, wells, springs, water producing formations, the depth to groundwater, and the elevation of the groundwater. These maps are intended to serve as tools in evaluating the impact of planned or proposed water developments in the region.

*Note: This investigation was funded by the Nye County Nuclear Waste Repository Project Office and was completed under the direction of Mr. Nick Stellavato. All work associated with this project was performed between August 7 and September 30, 1996.*

## PREVIOUS INVESTIGATIONS & OTHER SOURCES OF INFORMATION

### PREVIOUS INVESTIGATIONS

Many organizations and individuals have conducted studies on the hydrology and water resources of southern Nye County. In this chapter, the key studies are identified for four categories: regional studies that encompass all of the area and which may extend well beyond the boundaries of the county, and studies that are specific to either Amargosa Valley, Beatty, or Pahrump and the Federal lands that surround these communities.

Complete bibliographic citations are listed in the References Cited section at the end of this report. Also included in this section are the sources of data used in conducting this evaluation which include more than 70 books, reports, and technical publications. Other sources of information include the unpublished file data of a number of State of Nevada and federal agencies.

#### Regional Studies

A number of recent investigations have been conducted for southern Nye County and for the regional carbonate aquifer system of eastern and southern Nevada. The data and interpretations presented in a number of reports provide an important baseline of information on many aspects of the water resources of the region.

Cornwall (1972) prepared a 1:250,000 scale geologic map of southern Nye County and a detailed report on the geology and mineral resources of the county south of 38° latitude. Subsequent geologic maps have been prepared by the U.S. Geological Survey for the 1:24,000 scale quadrangles that comprise the Nevada Test Site.

Major regional investigations have been conducted by the Desert Research Institute, the State of Nevada, the U.S. Geological Survey, and the Nevada Bureau of Mines and Geology. The earliest reports that included southern Nye County were prepared by the Desert Research Institute. Mifflin (1968) compiled the results of the many reconnaissance reports for individual valleys in Nevada and used this work as the basis for delineating ground-water flow systems for the entire state.

**SOURCES OF INFORMATION**

**There are many sources of information on the water resources of southern Nye County:**

- NYE COUNTY NUCLEAR WASTE REPOSITORY OFFICE
- NYE COUNTY COMPREHENSIVE PLAN
- NEVADA STATE ENGINEER'S OFFICE
- NEVADA BUREAU OF HEALTH PROTECTION SERVICES
- NEVADA STATE CENSUS DATA CENTER
- NEVADA STATE DEMOGRAPHER
- NEVADA PUBLIC SERVICE COMMISSION
- UNIVERSITY OF NEVADA LAS VEGAS
- UNIVERSITY OF NEVADA DESERT RESEARCH INSTITUTE
- U.S. GEOLOGICAL SURVEY
- U.S. DEPARTMENT OF ENERGY
- U.S. DEPARTMENT OF INTERIOR

Hess and Mifflin (1978) evaluated the water supply potential of the regional carbonate aquifer and Mifflin and Hess (1979) further evaluated the regional carbonate flow systems in Nevada. Naff et al (1974) further evaluated interbasin groundwater flow in southern Nevada with a special emphasis on Ash Meadows and southern Amargosa Desert, the Nevada Test Site, and Pahrump Valley.

The Nevada Division of Water Resources published a series of reports in 1971-74 entitled Water For Nevada. These series of reports comprised the statewide Nevada State Water Plan.

This benchmark effort established the first comprehensive overview of the water resources of the state, including all of Nye County, and included

a map of basin perennial yields (Rush et al, 1971), summary data on each groundwater basin in the state (Scott et al, 1971), a depth to water map (Rush, 1974), and maps identifying lakes and reservoirs, precipitation, runoff, evaporation, discharge areas, and total dissolved solids in groundwater (Division of Water Resources, 1972).

The U.S. Geological Survey has published the most reports on the regional groundwater conditions starting with Eakin et al (1976), who appraised the water resources of the Great Basin as a whole and the need for planning of future groundwater development.

In the mid-to-late 1980s, the U.S. Geological Survey conducted a number of studies of the Great Basin as part of their national regional aquifer system analysis program. This program is summarized by Harrill (1986a).

As part of these regional studies, Plume and Carlton (1988) defined the distribution and characteristics of the aquifers of the region. Thomas et al (1986) prepared water level maps for the alluvial and consolidated rock aquifers, and Harrill et al (1988) provided a synthesis of the major groundwater flow systems of the Great Basin. Water chemistry data for portions of southern Nye County and northern Inyo County were presented by Welch and Williams (1987a and 1987b).

Since the early 1950s, the U.S. Department of Energy has sponsored many investigations concerning the hydrology and water resources of the Nevada Test Site and adjacent areas. While some of these studies are specific only to the test site, a number of significant regional studies have also been completed.

Eakin et al (1963) performed a reconnaissance hydrology study of the entire region surrounding the test site. Rush (1970) completed the Nevada Division of Water Resources reconnaissance level investigation of the test site and adjoining areas. Perhaps the most noted single publication is Winograd and Thordarson (1975) who provide a comprehensive overview of the regional hydrologic conditions with a special emphasis on the Nevada Test Site.

Water level data for the period 1952-1993 for Nye County and Inyo County, California are presented in a series of reports by the U.S. Geological Survey including Robie et al (1995), Reiner et al (1995), and Ciesnik (1995), while Perfect et al (1995) summarize the available hydrochemical data base for the Death Valley region.

Most recently, Laczniak et al (1996) addressed the hydrogeologic controls on groundwater flow at the test site with a special emphasis on the effects of underground nuclear testing at the facility.

The U.S. Department of Energy has also conducted groundwater and surface water monitoring at the test site and surrounding areas as part of their Environmental Surveillance Program, Long-Term Hydrologic Monitoring Program, Hydrologic Resources Management Program, and Environmental Restoration Program. Data collected as part of these programs have been published in a number of reports.

The results of the Environmental Surveillance and Long-Term Hydrologic programs are provided in annual reports, most recently by Black et al (1995) for calendar year 1994. Data compiled as part of the Hydrologic Resources Management and Environmental Restoration programs are being published in a series of data reports by IT Corporation. These reports are being finalized as of this writing.

Other recent investigations have been conducted as part of Yucca Mountain studies of the regional hydrogeologic regime. An overview of the hydrology and water resources of the region was prepared by French et al (1981).

Bedinger et al (1984a and 1984b) mapped groundwater levels, springs, the depth to water, groundwater units and groundwater withdrawals of the Great Basin and Bedinger et al (1989) evaluated the geology and hydrology of the Death Valley region. Faunt (1994) developed detailed digital hydrogeologic models of the Death Valley Region and D'Agnese (1994) developed detailed data sets, a revised conceptual model, and a preliminary numerical model of the Death Valley Flow System.

Luckey et al (1993) and Lobmeyer et al (1995) provide water level data for a number of monitoring wells at Yucca Mountain, Oasis Valley, and Amargosa Desert.

Pal Consultants (1995), sponsored by the National Park Service, developed yet another conceptual model of the Death Valley Ground-Water Flow System. This study was performed to provide the U.S. National Park Service with hydrologic information needed to help protect the water resources of Death Valley National Park and Devil's Hole National Monument from impacts outside of these areas. Specific actions cited as concerns include nuclear testing at the Nevada Test Site, Yucca Mountain, and mining, irrigation, and residential development.

In recent years, the regional carbonate aquifer system has been the focus of a number of studies. This system underlies most of eastern and southern Nevada including all of southern Nye County. Dettinger (1989 and 1992) provided summary information on the distribution of carbonate rock aquifers, their potential for development, and the hydrogeology of sites being considered for exploratory drilling.

Over the last two decades, numerical modeling has "been in the vogue" and numerous numerical models of the region have been developed. Pal Consultants, Inc. (1995) reports that at least 15 published models have been developed on behalf of Yucca Mountain, the U.S. Department of Energy Nevada Operations Office, the U.S. Geological Survey, and the Las Vegas Valley Water District.

Waddell (1982) and Czarnecki and Waddell (1984) developed two-dimensional groundwater flow models of the Nevada Test Site and Yucca Mountain region. Prudic et al (1993) performed a conceptual evaluation of the entire carbonate aquifer system and developed a numerical model of that conceptualization.

Schaefer and Harrill (1995) used Prudic's numerical model to simulate the effects of Las Vegas Valley Water District's proposed water withdrawals from 26 basins in east-central and southern Nevada. Although none of these basins are located in southern Nye County, the predicted impacts would extend into Pahrump Valley and Amargosa Valley. This model however, did not include existing water withdrawals in southern Nye County or projected future withdrawals. Dettinger et al (1995) further evaluated the distribution of the carbonate-rock aquifers and the potential for the development of these aquifers.

As of this writing, two region-wide models are currently under development. The U.S. Department of Energy, as part of their Environmental Restoration Program has recently developed a detailed geological model of all of southern Nye County and a numerical groundwater flow model of most of the southern part of the county, exclusive of Pahrump Valley.

The Department of Energy's model (currently being finalized and scheduled for completion in 1996) is a steady-state model, i.e., the model does not simulate any groundwater withdrawals (Personal communication: Mr. Doug Duncan, U.S. Department of Energy, Nevada Operations Office, Environmental Protection Division, 20 AUG, 1996).

The Las Vegas Valley Water District regional groundwater model is being finalized and is scheduled for completion in 1997 (Personal communication: K. Brothers, Director of Research, LVVWD, 20 AUG, 1996). This model includes Pahrump Valley and will simulate only the prepumping conditions and the historic water withdrawals that occurred through 1990.

**Amargosa Valley and Amargosa Desert**

As part of the cooperative reconnaissance studies of Nevada by the Nevada Department of Conservation and Natural Resources and the U.S. Geological Survey, Walker and Eakin (1963) completed the first comprehensive evaluation of the geology and groundwater of the Amargosa Desert hydrographic basin. In 1963, the U.S. Geological Survey completed an evaluation of the area between Las Vegas and Amargosa Valley to determine suitable locations for the townsite of Mercury.

In 1968, the Bureau of Reclamation appraised the water resources of Amargosa Valley as part of their Inland Basins Project aimed at determining the economic feasibility of large scale agricultural development in the area. This report concluded that

such development was economically viable but, in 1975, the Bureau of Reclamation issued their Amargosa Valley Concluding Report which found that the development was not economically viable, primarily on the basis of soil conditions.

A number of studies have focused on the environmentally sensitive areas at Ash Meadows and Devil's Hole. Bateman et al (1972) studied whether agricultural development in the area could be continued without adversely impacting the natural habitat of the desert pupfish. Bateman et al (1974) evaluated the management of groundwater in relation to the preservation of the pupfish.

An evaluation of the relationship between water levels in Devil's Hole and irrigation was performed by Dudley and Larson (1976). Avon and Durbin (1994) investigated water declines in Devil's Hole and concluded that the declines between 1988 and 1993 were most likely the result of reduced rainfall over the Spring Mountains and not groundwater withdrawals on the Nevada Test Site, Amargosa Valley, or Pahrump Valley.

Water level declines in the Amargosa Desert have also been the subject of investigations by the U.S. Geological Survey. Nichols and Akers (1985) documented water level declines of as much as 27 feet between 1962 and 1984. Kilroy (1991) further documented water level declines in the area and provided additional definition of the hydrologic conditions of Amargosa Desert.

Additional Yucca Mountain related investigations and other U.S. Department of Energy sponsored studies have been conducted which add to the baseline of information on the water resources of Amargosa Valley. Claassen (1983) evaluated the water chemistry of the west central part of the valley and the sources and mechanisms for recharge.

Specific reports have been prepared for many of the hydrologic aspects of Yucca Mountain and are summarized in the Site Characterization Plan for Yucca Mountain (Department of Energy, 1988) and subsequent activity plans and reports. Additional summary information on Yucca Mountain characterization activities are provided in annual Site Atlases published by the U.S. Department of Energy, Remote Sensing Laboratory, most recently in 1995.

**Beatty**

Malmberg and Eakin (1962 and 1964) completed the reconnaissance level hydrologic study of both Sarcobatus Flat and Oasis Valley and conducted a more detailed evaluation of the fluoride in the groundwater of Oasis Valley. Since that time, there have been no basin wide studies published, but there have been a number of reports prepared by the U.S. Geological Survey on the low-level radioactive disposal site near Beatty.

While these studies have concentrated on the waste disposal site located in the northernmost part of the Amargosa Desert hydrographic basin, the intensive data collection and monitoring at the site have added new baseline information for Beatty as well, especially in a report by Nichols (1986) on the hydrologic conditions of the area. The U.S. Geological Survey continues to collect data at the Beatty site as part of their Beatty Disposal-Site Investigation and Beatty Deep Unsaturated Zone projects.

**Pahrump Valley**

The water resources of Pahrump Valley were first investigated by Waring (1919). In 1947-48 the State Engineer's Office issued a summary report and more detailed report on the geology and water resources of Las Vegas, Pahrump, and Indian Springs Valleys (Maxey and Robinson, 1947 and Maxey and Jameson, 1948).

Little information was provided on Pahrump Valley in these reports. The authors did, however, note that groundwater level declines of up to one foot per year were occurring in some parts of the basin.

Malmberg (1967) conducted the first detailed investigation of the hydrologic conditions of Pahrump Valley. In this report the decline in spring discharge rates and pumping water levels in the basin are documented.

Continuing water level declines in Pahrump Valley were the focus of a U.S. Geological Survey study by Harrill (1986b) who documented water level declines of as much as 100 feet in portions of the basin. This investigation included the development of a numerical model of water withdrawals in the basin.

| Groundwater Basins of Southern Nye County | | | |
|---|---|---|---|
| **Basin Name and Number** | **Communities, Developments & Federal Facilities** | **DWP Area Summary** | **DWR Pumping Inventories** |
| Amargosa Valley 230 | Amargosa Valley, Crystal, Ash Meadows National Wildlife Refuge, Death Valley National Park, Devil's Hole National | 05/08/91 | 1985-1995 |
| Buckboard Mesa | Nevada Test Site | 02/07/92 | none |
| Crater Flat 229 | Nellis Air Force Range, Yucca Mountain | 04/12/91 | none |
| Frenchman Flat 160 | Nevada Test Site, Nellis Air Force Range | 02/07/92 | none |
| Jackass Flat 227A | Nevada Test Site, Yucca Mountain | 01/01/91 | none |
| Mercury Valley 225 | Nevada Test Site, Nellis Air Force Range | 02/07/92 | none |
| Oasis Valley 228 | Beatty, Nellis Air Force Range | 01/01/91 | none |
| Pahrump Valley 162 | Pahrump, Johnnie | 04/16/91 | 1983-1995 |
| Rock Valley 226 | Nevada Test Site | 02/07/92 | none |
| Sarcobatus Flat 146 | Sarcobatus, Scotty's Junction, Death Valley National Monument, Nellis Air Force Range | 04/26/91 | none |
| Yucca Flat 159 | Nevada Test Site | 02/07/92 | none |

**Federal Lands**

As noted previously, there have been numerous investigations related to the hydrology of the Nevada Test Site. The most important studies from a regional scale have already been discussed.

On a more localized scale, there are a few references of note as they contain additional baseline data of use in developing a better understanding of the hydrologic conditions of the region as a whole. Blankennagel and Weir (1973) documented in detail the hydrologic conditions of the eastern part of Pahute Mesa, a major source of water to Oasis Valley.

Young (1972) evaluated the water resources of the southwestern part of the test site for a water supply for the Nuclear Rock Development Area that once operated on the facility. More recently, the Nevada Environmental Restoration Report has prepared a number of well completion reports for new monitoring wells on the test site and conceptual models of the hydrologic regime of the test site in a number of unpublished work plans for site specific investigations of areas of soils and groundwater contamination.

Much less information is available for federal lands in Nevada beyond the boundaries of the Nevada Test Site. The Air Force maintains control of isolated strips of land in southern Nye County on either side of the Site. As no facilities or wells are located in these areas, no hydrologic information is available.

General data concerning the Nellis Air Force Range are available in Environmental Assessments that have been prepared in support of proposed Air Force actions. In 1991 The Special Nevada Report was issued by the Air Force, Navy, and Department of Interior in cooperation with the Departments of the Army and Energy. This report provides a synthesis of the water resources of the Nellis Air Force Range, the Tonopah Test Range, and the Nevada Test Site and summarizes the impacts of those facilities on the water resources of the region.

Data concerning Bureau of Land Management lands is generally limited to that published in regional or basin wide reports. Summary information concerning the water resources on Public Domain lands administered by the Bureau is contained in two recent Resource Management Plans and Environmental Impact Statements.

Portions of Sarcobatus Flat and the Beatty area are included in the Tonopah Resource Management Plan and Environmental Impact Statement (Bureau of Land Management, 1993) which includes no water resources data. Almost all of Amargosa Desert and all of Pahrump Valley are included in the State Line Resource Management Plan and Environmental Impact Statement (Bureau of Land Management, 1992) which provides a list of springs and summary statistics on the water resources of the State Line Resource Area.

In recent years, the National Park Service has become increasingly concerned over protection of the water resources of Death Valley National Park and Devil's Hole National Monument. These concerns have led to additional specific studies of springs in Death Valley and the unique environment of Devil's Hole being sponsored by the service including Brown and Lehman (1994) and Hoffman (1988). The park service is also cooperating with the Department of Energy and other agencies in the continued study and monitoring of Devil's Hole and is continuing to evaluate the water resources of Death Valley.

A considerable amount of material has been published on Death Valley. Probably the most comprehensive report is a U.S. Geological Survey professional paper by Hunt et al (1966) who provides detailed information on the hydrology or the region that includes Death Valley and Amargosa Desert. Pistrang and Kunkel (1964) conducted a reconnaissance level investigation of the Furnace Creek Wash Area. Also of note is a report by Miller (1977) that focused on the water resources of the park with details on the springs and water supplies.

## OTHER SOURCES OF DATA AND ANALYSES

### The Nevada State Engineer Office

The Nevada State Engineer Office is the regulatory authority governing water rights allocation in the state. Two divisions within the office, the Division of Water Resources and the Division of Water Planning, maintain extensive databases on the disposition of all water rights and applications, water wells, and water use. These divisions provided database abstracts on water rights and hydrographic summaries for the basins listed in the table above. Access was made available to the pumping inventories that have been completed for the areas of interest. These inventories are on file with the Division of Water Resources Clark County office.

The database abstracts list all water right holders and water right applicants in each hydrographic basin. Other information included in the abstracts are the diversion rates, the acres being irrigated, the annual duty, and the owner of record along with the application and certificate numbers. Information is also provided on the status of pending applications, the source of the water (underground, spring, or stream) and the legal description of the location of the point of diversion for each water right or application.

The hydrographic basin summaries provide information on the committed water resources, water use, designation orders where applicable, and information on previous water right denials within the basin. Information concerning actual water use is collected by the Division of Water Resources and summarized in Ground Water Pumpage Inventories. These inventories are generally performed annually for areas with high water used, including Amargosa Valley and Pahrump Valley, and less frequently for basins where the groundwater supplies are not as heavily developed.

Another important source of data is the information listed on the Well Drillers Report that is filed with the Division of Water Resources for every water well drilled in the state. These reports provide the location, depth, subsurface formations, and construction specifications along with information on the depth to water below the land surface. In many instances, the depth to water listed on the Well Drillers Report is the only measured water level ever taken. On a few reports information is also listed on well production rates and test results.

### U.S. Geological Survey Databases

The U.S. Geological Survey maintains extensive databases on the water resources of the United States. The Carson City District Office was contacted and

specific information requested from the databases so that the most current information available from this source is included in this baseline. Information concerning stream gaging records, spring discharge rates, and water level data was purchased for monitoring stations in Oasis Valley and Amargosa Valley as well as for selected locations on the Nevada Test Site.

Data files were downloaded via the Internet and converted into compatible files for use with the spreadsheets prepared as part of this investigation. Copies of several open-file reports were also provided by the Survey at no cost.

**Nevada Bureau of Health Protection Services**

The Nevada Bureau of Health Protection Services has regulatory control over public drinking water supplies in Nevada and has the responsibility for enforcing not only Nevada Administrative Codes but the provisions of the Federal Safe Drinking Water Act, as well. There are 36 public water supply systems in southern Nye County. In 1995, the Bureau of Health Protection Services completed formal Groundwater Vulnerability Assessments of 19 of these water supply systems and five systems on the Nevada Test Site have been completed in 1996.

As part of these surveys, water use estimates were developed, information on water supply components (wells, springs, and tanks) and water quality were compiled, and the vulnerability of each water supply source to contamination was assessed using an approved U.S. Environmental Protection Agency methodology. The results of these assessments are on file with the Bureau and were made available for use in this baseline study.

**Nevada Public Service Commission**

The Nevada Public Service Commission conducts inspections of some public water supply systems.and establishes standards of service for well production, storage capacity, and water quality. The commission was contacted and it was found that no inspection reports have been published for any of the water purveyors in southern Nye County.

According to information provided by the commission, there are inspections underway of the Central Nevada Utilities Company and Desert Utilities, both in Pahrump, but it will be some time before the reports are completed and available (Personal Communication: Mr. Roger Roepke. Nevada Public Service Commission, Carson City. 23 AUG. 1996).

**U.S. Census Bureau and Nevada State Census Data Center**

The U.S. Census Bureau has census data for Nye County that was retrieved from the Internet using a zip code search for Beatty and Pahrump. The Nevada State Census Data Center serves as a clearinghouse for the dissemination of data from the U.S. Census Bureau and the Nevada State Demographer's Office. The State Census Data Center provided historic census data for Beatty and Pahrump along with projections of future population for the period 1996-2016, and projected average annual growth rates. The State Census Data Center also conducted a special Geographic Information System search to provide the only available census data for Amargosa Valley.

**U.S. Department of Energy**

Beyond the baseline information that is available in the published sources cited above, the Department of Energy also has considerable information in files and in limited circulation reports. The department provided access to both unpublished data received from the U.S. Geological Survey and various contracting organizations as well as limited circulation reports.

The department also provided a copy of the Draft Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada, issued in January 1996 and draft materials prepared by IT Corporation for their Underground Test Area Project Phase I Data Analysis Task.

**Water System Operators**

Finally, the operators of the numerous public water supply systems in southern Nye County provided valuable information on the current operating characteristics of their water systems. The operators have the best knowledge of the issues and problems that they are faced with on an almost daily basis in their efforts to continue to meet the water demands of their customers. Many operators graciously shared information, their concerns, and their viewpoints.

## PROJECTING FUTURE POPULATION

In this section the basis that was used for projecting the future population of southern Nye County is presented and discussed. The basic approach used was to compile census data and projections of population growth and to use those rates to project the population for the period 1995 through 2050.

For most water supply evaluations, a shorter time frame of 10 to 20 years is considered adequate. These types of mid-term projections are indeed adequate for areas where the availability of water is not an issue. For southern Nye County however, there is only a finite amount of water that is available. Longer term projections are called for in this situation to determine when the supply of water may no longer meet the demand.

**FAST FACTS**

THE POPULATION OF NYE COUNTY IN 1990 WAS 17,800 AND HAS BEEN GROWING SINCE THE 1950 CENSUS.

NYE COUNTY'S POPULATION GREW BY 52 PERCENT BETWEEN 1990 AND 1995. MOST OF THIS GROWTH WAS IN THE SOUTHERN PART OF THE COUNTY WHICH TOPPED 20,000 FOR THE FIRST TIME IN 1995.

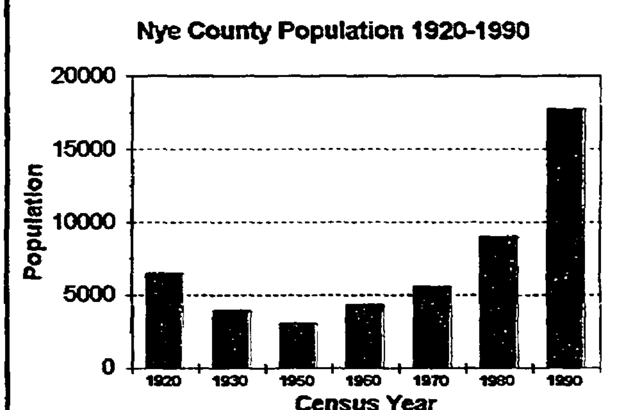
MAJOR GROWTH IS EXPECTED TO CONTINUE INTO THE NEXT CENTURY. PAHRUMP COULD BE HOME TO 150,000 BY THE MIDDLE OF THE NEXT CENTURY.

GROWTH IN THE BEATTY AREA (1,650 PERSONS IN 1990) IS EXPECTED TO BE SLOW BECAUSE OF THE CLOSING OF MINES THAT ARE MAJOR EMPLOYERS.

MODERATE GROWTH IS PROJECTED FOR AMARGOSA VALLEY TO A POPULATION OF 1,350 BY THE YEAR 2000. BY THE MIDDLE OF THE NEXT CENTURY, AS MANY AS 5,000 PEOPLE MAY RESIDE IN THIS COMMUNITY.

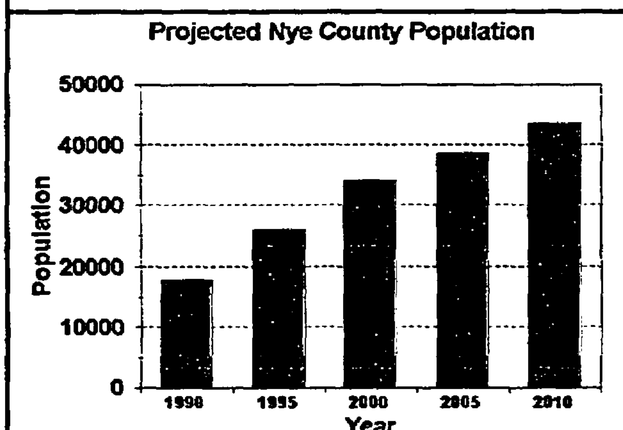
### Census Information

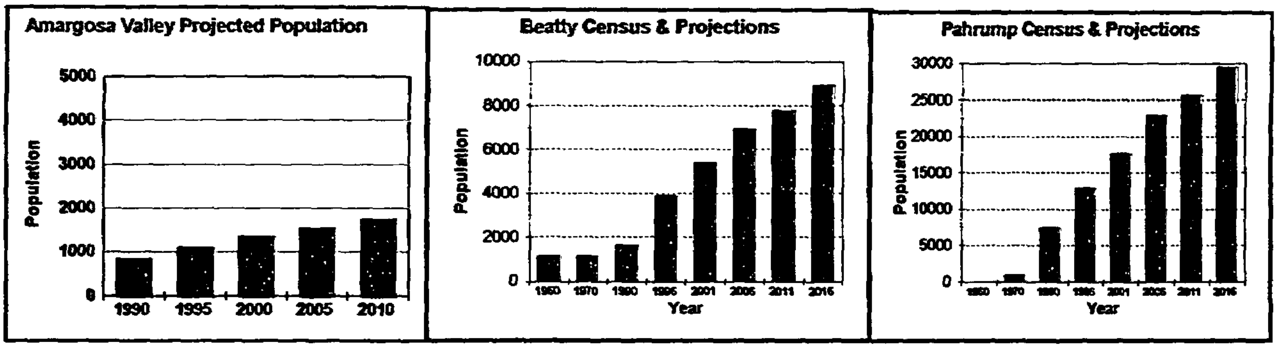
In 1990 the population of Nye County was just under 18,000 with populations of about 7,500 in Pahrump, 1,650 in Beatty, and 840 in Amargosa Valley. The 1990 census marked the fourth decade of growth in the county. In 1920 the population of Nye County was 6,504 and the county experienced a continual decline through the 1950 census which counted a population of just over 3,100. By 1960 this trend had been reversed and the population had increased to about 4,300. Moderate growth continued through to the 1980 census with about 1,000 new residents each decade. Between 1980 and 1990 the county began to experience phenomenal growth, an astounding 97% over the decade. The most current census estimates indicate that by the fourth quarter of 1995, the population of the county had grown to 26,937. This increase represents a 52 percent growth rate since the 1990 census.




### Projections of Future Populations

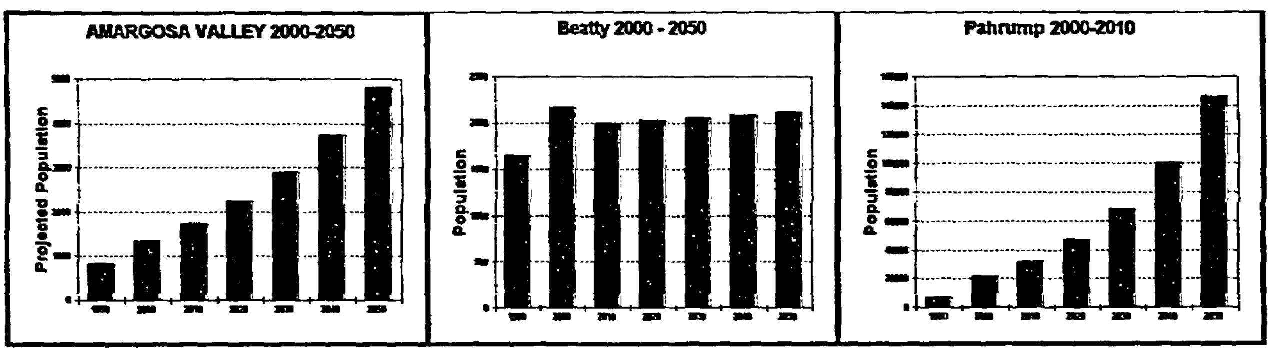
Projections of future water demand for southern Nye County must be based upon projected growth in the developed parts of the county. Although there are numerous projections that are available, there is little agreement between them and care must be exercised in selecting the appropriate projection. The baseline population estimate for projections is usually taken as the most recent national census results, in this case the 1990 census.






NYE COUNTY POPULATION PROJECTIONS

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
| AMARGOSA VALLEY | 838 | 1,100 | 1,350 | 1,540 | 1,740 | 2,245 | 2,896 | 3,735 | 4,818 |
| BEATTY | 1,652 | 1,930 | 2,170 | 1,950 | 2,000 | 2,030 | 2,060 | 2,091 | 2,123 |
| PAHRUMP | 7,440 | 15,170 | 22,100 | 27,740 | 32,190 | 46,997 | 68,618 | 100,180 | 146,262 |




The two most recent projections (Nye County Board of Commissioners 1995 and State Demographers Office, 1995 unpublished data) show a difference of only five percent for Nye County as a whole, but show differences of 55 percent for Tonopah, 31 percent for Pahrump, and 135 percent for Beatty. Older projections by Mountain West (1989) and the State Engineers Office (1973) for Nye County as a whole are 51 to 240 percent lower than the most recent estimates. Obviously there is considerable uncertainty in all of these projections. The projections made by the State Engineer's Office were published 23 years ago and are of no utility in making water demand estimates today.

The estimates made by Mountain West, although only eight years old, are also of limited or no utility as they are based upon the application of a model designed for predicting the migration of populations from urban to suburban areas, not the exploding population of southern Nevada. The estimates prepared by the State Demographer are based on a projected rate of growth for the county as a whole and assumes that the percentage distribution between the communities will remain the same. This assumption appears to be the basis for the large discrepancies between the state and county projections and lessens the suitability of the state projections.

The Nye County projections are based upon census data and economic information and take into account the impacts of future mine closings, impacts from the Yucca Mountain work force, and other considerations. Therefore, the Nye County projections are considered the most appropriate for projecting future water demand. As correctly noted in the Nye County Comprehensive Plan (Nye County Board of Commissioners, 1994), "there is no crystal ball for the future of Nye County and its communities." Any projection of future population is fraught with assumptions that can lead to significant errors. Nowhere is this more true than in the boom town environments of Nevada's mining towns and in the Pahrump Valley where growth reflects the phenomenal growth of metropolitan Las Vegas. Nonetheless, water planners must rely on such projections for identifying and meeting future water demands.

The Nye County projections indicate that the vast majority of the population growth in the county will happen in Pahrump. Only nominal increases in population are anticipated in Amargosa Valley and Beatty through the year 2010. For looking further into the future, growth beyond these projections must be assumed. For Beatty, it was assumed that the growth rate beyond 2010 will be equal to the projected growth rate for the period 2005-2010 (three percent or about 1.5 percent each decade). Based upon this projected growth rate, the population in Beatty in 2050 will still not have recovered fully to 2000 levels.

For Amargosa Valley, the projected growth between 2000 and 2010 (28 percent) was used to project growth to the year 2050. At this rate, the population of the area would grow to just over 4,800 by the middle of the next century. It should be noted, however, that accelerated growth is possible in this area as a result of its proximity to the "boomtown" of Pahrump. Much as the population of Pahrump grew as overflow from Las Vegas, Amargosa Valley may experience a similar overflow from Pahrump.

Based upon the Nye County projections, the population of Pahrump will grow from 22,100 in 2000 to 32,190 in 2010, an overall increase of 46 percent. If this rate of increase continues to 2050, the population of the basin will approach 150,000. In 1940, the population of Clark County was 16,414 or about the size of Pahrump today. One half century later, in 1990, the population of the county had exploded to 741,000. No one in 1940 could have anticipated the growth of the Clark County and no one today can anticipate similar growth in southern Nye County. While it is recognized that any attempt to project the population of an area more half a century is tenuous at best, it does provide a long-range target for water planners. This target must be continually refined as growth occurs so that the corresponding water demand can be projected again.

## GENERAL HYDROLOGIC CONDITIONS

### Location and Physiographic Setting

Southern Nye County is defined for this investigation as that portion of Nye County south of Township 7 South. This boundary was selected because it includes all non-federally owned lands south of the Nellis Air Force Range and the Nevada Test Site as well as the three major population centers of southern Nye County, Pahrump, Beatty, and Amargosa Valley. Summary information on the general topographic characteristics of the populated basins in southern Nye County is discussed below.

On the northwest is Sarcobatus Flat which is largely unpopulated except for small developments at Scotty's Junction and along Highway 95. Almost all of the land east of Highway 95 is reserved for the Nellis Air Force Range. Sarcobatus Flat is bounded on the southwest by the Amargosa Range rising to an elevation of more than 8,700 ft at Grapevine Peak and to the lower buttes and peaks of Pahute Mesa on the northwest. The Bullfrog Hills, rising to elevations of about 4,800 ft separate Sarcobatus flat on the southeast from Amargosa Desert and Oasis Valley. Sarcobatus Flat is an internally draining basin with all surface water draining toward the flats in the central and southernmost portions of the basin.

Oasis Valley is located to the southeast of Sarcobatus Flat and extends to the north and east into the Nevada Test Site. Most of the basin is on the Nellis Air Force Range. The populated areas are limited to the community of Beatty and smaller developments at Springdale and ranches. Oasis Valley is drained by the Amargosa River. North of Beatty, the river drains portions of Pahute Mesa while Beatty Wash drains the western slopes of Timber Mountain which rises to almost 7500 ft. At Beatty, the Amargosa River flows through a topographic gap between the Bullfrog Hills on the west and Bare Mountain on the east. These mountains also separate Oasis Valley from Amargosa Desert.

Amargosa Desert is a large basin that extends from just north of Highway 95 to the California state line. The valley is bounded by the Amargosa Range, Bullfrog Hills, and Bare Mountain on the northeast, Crater Flat, Yucca Mountain, and Jackass Flats on the north-central part of the basin, the Specter Range and Spring Mountains on the northeast, and unnamed hills on the east and southeast that separate the basin from Pahrump Valley. The only two communities within the basin are Amargosa Valley (formerly Lathrop Wells) and Crystal.

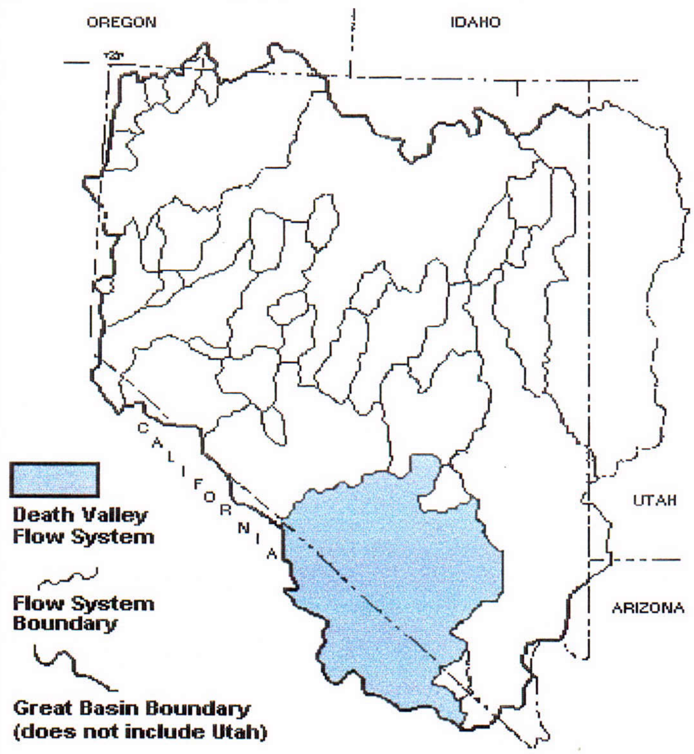
Pahrump Valley is located between Amargosa Valley on the west, Las Vegas Valley on the east, Indian Springs Valley on the north, and the California state line on the south. Pahrump Valley is the location of the community of Pahrump and the small settlement at Johnnie. The valley is bounded on the east by the Spring Mountains which achieve a maximum elevation of about 8,700 ft but rise to just under 12,000 ft at Mount Charleston, in Clark County.

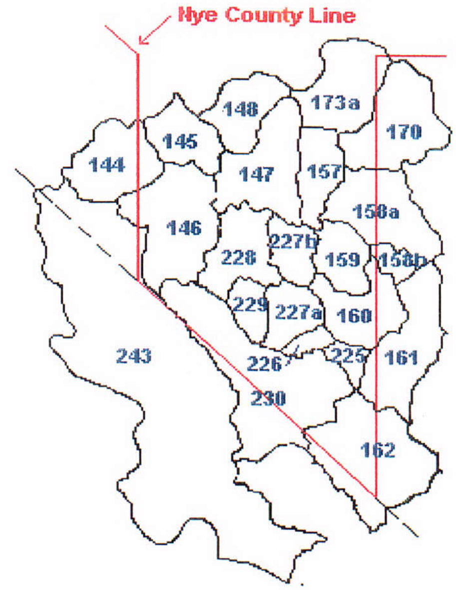
### Regional Hydrologic Conditions

Southern Nye County is situated entirely within the Alluvial Basins Groundwater Region as defined by the U.S. Geological Survey in Heath (1984). Within this region, groundwater generally flows from source areas in the mountains toward discharge areas in the valley low-lands. The individual basins are underlain by bedrock and are separated by the bedrock that outcrops in the bounding mountain ranges. Where groundwater flows from one basin to another, the basins are collectively called a flow system.

All of southern Nye County is situated within the Death Valley flow system, as defined by Harrill et al (1988). The Death Valley flow system is one of the larger systems in Nevada, comprising 24 individual groundwater basins in Nevada, and six basins in California with a total area of 15,800 square miles. Within the Death Valley flow system, groundwater flows from the recharge areas in the Amargosa Range, Pahute Mesa, Timber Mountain, and the Spring Mountains toward the regional groundwater discharge area at Death Valley and the lesser discharge areas at Ash Meadows in Amargosa Valley and in Pahrump Valley.

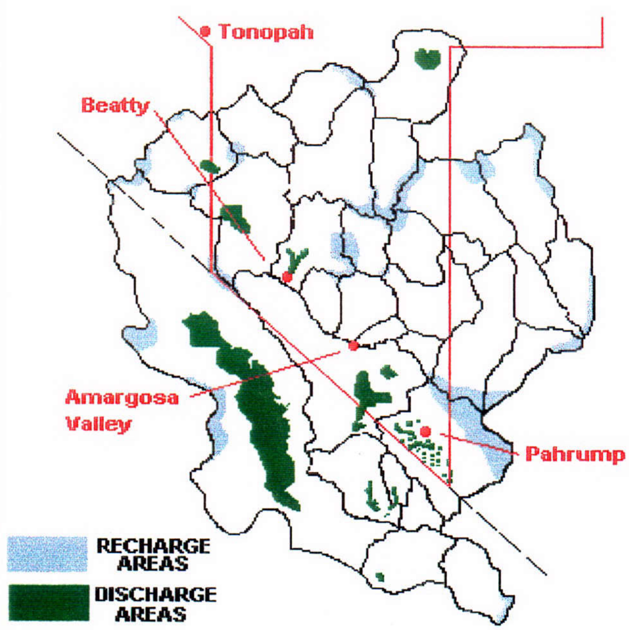
Little of the groundwater in this part of the county comes from rainfall over Nye County. The largest source of groundwater to the area is from the upland areas of Clark County where it originates as precipitation over the Sheep Range and the Spring




## HYDROGRAPHIC BASINS OF SOUTHERN NYE COUNTY

144 - Lida Valley
145 - Stonewall Flat
146 - Sarcobatus Flat
147 - Gold Flat
148 - Cactus Flat
157 - Kawich Valley
158a- Groom Lake Valley
158b- Papoose Lake Valley
159 - Yucca Flat
160 - Frenchman Flat
161 - Indian Springs Valley
162 - Pahrump Valley
225 - Mercury Valley
226 - Rock Valley
227a- Jackass Flats
227b- Buckboard Mesa
228 - Oasis Valley
229 - Crater Flat
230 - Amargosa Desert
243 - Death Valley

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**The Death Valley flow system encompasses all of southern Nye County. Flow within this system is from the recharge areas along the western boundary and northern part of the systems toward the regional discharge areas located in Amargosa Valley, Pahrump Valley, and Death Valley. Within the system are a myriad of groundwater regimes ranging from the wetlands in Ash Meadows to the arid Nevada Test Site where the depth to water in some places is more than 2,000 ft below land surface.**



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Mountains. An estimated 32,000 acre feet per year of groundwater flows westward into Nye County in the area northwest of the town of Indian Springs and an unknown quantity probably flows westward into the Ash Meadows area. Another 20,000 acre feet or more are derived each year from the western slopes of the Spring Mountains representing the major source of recharge to Pahrump Valley. In total, more than 52,000 acre feet of groundwater flow westward into Nye County from upgradient areas in Clark County each year. Much smaller quantities of underflow come into the southern Nye County basins from the north (an estimated 1,000 acre feet per year into Kawich Valley) and northwest (an estimated 1,300 acre feet per year into northern Sarcobatus Flat).

The largest source of groundwater to the region is from the precipitation over the individual basins. The total amount of recharge from precipitation over the region is not known but estimates have been published by the State of Nevada (1971), D'Agnese (1994), and Pal Consultants, Inc. (1995). The State's estimate of about 56,000 acre feet per year was derived during the original reconnaissance level investigations. Revised estimates of evapotranspiration and mass balances derived from computer models have been used in recent years to refine these estimates. The more recent estimates suggest that recharge to the valleys that comprise the Nevada portion of the Death Valley flow system is significantly greater than the State estimate, at least 45 percent higher. The total recharge estimated in the later evaluations ranged between 80,000 and 100,00 acre feet per year.

Some water discharged by wells and springs infiltrates back into the ground and reaches the water table, a process known as secondary recharge. Secondary recharge over agricultural fields is accounted for in the water use inventories by the application of a consumptive use value for individual crops. Spring discharge is largely consumed by evapotranspiration and no accurate estimates of secondary recharge from this source are available.

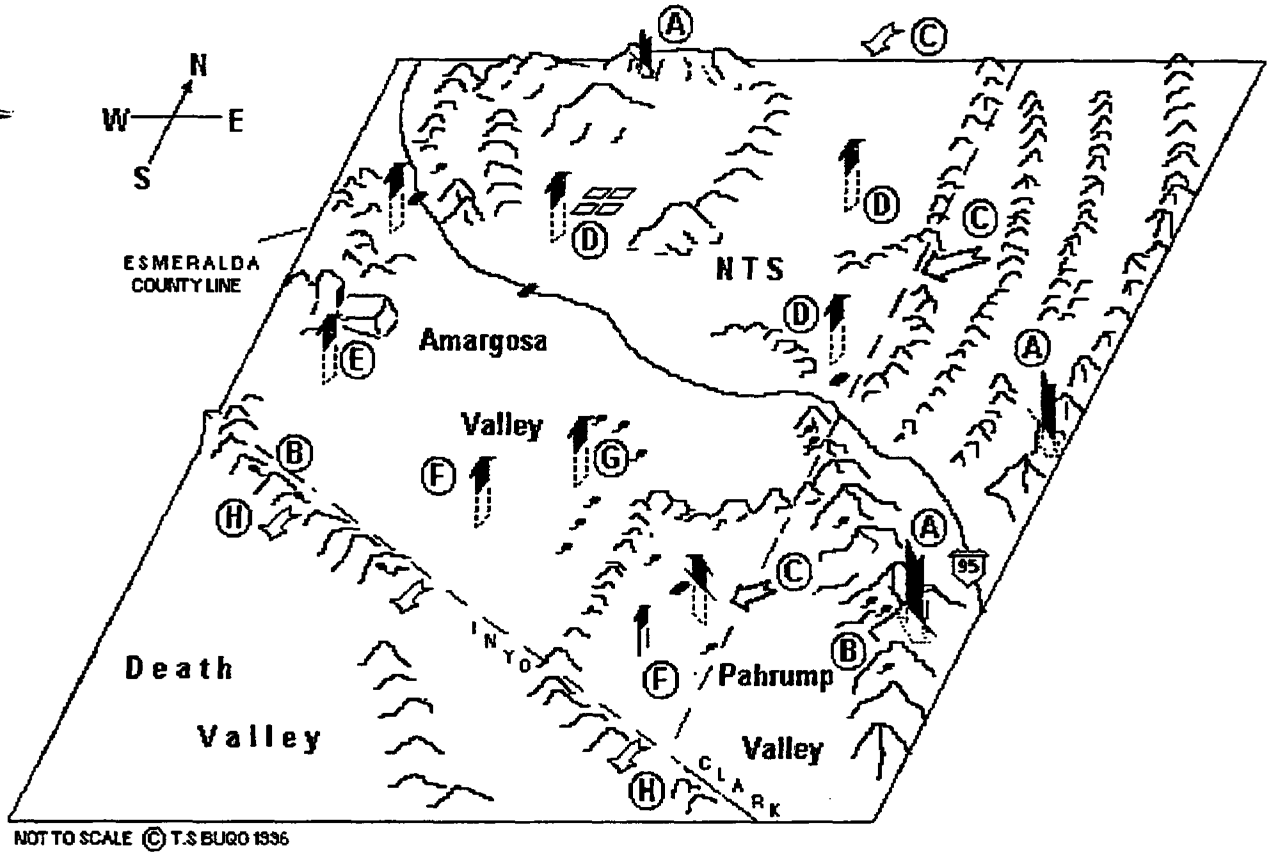
Natural discharge from the region is to spring discharge, evapotranspiration losses, and underflow out of the basins. For the purposes of this evaluation, it is assumed that all spring discharge is lost to evapotranspiration. Underflow can only be roughly approximated and there is little difference between the various published estimates. Estimates of evapotranspiration vary widely, however, with more recent investigators applying much higher rates of evapotranspiration than the State's published estimates. The D'Agnese estimate is more than double the value published by the State. The later evaluations estimated that evapotranspiration ranges from 45,000 to 63,000 acre feet per year with most of the difference related to estimates of the rate in Amargosa Desert.

The natural water budget has been disturbed by man through the reduction of spring discharge rates and the pumping of groundwater for agricultural, mining, and municipal purposes. The total quantity of water used each year in each of the basins of southern Nye County is not known but can be estimated on the basis of historic data, inventories, and water rights. The total annual groundwater withdrawals are estimated to be about 45,000 acre feet. It is interesting to note that while the committed groundwater resources exceed all of the published estimates of recharge, the actual quantity of groundwater used is significantly less than the recharge. Annual groundwater withdrawals over the late 1980s and 1990s to date are 45 to 55 percent less that the total recharge estimates by Pal Consultants and D'Agnese and 20 percent less than the total recharge published in the earlier estimates by the State of Nevada.

The variation between published estimates of key water budget parameters points to the uncertainty in the current understanding of recharge and discharge mechanisms in arid southern Nevada. More accurate estimates and more actual measurements of these parameters are needed to better define the basic elements of the water budget.

Groundwater Occurrence and Flow

Groundwater occurs at depth throughout southern Nye County. Plate 1 shows the depth to groundwater over the region. Shallow water (less than 10 feet below land surface) occurs in the central part of Sarcobatus Flat, in the Ash Meadows area in the southeastern part of Amargosa Valley, and in Oasis Valley near the Amargosa River. In most of the basins, the shallowest water occurs under the valley lowlands. In Pahrump Valley for example, the depth to water ranges from less than 50 feet in the lowland areas to more than 400 feet on the alluvial fans that rise from the lowland areas. The depth to groundwater is greatest under, and in the vicinity of




A - Most of the groundwater in southern Nye County originates as rain and snow over the Spring Mountains and Sheep Range in Clark County and over Pahute Mesa on the Nevada Test Site. This precipitation infiltrates the ground and percolates downward to the water table. The infiltration that reaches the water table is referred to as recharge.

B. Some of the recharge flows through fractures and is discharged to springs along the flanks of the Spring Mountains and Amargosa Range.

C. The largest source of water to southern Nye County is the underflow of water from upgradient areas. About 70,000 acre feet per year enter southern Nye County as underflow with almost all of this water coming from Clark County across Nye County's eastern boundary.

D. Limited quantities of groundwater are pumped to support the communities of Amargosa Valley, Beatty, and Pahrump as well as industrial uses on the Nevada Test Site.

E. Mining and milling is a major water user in some portions of Amargosa Valley and Crater Flat.

F. Irrigation of farmland is the largest user of water, amounting to more than 27,000 acre feet per year in Pahrump Valley and Amargosa Valley.

G. Natural consumption of water by plants, a process called evapotranspiration, is also very large, totalling more than 41,000 acre feet per year. The 24,000 acre feet per year discharged at Ash Meadows (in Amargosa Valley) is an important source of water for wildlife.

H. The groundwater that is not consumed by evapotranspiration by plants or pumping by man is discharged out of Nye County into California. An estimated 34,000 acre feet per year leave the county via underground flow into California.

**CONCEPTUAL HYDROLOGY OF SOUTHERN NYE COUNTY, NEVADA**

## Southern Nye County Groundwater Basins

**(Shaded basins are primary water supply basins of southern Nye County)**

| | Water Budget Parameters in Acre Feet Per Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Basin | Inflow | Et 1 | Et 2 | Et 3 | Outflow | Recharge 1 | Recharge 2 | Recharge 3 | Perennial Yield |
| Lida Valley | 200 | 0 | 0 | 180 | 700 | 500 | 1200 | 1200 | 350 |
| Stonewall Flat | ? | 0 | 0 | 110 | 200 | 100 | 1200 | 1200 | 100 |
| Sarcobatus Flat | 1300 | 3000 | 3000 | 3860 | 500 | 1200 | 1500 | 1500 | 3000 |
| Gold Flat | 0 | 0 | 0 | 0 | 3800 | 3800 | 6700 | 6700 | 1900 |
| Cactus Flat | 0 | 0 | 0 | 0 | 600 | 600 | 3100 | 3100 | 300 |
| Kawich Valley | 1000 | 0 | 0 | 0 | 4500 | 3500 | 7500 | 7500 | 2200 |
| Groom Lake Valley | 0 | 0 | 0 | 0 | 3200 | 3200 | 13000 | 13000 | 2800 |
| Papoose Lake Valley | 0 | 0 | 0 | 0 | <10 | <10 | (w/158a) | (w/158a) | <10 |
| Yucca Flat | 0 | 0 | 0 | 0 | 700 | 700 | 1900 | 1900 | 350 |
| Frenchman Flat | 32000 | 0 | 0 | 0 | 33000 | 100 | 990 | 990 | 16000 |
| Indian Springs Valley | 22000 | Minor | 700 | 700 | 32000 | 10000 | 8200 | 8200 | 600 |
| Pahrump Valley | 0 | 10000 | 13000 | 11000 | 18000 | 22000 | 37000 | 20000 | 19000 |
| Railroad Valley south | nd | nd | 200 | nd | 1000 | 6000 | 5500 | 5500 | 2800 |
| Mercury Valley | 16000 | 0 | 0 | 0 | 17000 | 250 | 340 | 340 | 8000 |
| Rock Valley | 17000 | 0 | 0 | 0 | 17000 | 30 | 40 | 40 | 8000 |
| Jackass Flats | 7200 | 0 | 0 | 0 | 8100 | 900 | 6600 | 6600 | 4000 |
| Buckboard Mesa | 5800 | 0 | 0 | 0 | 7200 | 1400 | (w/227a) | (w/227a) | 3600 |
| Oasis Valley | 2500 | 2000 | 4300 | 4300 | 1500 | 1000 | 3100 | 3100 | 2000 |
| Crater Flat | 1500 | 0 | 0 | 0 | 1700 | 220 | 110 | 110 | 900 |
| Amargosa Desert | 44000 | 14000 | 24000 | 43000 | 16000 | 600 | 410 | 410 | 24000 |
| TOTAL | 4800 | 29000 | 45200 | 63150 | 34000 | 56100 | 98390 | 81390 | 99800 |

Et = Evapotranspiration

Values in red are totaled independently of other values to avoid double counting of inflows and outflows.

Et 1 : State of Nevada (1971)
Et 2 : Pal Consultants (1995)
Et 3: D'Agnese (1994)
Recharge 1 : State of Nevada (1971)
Recharge 2 : Pal Consultants (1995)
Recharge 3: D'Agnese (1994)

| | Water Budget Imbalances | | |
|---|---|---|---|
| | Inflow + Recharge | Et + Outflow | % Imbalance |
| State of Nevada (1971) | 60900 | 63000 | 0.03 |
| Pal Consultants (1995) | 103190 | 79200 | 0.30 |
| D'Agnese (1994) | 86190 | 97150 | 0.13 |

Note: Because Penoyer, Three Lakes South, and Tikapoo Valley are not included in this table the totals shown do not match totals given in the Pal and D'Agnese reports.

**Shown above are published estimates of the components of the water budget for the basins of southern Nye County. There is little or no variation in the inflow and outflow estimates so single values were used for these parameters. As shown, there are considerable differences between the earlier State of Nevada estimates and later estimates by D'Agnese and Pal Consultants, Inc. Most of the differences in the more recent estimates can be attributed to the differences in the estimates of evapotranspiration and the different estimates of total recharge to Pahrump Valley.**

the Nevada Test Site where the depth to water ranges from about 525 feet in Frenchman Flat to more than 2,000 feet under the upland portions of Pahute Mesa.

The elevation of the groundwater surface is also quite variable across the region reflecting the locations of recharge and discharge areas, flow barriers, and groundwater pumping centers. Plate 2 shows the elevation of the groundwater surface across the region and the directions of groundwater flow. On the regional scale, flow is from the northern part of the Test Site to the south and from the Sheep Range and Spring Mountains to the west and southwest into Frenchman Flat, Amargosa Desert, and Pahrump Valley. Flow then is primarily to the southwest out of Nevada and eventually to the regional sink at Death Valley.

Aquifers and Aquitards

The principal water bearing units of the region are the alluvium, volcanic rocks, carbonate rocks, and clastic rocks. Geologic units that are capable of storing and transmitting groundwater at a rate that will allow economic recovery through conventional water wells are considered aquifers. Geologic units that do not transmit water fast enough for economic recovery through wells are called aquitards, that is, they retard the movement of water.

Most groundwater supplies in the region are obtained from the thick alluvial deposits in the valley areas. The alluvium has been the most heavily developed aquifer and is the source for the thousands of water supply wells in the area that supply the communities and farmers in Pahrump Valley and Amargosa Valley. The volcanic rocks are predominant in the upland areas north of Amargosa Desert and have been developed for water supplies for the Nevada Test Site, the community of Beatty, and by mines in Crater Flat. Carbonate rocks outcrop in the Spring Mountains and are believed to underlie most of Pahrump Valley and portions of Amargosa Valley. This aquifer has not been developed but does offer promise as a future source of water in the region. The distribution of these aquifers in southern Nye County is shown on Plate 3.

Aquifer Properties

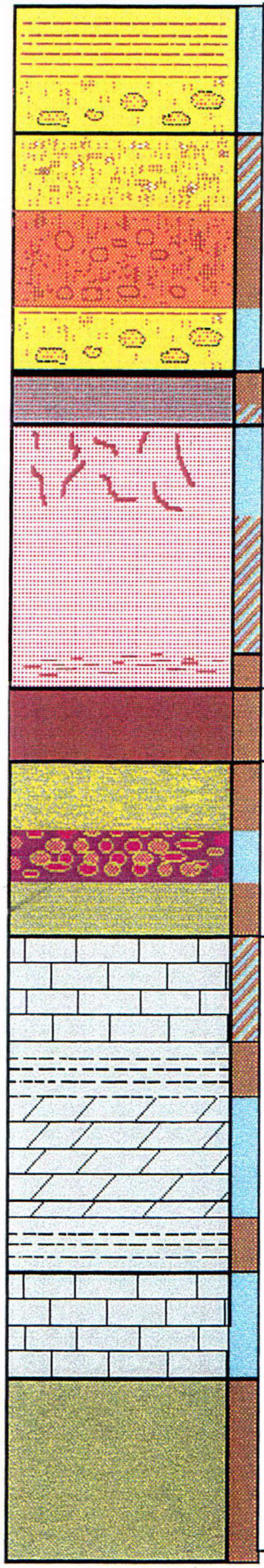
A great deal of information has been published on the geology of the region and the rocks that form the groundwater reservoirs. From the water supply perspective, the key hydrologic factors are the porosity, permeability, thickness, transmissivity, and storativity and of the soils and rocks that are present in southern Nye County.

Porosity - Porosity is the ratio between void space in a soil and rock to the total volume of that material and is a measure of the quantity of water that is stored in an aquifer. For example, unconsolidated sand has a porosity of about 25 percent. This means that for every cubic yard of sand present in an aquifer, one-quarter is air (void space) and three-quarters of that yard is sand particles.

The porosity of the rocks and alluvium that underlie Nye County determine the volume of groundwater that is held in storage. The actual quantity is huge, probably on the order of hundreds of millions of acre feet. In Amargosa Valley, the amount of water estimated to be stored in the valley fill sediments is 35,000 acre feet for every foot of aquifer thickness. Past studies have looked at recoverable water in the upper 100 feet of an aquifer as a measure of the potential resources of a basin. Using this approach, there are about 3.5 million acre feet of groundwater held in storage in the upper 100 feet of saturated alluvium in the basin. The amount of groundwater in the upper 100 feet of saturated alluvium in Pahrump Valley has been estimated at 3.9 million acre feet. Oasis Valley, on the other hand, has much more limited resources with an estimated 0.4 million acre feet in storage at the same depths.

Aquifer Thickness - The thickness of an aquifer is also an important characteristic with respect to water supply. Water wells producing from thick intervals are generally capable of producing more water with less impacts than wells that draw upon thin lenses of water bearing units. The thickness of the aquifers in Nye County is quite variable reflecting the nature of the deposition of the rocks and the geologic activity that has occurred since that time.

The alluvial aquifer that is present in most of the basins of Nye County typcially ranges in thickness from zero to several thousand feet. The alluvial aquifer may be absent in areas where serveral hundred feet of alluvium are present. For example, in lowlands of Frenchman Flat and the high alluvial fan on the west slopes of the Spring Mountains, there are large areas where 500 feet of alluvium are present but the top of the groundwater is in the underlying consolidated rock units.



| | |
|---|---|
| **Valley Fill Deposits** | **Alluvial Aquifers** - The saturated alluvium that fills the basins is the most important aquifer in southern Nye County. These deposits, where coarse-grained, yield hundreds and even thousands of gallons per minute to wells. The fine-grained lake bed and playa deposits are poor aquifers yielding only a few tens of gallons per minute with excessive drawdown of the water table. The alluvial aquifers in Amargosa Valley and Pahrump Valley have been heavily developed for irrigation, quasi-municipal, and domestic water use. Water in this aquifer comes primarily from leakage from the underlying regional carbonate aquifer or volcanic aquifers. At Ash Meadows, in Amargosa Valley, this leakage results in 30 springs and a large natural wetland area. |
| **Basalt** | **Basalt Flows** - Not a developed aquifer. Generally low productivity but can trasmit large volumes of water along base of flows. |
| **Tertiary Volcanic Rocks** | **Tuff Aquifers and Aquitards** - Volcanic ash deposits are called tuff and the younger tuffs in Nye County can yield hundreds of gallons per minute to deep water wells located in fractured zones. The tuffs are much less productive where bedded and, where densely welded, can be an effective aquitard. Perched aquifers are present in the uplands of the Nevada Test Site in these rock units. Natural interactions between groundwater and volcanic rocks has resulted in the presence of high levels of fluoride in the volcanic rock aquifers and volcanic derived alluvial aquifers in the Beatty area and in parts of Amargosa Valley. |
| **Granites** | **Granitic Stocks** - Almost impermeable, limited to small stocks on NTS. |
| **Continental Red Beds** | **Red Beds** - Includes the Chinle and Moenkopi formations in the Spring Mountains and potentially under parts of the Nevada Test Site and Pahrump Valley. Generally low transmissivity and poor well yields except where fractured or where Shiinarump Conglomerate is saturated. Often contains groundwater with high sulfate because of presence of extensive gypsum deposits. |
| **Regional Carbonate Aquifer Sequence**<br>Upper Carbonate Aquifer<br>Upper Clastic Aquitard<br>Lower Carbonate Aquifer<br>Lower Clastic Aquitard | **Regional Carbonate Aquifer System** - The regional carbonate aquifer system includes tens of thousands of feet of carbonate rocks with interbedded clastic rock units. The uppermost carbonates include the Kaibab and Toroweap formations in eastern Pahrump Valley which have gypsum deposits and high sulfate levels. The upper carbonate aquifer includes the Tippipah Limestone on the Nevada Test Site where it is underlain by an upper clastic aquitard that includes the Eleana formation and the Chainman Shale. Clastic rocks are quartzites and shales that have poor water transmitting characteristics. In the Spring Mountains and under Pahrump Valley this is a very thick sequence of carbonates that include the Bird Spring Formation, Monte Cristo Limestone, Sultan Limestone and Ely spring Dolomite, Eureka Quartzite, and Pogonip Group. The Bird Spring Formation and Monte Cristo Limestone have been shown to be excellent aquifers elsewhere in southern Nevada. |

**EXPLANATION**

Low potential for development due to depth, thickness, poor water transmitting properties, or likelihood of poor quality water.

No development potential, considered an aquitard.

Good potential for development if water rights are available. Can be very productive if thick permeable units are present.

**Composite Hydrostratigraphic Column for Southern Nye County**

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The total thickness of the alluvial aquifer in Amargosa Valley and Pahrump Valley is not known. In Amargosa Valley, an oil and gas exploration well (Felderhoff-Federal No. 5-1) was drilled in 1990-1991 to a total depth of 1,468 feet. This well was drilled about 3 miles south of the intersection of U.S. Highway 96 and Nevada Highway 373 (formerly Lathrop Wells). About 1,150 feet of alluvium were penetrated at this site. The thickness of alluvium thickens to the south toward the central part of the basin. In 1973, the Bureau of Reclamation drilled a test well 3 miles southwest of Lathrop Wells to a depth of 1,533 feet without drilling through the alluvium. The thickness of the saturated alluvium in Amargosa Valley probably ranges from only a few tens of feet near the mountainous areas to 2,000 feet or more near the California state line.

In Pahrump Valley, the U.S. Geololgical Survey performed geophysical surveys to determine the thickness of the valley-fill deposits. These surveys concluded that more than 4,000 feet of alluvium are present in the central lowland part of the basin. This alluvium thins to less than 1,000 feet to the northeast and northwest.

Transmissivity - Transmissivity is a measure of the rate that water can be transmitted through an aquifer and is based upon the permeability of a geologic unit and its thickness. In general the more coarse grained a material is, the higher the transmissivity will be, and the higher the well yield. Thus a well completed in the poorly transmissive clay deposits of a playa will probably not produce nearly the quantity of water as a well completed in the highly transmissive coarse sand and gravel deposits that form the alluivial fans.

For the consolidated rock aquifer of Nye County, the transmissivity depends on the type of rock present and the degree to which that rock has been broken up by faulting and fracturing. In general, carbonate rocks have higher transmissivity than volcanic rocks which in turn have higher transmissivities than granites. The transmissivity of a given rock type is usually highest in areas where the rock has been faulted and fractured. It is interesting to note that the very high transmissive properties of the regional carbonate aquifer were first proven in southern Nye County, through tests at the Nevada Test Site.

The range in transmissivity values is large across southern Nye County. The permeability of the alluvial deposits varies with their age and degree of consolidation. The permeability values for these deposits range from 0.02 to 140 feet per day. The transmissivity of these deposits ranges from 320 to 260,000 $ft^2$/day. The lower values occur in playa areas and in areas where the saturated alluvium is thin. The higher values occur in areas of well sorted sands and gravels that are hundreds or thousands of feet thick.

Large variations in the transmissivity also are present in the volcanic and carbonate rocks of the county. The volcanic rocks have reported values ranging from about 250 to 9,000 $ft^2$/day. Carbonate rocks have even larger reported ranges, from 10 to 250,000 $ft^2$/day. Wells completed in rocks at the low end of the range will only produce a few gallons per minute with very large drawdown in the well. Wells completed in the areas with the most transmissive carbonate rocks have been proven capable of producing several thousand gallons per minute with only minimal drawing down of the water table.

Storativity - Storativity is a measure of the amount of water that will be released from a square foot of an aquifer for each foot that the water level is dropped. For example, clay has a high porosity (as high as 50%) but a low storativity. A one cubic foot volume of saturated clay with that porosity contains one-half cubic foot of water or about 3.7 gallons. However, if this volume of clay is taken out of the water and allowed to drain, only about 0.04 cubic feet of water will be produced, a little more than a quart. The remaining 3.4 gallons of water (0.46 cubic feet) is retained between the particles of clay. In general, the storativity of alluvium decreases from the coarse-grained deposits of the alluvial fans to the fine-grained deposits of the playa areas. The storativity of consolidated rocks gererally varies most depending upon whether the aquifer is an unconfined (water table) or confined (artesian) aquifer.

Springs

There are numerous springs located throughout the region, particularly in the upland areas and at Ash Meadows. Plate 4 shows the locations of springs that have been identified from published reports, water right abstracts, and maps of the region. Many low discharge springs occur in the upland areas of

the Spring Mountains and other recharge areas in the region. Most of these springs are conduits for the discharge of excess recharge in the mountainous area. The discharge of these springs typically increases immediately after the spring snow melt with rapid drops in discharge over the late spring, summer, and early fall.

In some areas, groundwater discharges from the regional carbonate aquifer to the land surface. Springs of this nature typically have much larger discharges and the discharge rates are much more constant over the course of the year. Regional springs occur in the Ash Meadows area where 30 individual springs discharge a total of about 17,000 acre feet per year. Regional springs were once present in the lowland areas of Pahrump Valley but have largely been eliminated because of the lowering of groundwater levels by pumping.

Springs played an important role in the development of southern Nevada. During the pioneer days and until about 1910, almost all water development in southern Nye County was from springs. Wells did not become affordable until after that period. Many of the same springs that were developed around the turn-of-the-last century by the early ranchers are still supplying water for livestock.

Water Wells

Thousand of supply wells, test wells, and boreholes have been drilled in the region. Plate 5 shows the locations of wells that are listed in the U.S. Geological Survey data bases that cover the region. More than 600 wells have been cataloged by the Survey and water level data are available for more than 500 of these wells. The most recent water level measurements were used in the compilation of the depth to water and water elevation maps presented in Plates 1 and 2.

The production of individual wells depends on a number of factors including the aquifer material and its thickness, the depth and diameter of the well, and how the well was constructed. In general, well yields in Amargosa Valley have ranged from a few hundred to a few thousand gallons per minute with the highest reported yield being 3,000 gallons per minute. Well yields in Pahrump Valley are within the same range as for Amargosa Valley except in the Hidden Hills Ranch area, where well yields of only a few tens of gallons per minute can be achieved for limited periods of time.

Well yields in the volcanic rocks that supply the better quality water supplies to Beatty range from a recent low of 27 to 110 gallons per minute. These wells were all drilled to depths of about 700 feet and have hundreds of feet of screened intervals open to the volcanic rocks. Two wells completed in the the alluvium in the town of Beatty are less than 200 feet deep but produce yields of 90 to 180 gallons per minute. Wells drilled to depths of about 870 to 3,500 feet into the volcanic rocks of the southwestern part of the Nevada Test Site are capable of producing between 100 and 700 gallons per minute, with most of the production reported from depths above 1,300 feet.

Data on well yields in the carbonate aquifer are limted to the results of wells and tests on the Nevada Test Site. Tests conducted at several wells reported production rates ranging from 60 to 500 gallons per minute. Much larger well yields (2,000 to 3,000 gallons per minute) have been reported from this aquifer at two locations in Clark County, and there is the potential for such production from the carbonate aquifer in certain areas of southern Nye County.

There are two public water supply systems located in the Beatty area, the Beatty Water & Sanitation District, a non-profit utility that serves the community of Beatty, and Barrick Bullfrog, Inc. which serves the Bullfrog mine. Information on the history and present use of water by these water supply systems and water use in Oasis Valley and adjacent areas is discussed in detail in the following sections. Other water users in the area include mining operations, ranchers, and the U.S. Department of Energy's Yucca Mountain Project.

**Historic Water Use**

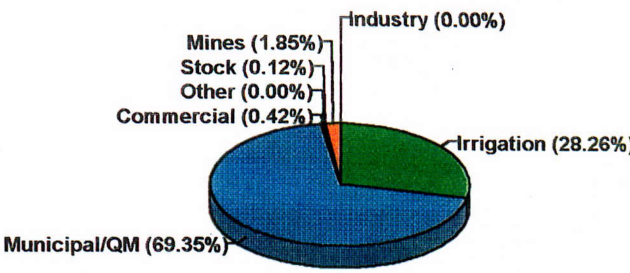
Historically, municipal water use in Oasis Valley has grown along with the community of Beatty while agricultural and mining use has fluctuated depending upon market conditions. The oldest water rights that are still active were issued in 1906-1920 for a number of springs with the water to be used for irrigation and stock watering. The oldest active groundwater right application was filed in 1922, and it was not until 1957 that applications were made for water for quasi-municipal purposes. In 1962, the Beatty Water & Sanitation District was formed and applied for the first municipal water rights in the basin. In April, 1980, Oasis Valley was designated by the Nevada State Engineer through Order 741.

Very few accurate estimates of past water use for the Beatty area are available. The U.S. Department of Energy (1988) reported that an estimated 896 acre feet per year were used in Beatty in 1985. This estimate was based upon an assumed number of residents per household and a rate of 1,800 gallons per day per household. Based upon more recent information, it appears that this estimate was at least double the actual value. In 1995, the total production of the Beatty Water & Sanitation District was metered for the first full year and total water use was measured at 128.2 million gallons or about 393 acre feet per year. As this value was based on actual production records, it represents the best available baseline for water use by the District.

Other active water permits holders in the community of Beatty include the Beatty General Improvement District (325 acre feet annual duty for irrigation) and the Phoenix Inn, Inc. (two permits with a combined annual duty of 100 acre feet for recreation).

Although no published estimates are available, it can be surmised that historic water use in Sarcobatus Flat (located northwest of Beatty) has varied depending upon the activities in the basin. From 1916 through 1948, a total of 29 certificated water rights were granted that are still active, 28 stock water rights and a small irrigation right. During the period 1952-1984, 12 more water right applications were filed which were certificated for mining and milling, irrigation, and stock watering and which are still active. In 1989, two applications for quasi-municipal use were filed that have been permitted. At present, there is little ranch activity and only a handful of residents in the basin. In August, 1989, Sarcobatus Flat was designated by the Nevada State Engineer through Order 999 and applications for new water rights for irrigation have been denied.
The only water use estimate available for Crater Flat

**Water Commitments by Sector**




**OASIS VALLEY - BASIN 228**

| SECTOR | COMMITTED GROUNDWATER (AFY) |
|---|---|
| Irrigation | 474 |
| Quasi-Municipal | 1,163 |
| Commercial | 7 |
| Stock Watering | 2 |
| Mines | 31 |
| TOTAL | 1,677 |



C03

(located northeast of Beatty) is 2,533 acre feet during 1985 according to the U.S. Department of Energy (1988). Only two active water rights have been certificated in Crater Flat, for 1920 and 1986 filings for stock watering purposes. A total of 12 filings have active permits, two permits for the Yucca Mountain site characterization activities and 10 permits for mining and milling.

Rayrock Mines, Inc. is currently starting up a mining operation in Crater Flat, the Daisy Gold Mining Company, and has eight of the mining and milling permits. According to information provided by the company, these permits have been rolled up into a single temporary water right permit through the year 2007. This water right has an annual duty of 645.7 acre feet per year, equivalent to the expected demand rate of 400 gallons per minute. The mine's original water right filings were protested by both the National Park Service and the Yucca Mountain Project. The Yucca Mountain Project withdrew their protest but the Park Service protest went to hearing. The State Engineer's ruling established the annual duty and conditions for monitoring of the water withdrawals. According to information provided by the Rayrock personnel, the company is hoping that additional reserves will be found and the operation could continue through the year 2012 or beyond if exploration efforts are successful.

The Cathedral Gold operation is also active in Crater Flat. This operation, formerly the Sterling Mine Joint Venture, according to the State Division of Water Resources abstract, has a permitted water right with an annual duty of 140 million gallons per year. However, mine personnel indicated that the mine is operating under a temporary permit with a duty of 50 million gallons per year but they are not using that amount at present. Currently the mine is operating on a year-to-year basis. The company is actively exploring for additional ore reserves and if reserves are found, the life of the mine could be extended another decade.

**Present Public Water Supply Sources and Issues**

The water supplies in the Beatty area are in a crisis condition reflecting the combination of low well yields and poor water quality. The Beatty Water & Sanitation District has six water supply wells, which until recently had a combined pumping yield of 565 gallons per minute with individual well yields ranging from 30 to 180 gallons per minute. At these rates, the supply wells are barely capable of meeting the peak demands during the summer months. In 1996 the production capacity of one well (Middle Well) declined from 75 gallons per minute to only 27 gallons per minute. During the summer of 1996, the three main water supply wells were operated continuously, the Middle Well was operated for 12 hours per day, one of the reserve wells was operated continuously, and the other reserve well was operated four to five days a week. Thus the peak daily demand is almost equal to the combined pumping yield of about 515 gallons per minute that were produced during the summer of 1996.

WATER SUPPLY ISSUES IN THE BEATTY AREA

WATER SUPPLY WELLS ARE NOT HIGH YIELDING WITH PUMPING RATES RANGING FROM 27 TO 180 GALLONS PER MINUTE.

BECAUSE OF LOW WELL YIELDS, THE WELLS ARE BARELY CAPABLE OF MEETING THE PEAK DEMAND SEASON IN 1996.

THE GROUNDWATER OF THE REGION CONTAINS NATURALLY OCCURRING LEVELS OF FLUORIDE AND MANGANESE THAT ARE ABOVE THE DRINKING WATER STANDARDS FOR THESE CHEMICALS.

APPLICATIONS TO APPROPRIATE NEW WATER RIGHTS IN AMARGOSA DESERT HAVE BEEN PROTESTED BY THE NATIONAL PARK SERVICE.

MINE CLOSURES AND OPENINGS CREATE CYCLES OF DEMAND IN BEATTY THAT ARE DIFFICULT TO PLAN FOR.

Two water supply wells located in the townsite have concentrations of fluoride that exceed the primary drinking water standards while two other wells approach the secondary standard for this naturally occurring constituent. Elevated levels of nitrates (as nitrogen) or manganese have also been detected in five of the supply wells and the water from four wells exceeds the primary standard for total dissolved solids. Of note is the fact that the two wells with the highest fluoride concentrations are also two of the highest producing wells with a combined yield of 270 gallons per minute, about 48% of the total pumping capacity of the system. This high percentage greatly restricts the use of blending to

keep the water supply under the standard for fluoride imposed under the Safe Drinking Water Act. Water quality poses significant limitations on the water supply available for the community of Beatty.

The Beatty Water & Sanitation District has imposed a moratorium on any new water hookups until additional supplies have been secured. The district has five certificated water rights and one permitted water right with a total combined annual duty of 378.89 million gallons per year (1163 acre feet). In 1995, the District pumped a total of 128.2 million gallons (about 393 acre feet) or slightly more than one-third of the annual duty. Thus water rights are not an existing limitation on the water supply that is available for the community.

To augment their existing water supplies, the district has worked on identifying new sources of better quality water. An evaluation of the southern part of Sarcobatus Flat found that water was legally available for appropriation but that it was not economically feasible to deliver the water to Beatty. This finding in part was the result of the acquisition of an additional 0.8 cfs of water rights from Barrick Bullfrog, Inc. for a water well located in northwestern Amargosa Valley. The district applied for an additional 2.0 cfs of appropriative rights from this well but expects this application to be denied by the Nevada State Engineer. The district has attempted to identify willing water right sellers in Amargosa Valley but has yet to receive a single response to this initiative.

Barrick Bullfrog, Inc. currently operates the Bullfrog mine southeast of Beatty. In 1995, the mine used 1,791 acre feet of groundwater for process water. The process water is entirely derived from Amargosa desert from the dewatering of the mining operation and from two of four wells located in northwestern Amargosa Desert.

The mining company has limited active water rights in Oasis Valley. The mining company has certificated water rights on two of the springs at Indian Springs, in Oasis Valley, which are not being used at this time. These water rights were included as part of a land acquisition transaction and the mine has never used the water. The spring rights in Oasis Valley, with a combined diversion rate of 0.07 cfs and a combined annual duty of 0.62 million gallons, are not currently being used and the mine has no plans to exercise their rights to these springs according to information provided by the mine.

The remainder of the company's water rights are located in Amargosa Valley and include two certificated spring rights and seven groundwater permits. The company has two certificated water rights for springs with a combined diversion rate of 0.07 cfs and a combined annual duty of 0.62 acre feet. The company has filed numerous applications for water rights over the years and is currently operating under a single temporary permit with a diversion rate of 0.446 cfs and an annual duty of 3,200 acre feet (about 1,042 million gallons per year). In 1995 the mine used 1,791 acre feet of groundwater. The peak annual demand was in 1990 when 1,833 acre feet were used.

According to information provided by the mine, the operations are expected to shut down in four years (2000) unless conditions change. Presently the mine uses about 12% of the groundwater that is pumped each year in Amargosa Desert. With the planned closure of the mining operation in 2000, additional water supplies may become available within the basin.

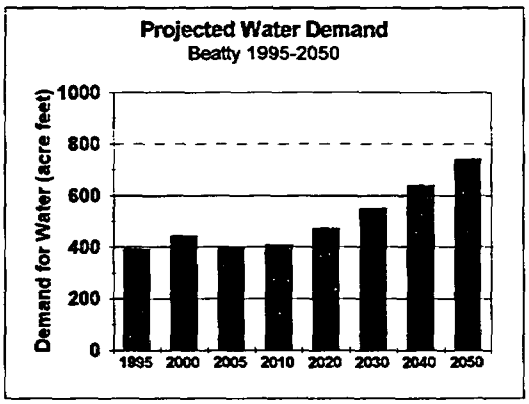
Given the proximity of the mine's existing wells to the community of Beatty, the use of the mine's existing water wells and permitted water rights could be a low-cost alternative water supply for the community if the water rights can be obtained. However, new water rights would have to be obtained for these wells because they are currently permitted under a temporary permit that will cease when mining operations cease. It may be possible to acquire water rights elsewhere in Amargosa Desert, and through a change application change the type of use to quasi-municipal, the place of use to the Beatty Water & Sanitation District service area, and the point of diversion to the Barrick Bullfrog, Inc. water supply wells.

The groundwater pumped by the mine also has elevated levels of fluoride although not as high as those in the Beatty Water & Sanitation District's reserve wells. According to information provided by the mine, the groundwater exceeds the secondary standard of 2 ppm but does not exceed the primary standard of 4 ppm. The fluoride content of the water from the District's two reserve wells in Beatty has averaged 6 ppm according to information compiled in a Hydro-Search study for the district.

**PROJECTED FUTURE WATER DEMAND - BEATTY**

**Per capita water use (gallons/day):** 182

| | YEAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
| **Projected Population** | 1930 | 2170 | 1950 | 2000 | 2322 | 2696 | 3130 | 3634 |
| | PROJECTED WATER USE | | | | | | | |
| **Water Use (gallons per day)** | 351260 | 394940 | 354900 | 364000 | 422604 | 490643 | 569637 | 661348 |
| **Water Use (gallons per minute)** | 244 | 274 | 246 | 253 | 293 | 341 | 396 | 459 |
| **Water Use (million gallons/year)** | 128 | 144 | 130 | 133 | 154 | 179 | 208 | 241 |
| **Water Use (acre feet/year)** | 393 | 442 | 398 | 408 | 473 | 550 | 638 | 741 |




**ASSUMPTIONS:**

1. **Barrick Bullfrog Operations to stop in 2000.**
2. **Population drops 2000-2005 due to mine closure.**
3. **Population increases 1.5% per year after 2005.**
4. **No new mining operations start in Oasis Valley.**
5. **Groundwater pumping capacity does not limit growth.**
6. **Per capita water use remains constant.**

## Future Water Demand

The future water demand in Beatty can be projected on the basis of current per capita water use and projected population trends. The most current population estimate for Beatty (provided by the Planning Information Corporation) was for 1995 during which the population rose from 1,861 to 1,974 residents in households with an average for the year of 1,920. This value differs only slightly from the Nye County projected population of 1,930 residents. Based upon the Nye County estimates and the metered water use for 1995, the rate of per capita water use in Beatty is estimated to be 182 gallons per day. This is a low value compared with other communities in southern Nevada. The use of Planning Information Corporation's estimate increases this rate by less than one gallon per day.

The projected water demand for Beatty between 1995 and 2000 is expected to increase by about 13 percent. Demand at that time is projected to decrease until 2010 to a level only about 4% above 1995 levels. The initial 5-year increase in the demand for water reflects the opening of new mining ventures whose workers are likely to settle in Beatty. The decrease from 2000 to 2005 in the population of the community coincides with the expected closure of the Bullfrog Mine. Assuming that the increases in peak demand will be consistent with the overall growth rates, than a peak demand of about 640 gallons per minute will occur in 2000 and decrease to about 590 gallons per minute in 2010.

Beyond the year 2010, the water demand in the Beatty area is assumed to increase at a constant rate of about 1.5 per cent per year. Even at this slow growth rate, the population of the community is projected to increase by 82 percent by mid-century with a total projected population of about 3,650.

Beyond the increased demand for the community of Beatty, there are likely to be other demands in Oasis Valley and the neighboring portions of Sarcobatus Flat, Crater Flat, and Amargosa Desert. In Oasis Valley, there are three active applications for water

rights, two applications for a total of 2.45 cfs for irrigation and one application for 0.2 cfs for commercial purposes. The BLM has also claimed federal reserved water rights at four springs and two surface water occurrences for stock watering. Two claims of vested water rights totalling more than 5 cfs have been put forth by the Lisle and Revert trusts. If these water rights are granted, the committed groundwater resources would significantly exceed the perennial yield of the basin and it is unlikely that it will be possible to obtain any additional water rights in the basin.

There are two applications for groundwater rights in Sarcobatus Flat for quasi-municipal purposes totalling 0.35 cfs. These applications have been protested. If granted, the total committed groundwater resources would still be less than the perennial yield and it may be possible to obtain additional water rights in the basin.

There are about 22 active water right applications in Amargosa Valley and dozens of requested changes to existing certificated water rights. The existing committed water right certificates and permits greatly exceed the established perennial yield of the basin. It is unlikely that any new water rights can be obtained in Amargosa Valley for use in Beatty until such time as all of the active water right change applications and applications for new water rights have been ruled on.

**Potential Future Water Supply Alternatives**

The following alternatives are available for meeting the future demand for water in Beatty:

- o Design, construction, and operation of a water treatment facility to remove chemical constituents to levels below regulatory standards.
- o The drilling of one or more new supply wells in Oasis Valley using the existing water rights.
- o Acquisition of new or existing water rights in Amargosa Desert and conveyance of that water to the community of Beatty.
- o The importing of water from one or more northern basins.

A water treatment plant would be costly and a considerable amount of time would be required for implementation. First, the necessary feasibility and design studies would have to be conducted. Funding would then have to be obtained and a facility constructed. The entire process could take several years and large capital investments. Further, additional water supplies would still have to be obtained to meet the projected shortfall in the year 2000. The District has evaluated various treatment alternatives including reverse osmosis, deionization, and other approaches.

These treatment alternatives were found to increase the demand for feed water by one-third and some options would require that the existing staff of four district employees would have to be increased to nine with a requirement for specialized hazardous materials training. Thus any treatment options would have a high operation and maintenance cost in addition to the initial capital expenditure needed to design and build a treatment facility. In total, these costs would make the price of treated water prohibitive.

The drilling of one or more new wells in Oasis Valley faces the same problems of low well yield and poor water quality that are plaguing the existing system. The best quality groundwater is from the District's Indian Springs Well which is capable of producing 110 gallons per minute of water with a total dissolved solids concentration of only about 205 ppm. If wells could be drilled nearby with similar characteristics, then three wells would be needed to replace the two existing poor quality wells currently being used to meet peak demand during the summer months. If the three wells were to produce the same volumes as the Indian Springs Well, then an additional 60 gallons per minute would become available, bringing the total pumping capacity to about 570 gallons per minute.

The drilling of three new water supply wells in the Indian Springs area could solve the water quality problems but would not meet the projected future peak daily demand of 640 gallons per minute in 2000. This shortfall might be addressed through drilling of one more well, strict conservation practices, an increase in storage, or by continuing to hold the two high-fluoride wells in reserve for meeting peak demand as is currently being done.

The District has considered drilling additional wells in the Indian Springs area and requested monies for this purpose under the provisions of AB 198. This request was turned down by the Board of Water Finance because of the relatively low well yields in the area.

The acquisition of new water rights in Amargosa Desert is constrained by the over appropriation of the basin and the certainty that any new water right applications will be vigorously protested by the National Park Service. Protests of this nature tend to add significant delays in the granting of water rights and may, in some cases, lead to the denial of the application. Therefore, the acquisition of existing water rights and the transfer of those rights to a new point of diversion nearer the community of Beatty is likely to take less time. However, as noted earlier, there has been no "stampede" to Beatty to offer up water rights for sale.

The fourth alternative, importing water from northern basins, would involve developing water supplies in basins in northern Nye County and conveying that water to Beatty. The primary disadvantages of this alternative are the cost and time to implement. First, existing water rights would have to be acquired or new rights obtained through the appropriation process. Next, environmental clearances would have to be obtained for the new well site(s) and the pipeline routes. If substantial federal funds are required, further delays may be inccurred to prepare an Environmental Assessment. While this approach could be used to develop a more reliable source of fresh water over the long term, it would be difficult, if possible at all, to be done in time to meet the shortfall projected for the year 2000.

There are six public water supply systems in Amargosa Valley and four systems on the Nevada Test Site. Other water users include mining operations, a number of farms and ranches, and domestic users. Information on these public water supply systems and other water users in Amargosa Valley is discussed in the following sections.

**Historic Water Use**

Groundwater pumping in Amargosa Valley began to grow significantly in the late 1950s and by 1962, there was about 1,400 acres of farmland under cultivation using about 3,000 acre feet of water. According to information presented by D'Agnese (1994), water used for irrigation in the basin grew to almost 9,300 acre feet in 1967. By 1973, water use had declined to about 7,000 acre feet.

In 1985, the Nevada Division of Water Resources began annual pumping inventories in the basin. In 1985, the state inventoried 9,672 acre feet of groundwater withdrawals for all purposes Of this amount, the majority (8,472 acre feet) was used for irrigation. Pumping declined significantly and by 1989 the total agricultural water use had fallen to only 1,566 acre feet, and total water use in the basin was only 3,921 acre feet. The mining industry was the only sector with an increase in water use during this period, with consumption increasing from 950 acre feet in 1985 to 2,220 acre feet in 1989.

In 1990 water use began to grow again and by 1994 agricultural water use had almost doubled from 1985 levels, totalling 9,977 acre feet. From 1994 to 1995, the use of water for irrigation in the basin grew 24% while all other water use grew by only two percent. Much of the increase in water use can be attributed to the forfeiture proceedings that are on-going as of this evaluation. These forfeitures are discussed in more detail in a later section.

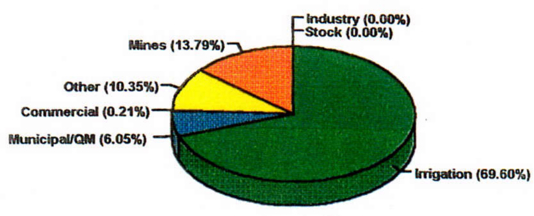
The mining sector is the second largest water user in the basin accounting for 2,571 acre feet of groundwater pumpage in 1995. The major water users for mining and milling are Barrick Bullfrog, Inc. (1,791 acre feet), American Borate (164 acre feet), and IMV Floridin (349 acre feet). As noted in the discussion for Pahrump, the Bullfrog operation is scheduled for closure in 2000.

The other water users in the basin are limited to commercial operations including a dairy and the new casino at the state line, a few public water supply systems, and domestic water users. Water used by the dairy for irrigation is included within the total above. Other water use by the dairy is not known. Assuming a water use of 10 gallons per day per head, the total water used by the dairy is probably less than 200 acre feet per year.

According to the Nevada Division of Water Resources, the quantity of water pumped for quasi-municipal purposes and domestic use is small, on the order of 100 acre feet per year. This rate is based upon the assumption that domestic water users consume one acre foot of water per year. Historically, this volume has fluctuated between 100 and 230 acre feet per year with the peak inventoried in 1985.

Historic water use on the Nevada Test Site has varied considerably over the history of the facility. In the 1950s, water use was less than 250 acre feet per year. In the 1960s, water use grew to a maximum of about 1,500 acre feet in 1964 and

**Water Commitments by Sector**




**AMARGOSA DESERT -Basin 230**

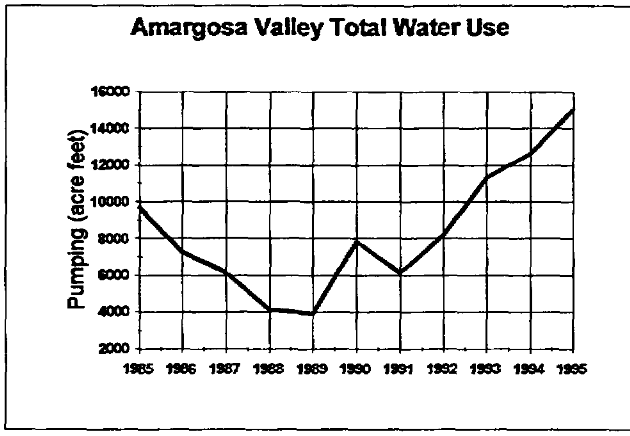
| Sector | Committed Groundwater (AFY) |
|---|---|
| Irrigation | 28,600 |
| Quasi-Municipal | 2,486 |
| Commercial | 85 |
| Mining & Milling | 5,667 |
| Other | 4,255 |
| Total | 41,093 |

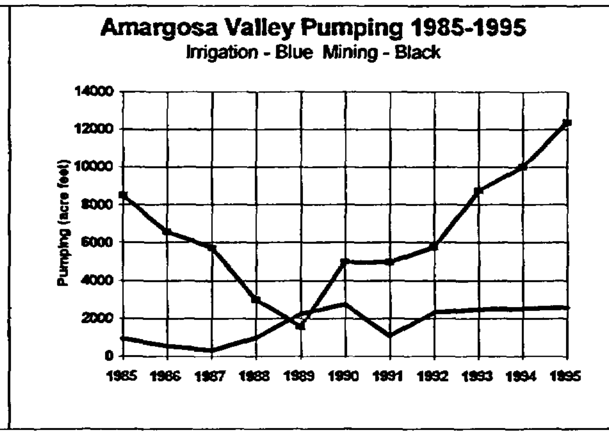


C04

NEVADA DIVISION OF WATER RESOURCES GROUND WATER PUMPAGE INVENTORIES 1985-1995

| AMARGOSA VALLEY | INVENTORIED PUMPING IN ACRE FEET | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | YEAR | | | | | | | | | | |
| TYPE OF USE | 1995 | 1994 | 1993 | 1992 | 1991 | 1990 | 1989 | 1988 | 1987 | 1986 | 1985 |
| IRRIGATION | 10839 | 8892 | 8559 | 5711 | 4717 | 4603 | 1266 | 2666 | 4500 | 5553 | 5807 |
| UNPERMITTED IRRIGATION | 1515 | 1085 | 150 | 50 | 225 | 350 | 300 | 312 | 1200 | 1000 | 2665 |
| INDUSTRIAL-MINERAL | 349 | 340 | 495 | 348 | 335 | 384 | 525 | 569 | 298 | 284 | 950 |
| COMMERCIAL | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 20 |
| QM AND DOMESTIC | 100 | 100 | 100 | 100 | 100 | 125 | 125 | 125 | 125 | 125 | 230 |
| AMERICAN BORATE | 431 | 377 | 512 | 306 | 115 | 503 | 888 | 427 | 4 | 266 | |
| ST. JOE BULLFROG | 1791 | 1791 | 1474 | 1639 | 620 | 1833 | 807 | | | | |
| Total | 15035 | 12595 | 11300 | 8164 | 6122 | 7808 | 3921 | 4109 | 6137 | 7238 | 9672 |




averaged about 1,000 acre feet per year over the decade. Records are not available for the period 1972 through 1982, inclusive. Water use at the Test Site grew from about 1,500 acre feet in 1983 to almost 2,500 acre feet in 1989. Since that time, water use has declined at the Test Site, reflecting the slowdown in operations at the site and the current moratorium on underground nuclear testing. By 1994, the total water use had declined to about 1,500 acre feet.

**Present Public Water Supply Sources and Issues**

There are no major water purveyors in Amargosa Valley. Three of the seven public water supply systems are transient systems and supply the school, senior center, and town complex with drinking, culinary, and irrigation water. According to the system operators, the school serves about 150 persons, the senior center about 20, and the town complex also serves a work force of about 20 persons. Exact water use is not known but is probably no more than 20 acre feet per year with most of this quantity consumed for water of the park and sports fields. Existing water rights are adequate and no issues were identified.

The Amargosa Valley Water Association serves a total population of 25 persons through 22 service connections. Desert Village, Inc. was contacted but did not provide any information. According to state records, this system has two connections and serves a transient population of about 20 persons.

The other three public water supply systems provide drinking water supplies to an estimated population of about 150 users. The Amargosa Water Company is a homeowners association that currently has 12 connections and serves a total population of about 40 persons according to the system operator. This system was originally the IMV Floridin public water supply system and was sold by the company to the homeowners. The system has a single well that has consistently produced water with fluoride concentrations that exceed the secondary drinking water standard of 2 ppm. Because of the cost

**WATER RIGHT FORFEITURES IN AMARGOSA VALLEY THROUGH SEPTEMBER 4, 1996**

| CERT | NAME | AMOUNT FORFEITED (ACRE FEET) | AMOUNT RETAINED (ACRE FEET) |
|---|---|---|---|
| 65675 | Leake | 35.48 | 14.52 |
| | Richardson | 5.46 | 7.02 |
| | White | 35.48 | 14.52 |
| | Rook | 17.98 | 7.02 |
| | Selbach | 5.48 | 7.02 |
| | Porsche | 9.98 | 12.02 |
| | Rook | 88 | 0 |
| | Copeland | 12.5 | 0 |
| | Dillard | 12.5 | 0 |
| | Jackson | 12.5 | 0 |
| | Hulse | 12.5 | 0 |
| | Black | 12.88 | 7.02 |
| | Jacobs | 72 | 0 |
| | Cypert | 490.1 | 0 |
| 7238 | Mills | 248.58 | 5.52 |
| | Welch | 50 | 0 |
| 7975 | Richards | 126.5 | 40 |
| 6642 | Honig | 100 | 0 |
| 6643 | Honig | 800 | 0 |
| 7696 | White | 105.96 | 94.04 |
| 4658 | Piper | 50 | 0 |
| 5593 | Selbach | 377.98 | 22.02 |
| 5762 | none listed | 180 | 20 |
| 5906 | Claessens | 200 | 0 |
| 5754 | Stevens & Sack | 120 | 0 |
| 6008 | Mulkey & Fellwock | 400 | 0 |
| 5478 | Mason | 61.25 | 0 |
| 5789 | Nye County | 200 | 0 |
| 5790 | Aston | 200 | 0 |
| 6660 | Honiq | 175 | 0 |
| 6385 | Honig | 100 | 0 |
| 6099 | Honig | 400 | 0 |
| 6117 | Cortner | 10.98 | 14.02 |
| | Coucher | 42.98 | 7.02 |
| | McAllister | 42.98 | 7.02 |
| | Engh | 100 | 100 |
| | Johnson | 102.86 | 8.14 |
| | Holtz | 431.98 | 77.02 |
| | TOTAL | 5449.89 | 463.94 |

associated with compliance with all the applicable government regulations, it is anticipated that this water company will be discontinued in 1998 and the individual homeowners will probably be drilling domestic water wells for each property. Currently, the system pumps at their full appropriative right of 10 acre feet per year.

There are four public water supply systems on the Nevada Test Site operated by the U.S. Department of Energy. In 1996, two systems were consolidated into a single water supply system. These systems provide drinking water supplies for the development at Mercury and for the forward areas of the Test Site. Most of the groundwater is withdrawn from Yucca Flat.

A total of 12 supply wells are currently active at the Test Site and 11 of these wells are used as a source of drinking water. Construction and fire-control water are supplied by other wells and the springs and seeps on the facility are not used for water supplies. The Department of Energy, under the Federal Reserve Water Rights doctrine, is entitled to withdraw the quantity of water need to support the mission of the Nevada Test Site. Water that may be used for other actions that are determined to be outside the mission of the facility will require the appropriation of that water in compliance with Nevada Water Law. Thus the Department of Energy's water use for Yucca Mountain must be appropriated while use on the Test Site for underground testing, waste disposal, and other missions need not be appropriated.

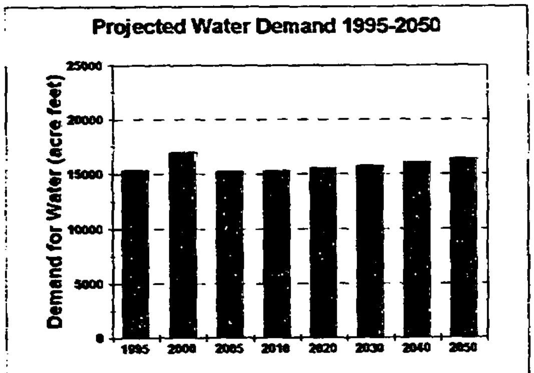
### Water Right Forfeitures

As a result of a petition by Amargosa Resources, Inc., the water rights situation in Amargosa Valley has been in considerable turmoil over the last three years. Numerous change applications have been filed to divide former large irrigation certificates into smaller water rights for lands that have been subdivided. A series of hearings have been held and a total of 5,450 acre feet of certificated water rights had been forfeited as of September 4, 1996. A preliminary table of water right forfeitures was provided by the Division of Water Resources and appears at left. One more hearing is scheduled for an additional 20 water rights that were included in the petition to initiate forfeiture.

PROJECTED FUTURE WATER DEMAND - AMARGOSA VALLEY

**Per capita water use (gal/day):** 319
*(1 afy/r for houshold of 2.8 persons)*

| | YEAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
| Projected Population | 1180 | 1350 | 1540 | 1740 | 2245 | 2896 | 3735 | 4818 |
| **WATER USE** | PROJECTED WATER USE | | | | | | | |
| Gallons per day | 350743 | 430457 | 491040 | 554811 | 715834 | 923410 | 1190931 | 1536254 |
| Gallons per minute | 244 | 299 | 341 | 385 | 497 | 641 | 827 | 1067 |
| Million gallons/year | 128 | 157 | 179 | 203 | 261 | 337 | 435 | 561 |
| Acre feet/year | 393 | 482 | 550 | 621 | 802 | 1034 | 1334 | 1721 |
| IRRIGATION WATER (acre feet) | 12354 | 13911 | 13911 | 13911 | 13911 | 13911 | 13911 | 13911 |
| MINING & MILLING (acre feet) | 2600 | 2600 | 800 | 800 | 800 | 800 | 800 | 800 |
| TOTAL (acre feet) | 15347 | 16993 | 15261 | 15332 | 15513 | 15745 | 16045 | 16432 |




ASSUMPTIONS:

1. Barrick Bullfrog, Inc. will stop operations in 2000.
2. Mining & milling use will be 800 afy after 2000.
3. Agricultural water use increases 5% per year until 2000.
4. After 2000, agricultural water demand remains constant.
5. Quasi-municipal & domestic use increases 2.5% per year.
6. Quasi-municipal & domestic use = 1afy per household.
7. No mining operations start that use water from basin.
8. No groundwater is exported from the basin.

Amargosa Resources, Inc. filed five water right applications in December, 1992 requesting a diversion rate of 20 cfs for one point of diversion and 8 cfs at each of 4 additional points of diversion with a requested annual duty of 1,887.25 million gallons for each of the applications. and a combined annual duty of 9,436 million gallons per year (almost 29,000 acre feet per year) for municipal use. These applications were changed in July, 1994 to change the type of use to wildlife. Amargosa Resources, Inc.'s plans for their water right filings are unknown. The State Engineer has directed this organization to state their intent for pursuing these applications. In the event that the deadline for this statement of intent is not met, the applications may be denied.

## Future Water Demand

The projections of future water demand in Amargosa Valley are made more difficult by the recent increases in agricultural pumping, expansion of the dairy, and poor estimates of water consumption for quasi-municipal and domestic purposes. Therefore. certain assumptions are needed to evaluate the future demand.

For the purposes of this evaluation it is assumed that water used by the mining industry will stay at a constant rate of 2,600 acre feet per year, slightly more than the total volume used in 1995, until the year 2000. From 2000 and beyond, the projected water demand for mining and milling is reduced to 800 acre feet per year reflecting the shut down of the Barrick Bullfrog, Inc. operation and the continuing operations at American Borate and IMV Floridin.

Agricultural water may gradually increase over 1995 levels as additional farmland is cultivated for the production of forage or other crops. This increase is projected on the basis of discussions with area farmers and historic trends in pumping. For the purposes of this projection, it is assumed that the water used for irrigation will increase by five percent a year for the period 1996-2000 and then stabilize at

that level. Based upon this assumption, water use will increase to about 13,900 acre feet in 2000 and will remain constant after that time. Some Amargosa Valley residents indicated that the full "farmout" of arable land could be reached as soon as 1998.

Quasi-municipal and domestic water use is projected to grow at a rate of about 2.5 percent per year. This value is based upon the County's census projections for the period 2000-2010. During this period of time, the population is projected to grow by almost 30 percent. Growth at this moderate rate is expected to continue until the middle of the next century. It is projected that by 2050 over 4,800 people will live in Amargosa Valley with a total demand for water of about 1,720 acre feet.

Future water use on the Nevada Test Site is uncertain at this time. This uncertainty reflects the wind down of underground nuclear testing. The most current estimates of future water use at the facility are contained in a letter from the Department of Energy dated September 3, 1996 and the Draft Environmental Impact Statement for the Nevada Test Site dated January, 1996. According to these sources, a heavy industrial facility may be constructed in Frenchman Flat and a Solar Enterprise Zone may be constructed in Jackass Flat or Mercury Valley. Based upon the estimated water demands for these facilities, the overall demand for water at the facility could exceed 7,800 acre feet per year. Most of this demand would be related to the construction of a solar enterprise zone which would require an estimated 3,250 to 5,550 acre feet per year. There is adequate unappropriated water in both Fortymile Canyon (Buckboard Mesa and Jackass Flat) and Mercury Valley to allow the construction and operation of the zone.

The proposed additional withdrawals at the Test Site are difficult to take into account in projecting the future demand for water in southern Nye County. The new facilities and uses of water are only proposed, and there are alternative locations in Clark County for the proposed solar enterprise zone. No timetable has been given for actually constructing these facilities and it could be a decade or more before ground is actually broken. Therefore, for the purposes of forecasting the water withdrawals at the Nevada Test Site it is assumed that water demand will continue at the rate of 1,500 acre feet per year until the year 2005. It is assumed that the solar enterprise zone will be constructed in 2006 and will increase the annual demand for water to 7,800 acre feet.

**WATER SUPPPLY ISSUES**

WATER SPECULATORS HAVE RECENTLY INITIATED THE FORFEITURE OF MORE THAN 5,000 ACRE FEET OF WATER RIGHTS.

NATURALLY OCCURRING FLUORIDE CONCENTRATIONS IN THE NORTHWESTERN PART OF THE BASIN EXCEED DRINKING WATER STANDARDS.

EXPANSION OF THE DAIRY MAY RESULT IN AN INCREASED DEMAND FOR LOCALLY GROWN FORAGE AND, AS A CONSEQUENCE, INCREASE THE DEMAND FOR GROUNDWATER.

AMARGOSA VALLEY, BECAUSE OF ITS PROXIMITY TO PAHRUMP, MAY EXPERIENCE ADDITIONAL GROWTH DUE TO "OVERFLOW" FROM PAHRUMP.

### Potential Future Water Supply Alternatives

Based upon the projected future water use, the demand for water in Amargosa Valley by the middle of the next century will be about 16,430 acre feet per year. This projected volume represents only a seven percent increase over 1995 pumping levels. This value is still less than 70 percent of the perennial yield of the basin. It should be possible to draw water from the alluvial aquifer to meet this future demand and alternative water supply sources will not be needed.

The slow projected growth in water demand in Amargosa Valley is based upon the closure of the mine and a "leveling off" of agricultural production. One or more new mining ventures or a greater expansion of irrigated agriculture could yield to an increase beyond that projected above. Even then, the demand for water in the basin would still be appreciably less than the perennial yield indicating that water availability will not be a constraint on future growth in the basin in the foreseeable future.

## PAHRUMP VALLEY AREA

There are 22 public water supply systems in Pahrump Valley. Water is also used for farming, ranching, and commercial purposes. Information on the public water supply systems and other water users is discussed in detail in the following sections.

### Historic Water Use

The development of groundwater supplies in Pahrump Valley followed the development patterns of the entire southern part of Nevada. In the late 1800s and early 1900s, spring discharges were more than adequate to provide for the irrigation of forage crops, fruit trees, and grapes at the few ranches in the valley. Many of the wells drilled between 1910 and 1920 were artesian and provided an excellent source of water for additional farming. By the mid 1940s, the estimated annual pumping rate of 10,000 acre feet per year was still comfortably under the perennial yield of 19,000 acre feet.

Then cotton became king in Pahrump Valley, and a boom in drilling new irrigation wells began. By 1962 more than 3,300 acres of cotton had been planted along with almost 3,200 acres of other crops. Between the mid 1940s and 1962, the total groundwater pumped in the basin almost tripled to about 28,000 acre feet per year. Cotton began to decline in 1964 but the acreages irrigated for other crops continued to grow to a peak of 8,400 total acres under irrigation in 1969. The peak pumping rate of 47,100 acre feet occurred in 1968 and has declined significantly since that period. This decline has largely reflected the continued conversion of farmland to urban use.

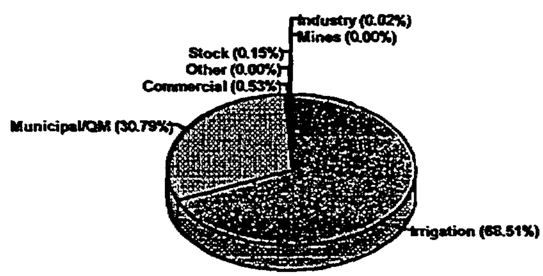
By 1995, the use of groundwater for the irrigation of crops had dropped to about 14,183 acre feet, only 30% of the pumping in 1968. The 1995 pumping value is based on the annual pumpage inventory conducted by the Division of Water Resources. Total pumping in the basin in 1995 was inventoried at 23,621 acre feet, about one half of the 1968 peak of 48,000 acre feet.

Agricultural water use within the basin can vary as much as 22% from one year to the next reflecting both cropping patterns and seasonal rainfall.

For example, the total irrigation water used in 1995 was 17% less than the amount used in 1994. However, the total water used for irrigation in 1995 was actually about one percent <u>more</u> than that used in 1993. Overall, the quantity of water used for irrigation since 1985 has remained fairly constant, fluctuating between 14,000 and 19,000 acre feet per year.

While the demand for irrigation water has declined significantly over the last three decades, the demand for water for municipal, quasi-municipal, and domestic purposes has continued to grow. In 1976, the U.S. Geological Survey estimated that 2,000 acre feet were pumped in 1975 for public water supplies and commercial use, and another 800 acre feet were pumped for domestic use. By 1995, water pumped for these purposes had almost tripled, totalling an estimated 8,258 acre feet per year.

**Water Commitments by Sector**

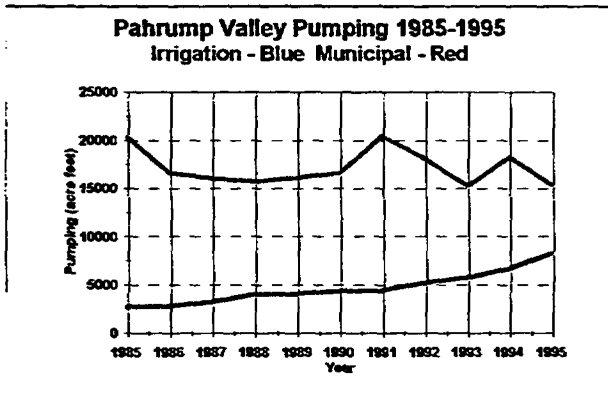


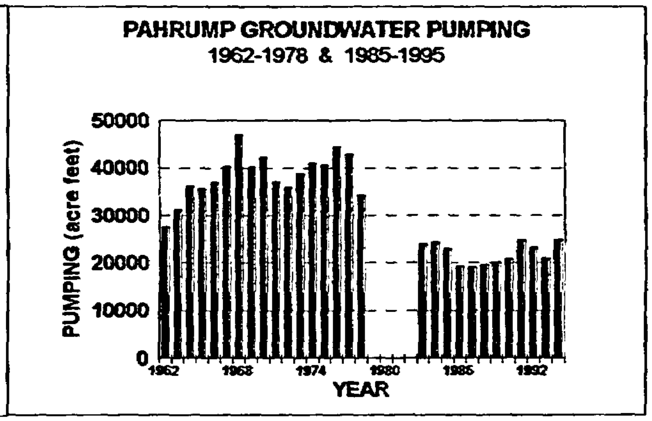

**PAHRUMP VALLEY - Basin 162**

| Sector | | Committed Groundwater (AFY) |
|---|---|---|
| Irrigation | | 44,259 |
| Quasi-Municipal | | 19,892 |
| Commercial | | 341 |
| Stock | | 94 |
| Industry | | 10 |
| Other | | 2 |
| | Total | 64,598 |

NEVADA DIVISION OF WATER RESOURCES GROUND WATER PUMPAGE INVENTORIES 1985-1995

| PAHRUMP VALLEY | INVENTORIED PUMPING IN ACRE FEET | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | YEAR | | | | | | | | | | | | |
| TYPE OF USE | 1995 | 1994 | 1993 | 1992 | 1991 | 1990 | 1989 | 1988 | 1987 | 1986 | 1985 | 1984 | 1983 |
| IRRIGATION | 14183 | 17067 | 14051 | 16893 | 19257 | 15374 | 14868 | 14475 | 14804 | 15424 | 19140 | 20464 | 21126 |
| GOLF COURSE | 1180 | 1180 | 1180 | 1180 | 1180 | 1180 | 1180 | 1180 | 1180 | 1180 | 1183 | 1183 | 477 |
| CAL-VADA | 2724 | 1817 | 1545 | 1462 | 1087 | 1279 | 1088 | 1240 | 1302 | 1120 | 1180 | 1204 | 1200 |
| QM AND DOMESTIC | 5534 | 4841 | 4186 | 3754 | 3322 | 3020 | 2996 | 2749 | 1861 | 1684 | 1550 | 1500 | 1350 |
| Total | 23621 | 24905 | 20962 | 23289 | 24846 | 20853 | 20132 | 19644 | 19147 | 19408 | 23053 | 24351 | 24153 |




The recent population boom in Pahrump has accelerated the demand for water. In fact, based upon the 1995 and 1994 inventories performed by the Division of Water Resources, the demand for water for all municipal purposes (municipal plus quasi-municipal and domestic not including Champion Golf Course) grew by 24% between the two years and marked the fourth straight year that the municipal water demand in Pahrump has grown by more than ten percent.

The decline in irrigation water and the increased demand for water for urban development have offset each other over the last decade. As a result, the 1995 total pumping of 23,621 acre feet from Pahrump Valley is only a 2.5 percent increase over the total pumping in 1985.

**Present Public Water Supply Sources and Issues**

Central Nevada Utilities is the single largest water purveyor in the valley, operating five separate public water supply systems, Central Nevada Utilities, Country View Estates, Shamrock Water System, Calvada North, and the CNU Winery Well. As of 1995, this utility serviced a total of almost 1,200 customers and provided drinking water supplies for a total estimated population of about 3,150 persons. The utility operates eight water supply wells with a combined pumping capacity of almost 3,000 gallons per minute.

In 1995 the utility pumped a total of 1,791 acre feet of groundwater for public drinking water supplies, commercial use, and irrigation of the executive golf course. Another 1,180 acre feet are pumped each year for irrigation of the Champion Golf Course. If this golf course is included with the urban totals, then the total water pumped for municipal purposes by Central Nevada Utilities during 1995 was 2,971 acre feet.

According to the system operator, the most significant issue facing Central Nevada Utilities at this time is the need for increased storage capacity. An increased capacity is needed to provide the flows needed to meet the requirements of fire codes. The system has adequate water rights and pumping capacity to meet existing and anticipated future demands.

Many of the public water supply systems in Pahrump are small entities. A number of the systems are associated with mobile home parks, including the Anchor Inn Park, Big Five Trailer Park, Big Valley Mobile Home Park, C-Valley Mobile Park,

Chipmunk Retreat, Escapee's Coop of Nevada, Mountain View Mobile Home Park, Pahrump Mobile Home Park, and Sunset Mobile Home Park. Of these, Escapee's Coop is the largest serving an estimated annual transient population of about 290 persons. These small systems all rely upon one or two wells for water supplies. The systems with two wells typically only pump one well keeping the second well as a backup source.

Well yields at the mobile home parks are typically small, ranging from 10 to 20 gallons per minute and even then, for only a few hours each day. In total, these small systems serviced 237 connections in 1995 with a total estimated population of 800 persons. Based upon metered use at Escapee's Coop and operator supplied rates for Chipmunk Retreat, Mountain View, and Anchor Inn mobile home park, the average daily consumption rate for a mobile home park ranges from about is about 150 gallons per day per person. Based upon this rate, the total 1995 demand for these systems is estimated about 135 acre feet per year.

Other smaller supply systems provide drinking water supplies to small, but growing, subdivisions including Desert Utilities and the Desert Mirage Homeowners Association. Desert Utilities serviced about 120 customers and a total estimated population of about 200 persons in 1995 from a single water supply well. Desert Mirage Homeowners Association serviced 12 customers totalling about 40 persons but demand is expected to double in the next few years as the remaining lots have been sold. The East Park Commercial Subdivision, another small system, services a RV park and a 45-unit motel with about six connections with a total transient population estimated at about 200 persons. Assuming a rate of 1.0 acre feet per year for each service connection and 50 gallons per day for each transient customer at the RV park and motel, then the total water used by these three supply systems is estimated at about 145 acre feet per year.

Other public water supply systems include the Nye County Complex, Double Eagle Casino, LDS Church/Pahrump Ward, Pahrump Community Church, Pahrump Primary School, and the Pahrump Senior Citizens Center. Water use at these facilities is minimal compared to the other water supply systems because of the limited number of water users. In 1995, these systems had a total of 27 service connections believed to serve as many as 500 persons during working hours. The total water use is not known but, assuming an average rate of 10 gallons per day worker or visitor, the total annual use is estimated at only less than 60 acre feet per year.

Dodge's Market/Pahrump Trading is listed in state files as having 25 service connections and serving a population of 30 persons. The phone number for Dodge's Market has been discontinued and neighbors indicated that the market folded in 1995. There is no phone number listed for the operator of record and no public information could be found concerning this system.

Based upon these estimates, the groundwater withdrawals in Pahrump in 1995 for public drinking water supplies, commercial use, and other municipal purposes totalled 3,310 acre feet. This value represents only about 14% of the total water use in the area. The total estimated resident population served by these systems is 4,190 persons or about 28% of the total population of Pahrump in 1995.

The remainder of the population draws its water supply from the many domestic water wells located throughout the developed areas of the valley. These wells are typically low-yield wells that are not metered and measurements or accurate estimates of actual consumption are not available. The Division of Water Resources annual pumpage inventories assume that each domestic water well accounts for one acre foot per year of water but believes that this volume of water may be somewhat more than the actual usage.

In most basins in Nevada, the water use by domestic wells is only a fraction of the total water demand. For example, in Amargosa Valley the total estimated water use by domestic wells is only 100 acre feet per year. In Pahrump Valley, however, the manner of urbanization has led to the drilling of hundreds of new domestic wells each year. In 1995 alone, there were 693 new domestic wells drilled in the basin. The Division of Water Resources estimated that the total water used by domestic wells and the smaller public water supply systems in the Valley was 5,534 acre feet, about 23% of the total pumpage in the basin. By comparison, in 1994 there were only 97 domestic wells drilled in Las Vegas Valley and the total pumpage by all domestic wells in the valley was estimated at 6,909 acre feet, representing 10% of the groundwater pumped in that basin.

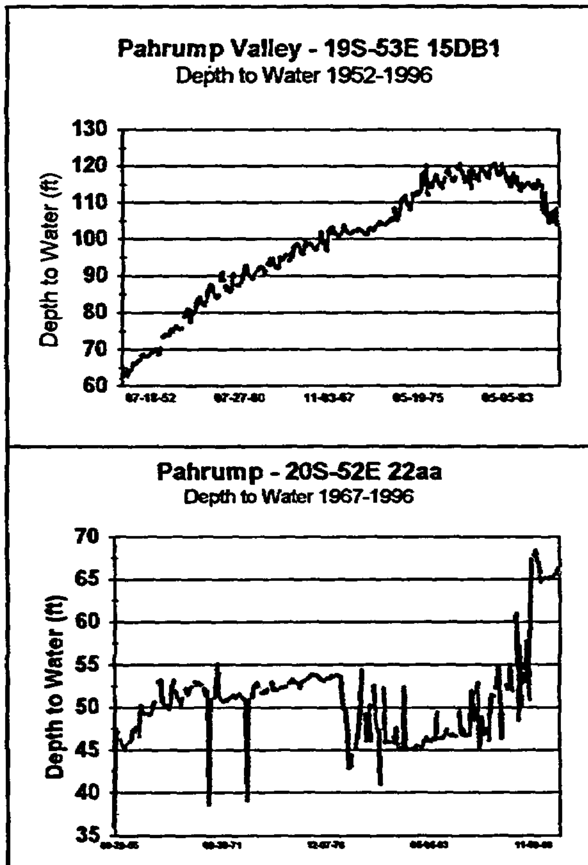
The actual water used by a domestic well owner varies depending upon the size of the homesite, the landscaping, the number of occupants, and other factors. As a consequence, the actual amount of water used in Pahrump Valley by domestic well owners is not known and probably will never be known with any high degree of accuracy. In lieu of more refined estimates, the Division of Water Resource's methodology of assuming one acre foot of water consumption is used for each domestic well is used in this evaluation as well for projecting future demand.

Historically, a major issue in the Pahrump Valley was the drawdown of the water table. In 1986 the U.S. Geological Survey published the results of an evaluation of groundwater depletion in Pahrump Valley. This evaluation reported that the static water table had dropped as much as 60 feet between 1962 and 1975 and predicted that water levels would continue to decline until pumping was reduced. As noted previously, water use was significantly reduced after 1976. The demand for water dropped by 60 percent to about 19,150 acre feet in 1987. Since 1987, water demand has fluctuated ranging between 19,000 and 25,000 acre feet per year.

The U.S. Geological Survey evaluation by Harrill (1986b) included hydrographs (graphs that depict the elevation of the water table over time) for six wells in Pahrump Valley and discharge rates for Bennetts Spring and Manse Spring. The Survey has continued to monitor the water levels in three of these wells and long-term monitoring data is available for other wells. For the period between 1976 and 1995, water levels recovered about 15 feet in two of the observation wells in the northern part of Pahrump and at one observation well in the southern part of the community. Conversely, water levels declined 10 to 15 feet between 1976 and 1988 at two observation wells located near the state line in the northwestern and southern areas of Pahrump. Since 1988, water levels in these wells appear to have stabilized.

The decline in water levels in the basin resulted in the elimination of spring discharges at two locations, Bennetts Spring and Manse Spring. Bennetts Spring, reported to discharge over seven cfs in the late 1800s, had declined to less than two cfs by 1958 and by 1959 was dry. Manse Spring declined from a reported six cfs in the late 1800s to 0.5 cfs in 1974. By 1976, Manse Spring was dry.

A rigorous evaluation of the extensive water level and spring discharge data that have been collected for the Pahrump Valley is beyond the scope of this supply and demand study. The amount of change in the water level in any given well can vary depending upon the types of sediments present, the degree of confinement of the aquifer, the depth of the well, variations in pumping in nearby wells, recharge, and other factors. In general, it appears that the dramatic drawdown that occurred during the large scale agricultural water withdrawals of the 1960s and 1970s has stopped and partial water level recovery has occurred in some parts of the basin while water levels have stabilized in other parts. Further evaluation of the water level records could help determine optimal pumping rates for some well fields and the quantity of leakage from the carbonate aquifer into the alluvial aquifer.



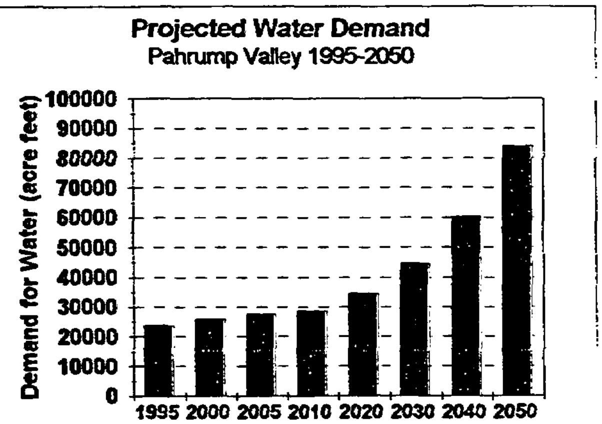

**Water level graphs for two wells in Pahrump Valley show very different rates of water level decline. The drop in water levels will vary depending on where a well is located and what type of aquifer is present.**

## PROJECTED FUTURE WATER DEMAND - PAHRUMP VALLEY

**Per capita water use (gallons/day):** 486

**(1995 DWR Inventory for QM + dom + Calvada divided by 1995 census projection)**

| | YEAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
| Projected Population | 15170 | 22100 | 27740 | 32190 | 46997 | 68616 | 100180 | 146262 |
| | PROJECTED DRINKING WATER USE | | | | | | | |
| Water Use (gallons per day) | 7372620 | 10740600 | 13481640 | 15644340 | 22840542 | 33347376 | 48687480 | 71083332 |
| Water Use (gallons per minute) | 5120 | 7459 | 9362 | 10864 | 15861 | 23158 | 33811 | 49363 |
| Water Use (million gallons/year) | 2691 | 3920 | 4921 | 5710 | 8337 | 12172 | 17771 | 25945 |
| Water Use (acre feet/year) | 8258 | 12030 | 15100 | 17523 | 25583 | 37351 | 54533 | 79618 |
| IRRIGATION WATER (acre feet) | 15363 | 13827 | 12444 | 11200 | 8960 | 7168 | 5734 | 4587 |
| TOTAL (acre feet) | 23621 | 25857 | 27544 | 28722 | 34543 | 44519 | 60268 | 84206 |




ASSUMPTIONS:

1. Per capita use does not include Champion golf course.
2. Agricultural water use decreases 20% per decade.
3. Groundwater availability does not limit growth.
4. Domestic water use = 1 acre foot/year.
5. Municipal & domestic use goes up 4% per year after 2010.
6. Per capita water use remains constant.

### Future Water Demand

Between 1990 and 1995 the population of Pahrump doubled and the demand for water for quasi-municipal and domestic use almost doubled, from 4,300 acre feet in 1990 to 8,260 acre feet in 1995. The most recent population projections do not predict that this level of growth will continue but do predict a long-term growth rate of about four percent per year. At this rate, the population will double every 18 years and a corresponding increase in the demand for water is expected.

The per capita water use in Pahrump can be estimated on the basis of meter data for Central Nevada Utilities and estimates of the water used by other water supply systems and domestic wells. According to the 1995 pumpage inventory, the utility provided water for 30 acres of tree farms, 12 acres of park, a 50 acre executive golf course, 1,067 residences, 131 commercial customers, 6 schools, and 13 irrigation customers. The total volume of water pumped, including transmission losses, was 2,724 acre feet. The total volume pumped for other quasi-municipal systems and domestic wells was estimated at 5,534 acre feet. Based upon these pumping volumes and the census data, the per capita water demand is calculated to have been 486 gallons per day in 1995. This value is somewhat higher than the 390 gallons per day per capita water use reported in recent years for Las Vegas. The higher demand rate in Pahrump reflects in part the disproportionate area of golf courses, tree farms, and parks on the Calvada property relative to the number of residents served by the utility.

If the current per capita water demand is not reduced and the population continues to grow as projected, the water forecast for Pahrump is bleak. By the year 2011, the demand for water for municipal, quasi-municipal, and domestic purposes will begin to exceed the perennial yield of the basin. If it is

assumed that irrigation water use declines by 10 percent over the same period, then the groundwater withdrawals from the basin in 2005 will total about 27,500 acre feet. While this volume is 4,000 acre feet greater than the 1995 total and 50 percent greater than the perennial yield, it is still well below the peak withdrawal years of the 1960s and 1970s.

By the middle of the next century, the demand for municipal water under this scenario will grow to almost 80,000 acre feet, more than four times the perennial yield. Any groundwater pumped for irrigation of crops will simply add to this overdraft. If agricultural water use continues to decrease by 20 percent each decade, then by 2050 the total demand for water for irrigation and municipal use is estimated at about 84,000 acre feet. This value represents a probable worst case planning scenario.

Any reduction in the per capita water use rate would, of course, have a corresponding effect on the annual demand for groundwater in the basin. Through conservation measures, changes in residential density, education, and pricing, the per capita demand for water can be reduced. However, even rigorous conservation methods would not eliminate overdraft of the basin; they would only delay the overdraft. For example, at a per capita water demand of 250 gallons per day, the demand for municipal supplies would not exceed 19,000 acre feet per year (the perennial yield) until the year 2030. By the year 2050, this demand would grow to 41,000 acre feet or almost the amount of water withdrawn during the peak agricultural periods of the past. It should be noted that achieving a per capita demand of 250 gallons per day would be difficult and this scenario represents a best case situation.

The well-documented history of past water level declines in the basin clearly indicates that groundwater withdrawals in excess of 30,000 acre feet per year will likely cause water levels across the basin to begin to decline again. In their 1976 study, the U.S. Geological Survey used a numerical model to simulate 65 years of pumping at 40,000 acre feet per year. This model predicted water level declines of 50 feet over that period of time. It should be noted however, that this model also indicated that the recharge rate of the basin ranges from 26,000 to 37,000 acre feet per year, appreciably more than the estimated perennial yield that is used for water planning purposes.

A gradual decrease in pumping rates, subsidence, and water quality degradation can all result from the overdraft of a groundwater basin. The U.S. Geological Survey found that the long-term overdraft of the basin could result in two feet or more of subsidence over an area of about 7 square miles and lesser amounts of subsidence over a much larger area of the valley. Subsidence of this nature, although seldom catastrophic, can nonetheless be costly as it can destroy building foundations, shear well casings, and damage roadways.

It may be possible to reduce the potential for subsidence by carefully managing the groundwater withdrawals in the area. If withdrawals from areas of fine-grained sediments are reduced in favor of increased withdrawals from more stable areas, the effects may be reduced. However, the presence of 22 separate public water supply systems and the many individual domestic wells makes the implementation of such an approach impractical at best. In the last two years alone, more than 1,300 domestic wells have been drilled in Pahrump Valley. Drilling of domestic wells at this rate only increases the water supply problems facing the community in the near future.

**Potential Future Water Supply Alternatives**

Given the projected future population of Pahrump and the associated water demand, the alternatives for meeting this demand are limited. The alternatives that have been identified are as follows:

1. Managed overdraft of the basin;

2. Development of the carbonate aquifer that underlies the basin;

3. Importation of water from other basins;

4. Administrative actions; and

4. A combination of the any of these alternatives.

Managed Overdraft

If additional water supplies cannot be obtained, then Pahrump will have to rely solely on the water resources of Pahrump Valley. Given that existing water use already exceeds the perennial yield and large-scale development is continuing, overdraft of

the basin is expected to increase with time. Based upon the census and water demand projections discussed earlier, groundwater withdrawals will exceed 30,000 acre feet per year by about 2010. At that time, problems with declining well yields, subsidence, and water quality are likely to begin. Under the best case scenario, this level of overdraft is not expected to begin until about 2040.

To mitigate these problems, the distribution of supply wells in the basin will need to be optimized. Pumpage from areas prone to subsidence could be reduced in favor of wells located higher on the alluvial fan of the Spring Mountains. Recharge wells could be used during off peak months to stabilize water levels in some areas. Decreased water quality could be mitigated either through treatment or through the mixing of water from various sources to meet chemical standards.

One of the problems that hampers effective management of the groundwater resources of Pahrump is the lack of a community-wide water utility. None of the public water supply systems have the resources to solve the future supply problems of the community; each system is concerned only with meeting its own more limited demands. Likewise, domestic well owners have little incentive for working toward a long-term solution until their wells actually go dry. Another problem that hampers water resource management is the public perception that the water resources of the basin are unlimited. Some landowners or their agents that are anxious to sell land have a tendency to overstate the resources that are available. The public needs to be educated that the water supplies are not unlimited and that a serious water supply problem cannot be avoided without the cooperation of all water users in the community.

Development of the Carbonate Aquifer

The carbonate aquifer that underlies Pahrump Valley has the potential for supplementing the water resources available to the community. Very little is known about this aquifer in southern Nye County, but it has been proven to be very productive in areas of northern Clark County. There are favorable carbonate rocks and geologic structures in the vicinity of Pahrump. These features suggest that productive water supply wells might be drilled into this water source. The U.S. Geological Survey, in their 1976 study of the basin, concluded that groundwater withdrawals from the alluvial aquifer would not intercept an appreciable amount of the groundwater that currently discharges out of the basin into California. In fact, their modelling results indicate that pumping in 1976 captured only 200 acre feet of the 18,000 acre feet that discharge out of the basin each year. It may be possible to intercept a much greater quantity of this discharge by carefully managed groundwater withdrawals from the carbonate aquifer.

To develop the carbonate aquifer, water rights would have to be obtained and exploration and testing would need to be done to determine the yield potential of the aquifer and the best locations for supply wells. The locations of wells should be selected to maximize the capture of discharge out of the basin and well yields while minimizing overall production costs. Several production water wells, one or more storage tanks, and miles of pipeline would then have to be constructed to convey the water to the developed areas of Pahrump.

Any water withdrawals from the carbonate aquifer would have to be managed to maximize well efficiency while minimizing any adverse impacts. Monitoring of water production rates and water levels in the aquifer would probably be required as a condition of the water right permits that are issued for this source.

The actual quantity of groundwater that discharges out of Pahrump Valley via the carbonate aquifer is not known and it may be appreciably more than the 18,000 acre feet estimated by previous studies. The quantity is not unlimited, however, and even under the most optimistic scenarios, the combined yield from this aquifer and the alluvial aquifer cannot be expected to meet the long-term demand of the community.

Water Importation

The water supplies of Pahrump Valley could be supplemented with water from other basins in the region. The alternatives are rather limited, however, for this option. It can be safely assumed that no additional water can be obtained from the east from either Las Vegas Valley or Mesquite (Sandy) Valley. To the north, the future availability of water will be determined by water use on the Nevada Test Site. Currently unused water in Mercury Valley and Rock Valley could be developed and conveyed to

Pahrump. The same steps and restrictions that were noted for the development of the carbonate aquifer in Pahrump Valley would also apply to the development of the alluvial or rock aquifers in these two basins.

Unused water in Amargosa Valley could also be developed and conveyed to Pahrump. As noted in the section on Amargosa Valley, actual water use in the basin is less than the perennial yield. If water rights can be obtained in this basin, then supplemental water supplies could be developed using the same approach and subject to the same restrictions as outlined above.

Any attempts to obtain new water rights in any of these three basins are likely to be vigorously protested by the National Park Service. The acquisition of existing water rights through direct purchase of agricultural water rights in Amargosa Valley and the change of the water rights may not be protested by the Park Service as no increase in the overall water withdrawals from the basin would occur if this approach were used.

There are no water rights available for purchase in Mercury Valley or Rock Valley. The perennial yield of Rock Valley is 8,000 acre feet and no water is currently appropriated or used in that basin. Only one water right is active in Mercury Valley, a small spring diversion for recreation purposes, but the Department of Energy has reserved rights for water pumped from Army Well 1 at the southern boundary of the Nevada Test Site. The perennial yield of this basin is also 8,000 acre feet per year. The peak historic pumping from this basin was 428 acre feet in 1992 indicating that there may be as much as 7,500 acre feet available in this basin. While there is unused groundwater in these two basins, the basins are situated hydraulically upgradient of the environmentally sensitive areas of Ash Meadows and Devil's Hole. The U.S. Fish and Wildlife Service can also be expected to protest any applications to develop water supplies from these areas.

If additional water supplies cannot be obtained from Amargosa Valley, it may be possible to develop water in other basins in the northern part of the county and convey that water to Pahrump. Such an approach would be very costly and could take decades to implement. However, if water supplies cannot be developed from adjacent basins, then importation of water from more distant basins may be the only way that growth in Pahrump can be sustained.

Administrative Actions

A number of administrative steps can be taken to decrease the demand for water in Pahrump. The development and implementation of a conservation program with penalties for water wasters has been successful elsewhere in Nevada. Regulations can be adopted concerning landscaping, water features, and plumbing fixtures that provide incentives for sound water use and penalties for extravagant use.

Zoning that increases the residential density can decrease the overall demand for water. As a last resort, a moratorium on new development can be imposed; however, such measures are seldom popular and may result in severe political ramifications. An increase in water rates can be a very effective way of reducing water consumption but is again a very unpopular measure.

A key area where administrative controls may be of benefit is with respect to domestic wells. The continued drilling of hundreds of new wells each year is only going to exacerbate the overall water supply problem. Regulations may be required to insure that new wells are properly designed and constructed, water use may have to be more closely inventoried, and restrictions on water use may have to be mandated. Enabling legislation may be required to give the County authority to issue and enforce such regulations.

Combined Alternatives

In all likelihood, the continued growth of the Pahrump area will require that each of the alternatives be evaluated and implemented as appropriate. County planners should keep all options open for as long as possible until new supplies of water have been secured and the obstacles to basin-wide water management resolved.

Each alternative has its own potential and pitfalls and different requirements in terms of cost and time to implement. For the short term a combination of conservation, public education, regulation, and managed overdraft are probably most appropriate. During this period, the development potential of the carbonate aquifer can be assessed and the potential for water importation further evaluated.

## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

Based upon the evaluation of the baseline information developed as part of this evaluation, a number of conclusions have been reached concerning water demand and supply in southern Nye County:

1. The community of Beatty has the most urgent water supply problems at this time because of falling well yields and water quality limitations. The existing pumping capacity is not adequate to meet the projected peak demands between 1997 and 2000, and one or more new wells will be needed. A source of better quality water will have to be identified and developed as soon as possible to avoid prohibitively expensive treatment options.

2. Future demands for water in the Beatty area are expected to increase at a moderate rate of 2.5% per year. At this rate, the demand for water is projected to increase from the 1995 consumption of about 400 acre feet per year to about 750 acre feet per year by 2050.

3. Although the water resources of Amargosa Valley are over appropriated, the actual volume of water being withdrawn from the basin is still well below the perennial yield. The supply of water in the community and the quality of that water are adequate for meeting the projected future demands for both public drinking water and irrigation.

4. Future water use in Amargosa Valley is expected to peak in 2000 and then decline through 2005 as a result of the anticipated shutdown of the Bullfrog mine. Demand for drinking water supplies is then projected to increase at a moderate growth rate of 2.5% per year. At this rate, the total projected demand in 2050 for drinking water supplies, irrigation, and mining is projected to be about 16,450 acre feet per year, still well below the perennial yield of the basin.

5. Because of the recent boom in the population of Pahrump and the projected continued growth rate of four percent per year, the development of adequate water supplies to meet the future demand of this community poses the greatest challenge to Nye County water planners.

6. Unless stringent water conservation measures are taken, overdraft of the groundwater reservoir in Pahrump is expected to accelerate over the coming decades. Even with such measures, the demand for municipal and domestic water supplies is projected to be double the perennial yield by the year 2050. Projected water demand by the year 2050 is projected to be at least 41,000 acre feet per year and could be as high as 80,000 acre feet per year or more.

7. If appropriate actions are not taken, overdraft of the Pahrump groundwater basin will likely result in accelerated water table declines, land subsidence, and water quality deterioration problems beginning when total pumping exceeds 30,000 acre feet per year, projected to occur in about 2011 under the worst case scenario and about 2040 under the best case scenario. The adverse impacts of this overdraft can be somewhat mitigated through the management of groundwater pumping on a basin wide development.

8. Water planning and the implementation of conservation techniques in Pahrump are hampered by the lack of a single, community wide water supply system. The uncontrolled drilling of hundreds of new domestic wells each year and public perception that the water resources of the valley are unlimited also hamper effective water resources management and planning.

9. The carbonate aquifer that underlies the Pahrump basin has the potential to supply 18,000 acre feet or more of supplemental water for the community. The development of this source does not, however, offer a permanent solution to the water supply problems that the community is faced with. Development of the carbonate aquifer would require a well-planned program of exploration, testing, and design to insure that development of this source does not compound the overdraft problems in the basin.

10. Projected long-term water demands will probably have to be met in part with water imported to Pahrump Valley from other basins in Nye County. The only reasonable alternative may be to restrict future growth to a level compatible with existing water supplies in the basin.

## Recommendations

Based upon the findings and observations made as part of this baseline evaluation, the following recommendations are made:

1. The County should continue to take a proactive approach in the planning and management of the limited water resources of southern Nye County.

2. The County should actively solicit the cooperation and support of the Nevada State Engineer's Office, the National Park Service, Fish and Wildlife Service, Air Force, Department of Energy, and Bureau of Land Management and representatives from the mining industry, farm organizations, environmental organizations, and land developers in formulating strategies and plans to meet the long-term water demands of the communities of Beatty and Pahrump, while addressing the concerns of the public and the federal agencies that control much of the land and water resources of the county.

3. The County should actively encourage and support the development and implementation of conservation efforts by the public water systems and other water users in Beatty, Amargosa Valley, and Pahrump and assist in increasing public awareness of the water supply problems and issues.

4. The County should consider developing and implementing regulations placing more controls on the drilling of domestic water wells in Pahrump Valley. The County may wish to adopt provisions similar to those taken in Douglas and Washoe Counties to insure that water is available for subdivisions prior to their approval.

5. The County should consider conducting a focused study of the carbonate aquifer system underlying Pahrump Valley as a supplemental water source for the community. This study should identify the potential of the aquifer and identify a phased strategy for developing this source.

6. The County should consider conducting a baseline water supply and demand evaluation of the northern part of Nye County to define water supply issues in that area so that the water resources can be evaluated and managed on a county-wide basis.

7. The County should conduct an evaluation of the feasibility of developing water supplies in "water rich" basins in the the northern part of the county for conveyance to communities with water supply shortfalls throughout the county.

8. The County should further evaluate the current overdraft conditions in Pahrump Valley by assessing historic and current water level trends in the basin, recharge to the basin, and discharge out of the county into California.

9. The County should update the water supply demand projections at least every 10 years and re-evaluate the water supply alternatives as new census and water use data become available.

*About the Author: Tom Buqo is a consulting hydrogeologist in Blue Diamond, Nevada. Since graduating from the University of Arizona in 1976, he has investigated the water resources of Nevada and the desert southwest. He has evaluated the water supplies of more than 50 basins in Nevada and Utah and has worked in Nye and Esmeralda Counties since 1978.*

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# YUCCA MOUNTAIN

# GROUND MOTION DATA PACKAGE

## VOL. 1

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# YUCCA MOUNTAIN

# GROUND MOTION DATA PACKAGE

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*electronic file

*electronic file

*electronic file

# Section 1:

# Introduction

**Woodward-Clyde** **Memorandum**

To: Ground Motion Experts

From: Norm Abrahamson
Ann Becker

Office: SLC

Date: February 25, 1997

Subject: Point Estimate Points

To avoid confusion, the following summarizes the data and due dates for your point estimates for the Yucca Mountain ground motion project. The Magnitude-Distance pairs for each submittal are summarized on the attached tables. At the interim meeting there was discussion of eliminating 1 Hz considering that 0.33 Hz had been included (May 2 deliverable). Although the 1 Hz values are still required at this time, their elimination is being negotiated.

| Date | Components | Frequencies | M-D Pairs |
|---|---|---|---|
| March 7 | Horiz | 0.5, 20 Hz | 16 Sets |
| March 14 | Horiz, Vert | 0.5, 5, 20 Hz<br>pgv | 16 Sets |
| May 2 | Horiz, Vert | 0.33, 0.5, 1, 2, 5, 10, 20 Hz<br>pga, pgv | 28 Sets |

The elicitations will be on the information provided in the March 14 submittal. The elicitation schedule is: Anderson: Wed 3/19, 8 am - 12 noon
Boore: Thurs 3/20, 8 am - 12 noon
Campbell: Tues 3/18, 8 am - 12 noon
McGarr: Wed 3/19, 1 pm - 5 pm
Silva: Mon 3/17, 10 am - mid/late afternoon
Somerville: Thurs 3/20, 1 pm - 5 pm
Walck: Tues 3/18, 1 pm - 5 pm

A Campbell code to compute scale factors using his hybrid empirical model is available through ftp at: users.aol.com (anonymous user login), then cd to eqecolo, then cd to campbell. Ftp kwcy.exe, run it, and it unpacks into several files including a fortran code.

| Data still pending are: | Probable delivery date |
|---|---|
| Silva finite fault runs (300 m velocity) | 3/3 |
| Anderson finite fault runs (300 m velocity) | 3/3 |
| Brune precarious rock constraints | 3/3 |
| Silva point source vertical | 2/27 |
| Revised data package (the 'Interim Meeting package'; revised as of 2/26) | 2/27 |

# 16 M-D Pairs, Due March 7

| Distance[1] | Deep Focus[2] | | Shallow Focus[2] | | | | | |
|---|---|---|---|---|---|---|---|---|
| (km) | M5.0 | 5.8 | 5.0 | 5.8 | 6.5 | 7.0 | 7.5 | 8.0 |
| 1 | | | SS, HW | | SS, HW, FW | | | |
| 3 | | | | | | | | |
| 5 | SS, HW | | | | HW, FW | | | |
| 10 | | SS | | | | SS | | |
| 20 | | HW | | | | | | |
| 50 | | | | | SS, HW | | SS, HW | |
| 100 | | | | | | | | |
| 160 | | | | | | | | |

[1] Horizontal distance from surface expression of fault (up-dip extension).

[2] See handout from interim meeting for definition of Shallow and Deep foci. Shallow focus is centered at 5 km depth (and cannot extend into air). Bottom of deep focus rupture is at 14 km depth. Rupture width from Wells and Coppersmith (1994), 'all mechanisms'.

**Deliverables are**

- **values of $\mu$, $\sigma$, $\sigma_{\mu}$, $\sigma_{\sigma}$**
- **horizontal component only**
- **strike slip faulting ('SS') and/or normal faulting (hanging wall denoted 'HW', foot wall denoted 'FW'), as shown**
- **0.5 and 20 Hz**

# 16 M-D Pairs, Due March 14

| Distance[1] | Deep Focus[2] | | Shallow Focus[2] | | | | | |
|---|---|---|---|---|---|---|---|---|
| (km) | M5.0 | 5.8 | 5.0 | 5.8 | 6.5 | 7.0 | 7.5 | 8.0 |
| 1 | | | SS, HW | | SS, HW, FW | | | |
| 3 | | | | | | | | |
| 5 | SS, HW | | | | HW, FW | | | |
| 10 | | SS | | | | SS | | |
| 20 | | HW | | | | | | |
| 50 | | | | | SS, HW | | SS, HW | |
| 100 | | | | | | | | |
| 160 | | | | | | | | |

[1] Horizontal distance from surface expression of fault (up-dip extension).

[2] See handout from interim meeting for definition of Shallow and Deep foci. Shallow focus is centered at 5 km depth (and cannot extend into air). Bottom of deep focus rupture is at 14 km depth. Rupture width from Wells and Coppersmith (1994), 'all mechanisms'.

**Deliverables are**

- **values of $\mu$, $\sigma$, $\sigma_{\mu}$, $\sigma_{\sigma}$**
- **horizontal and vertical components**
- **strike slip faulting ('SS') and/or normal faulting (hanging wall denoted 'HW', foot wall denoted 'FW'), as shown**
- **0.5, 5, 20 Hz, pgv**

# 28 M-D Pairs, Due May 2

| Distance[1] | Deep Focus[2] | | Shallow Focus[2] | | | | | |
|---|---|---|---|---|---|---|---|---|
| (km) | M5.0 | 5.8 | 5.0 | 5.8 | 6.5 | 7.0 | 7.5 | 8.0 |
| 1 | SS | | SS, HW | SS | SS, HW, FW | SS | SS | |
| 3 | | | | | | | | |
| 5 | SS, HW | HW,FW | | HW, FW | SS, HW, FW | | | |
| 10 | | SS | SS, HW | SS, HW, FW | SS, HW, FW | SS, HW, FW | SS, HW | |
| 20 | | HW | | | SS, HW, FW | | | |
| 50 | | | SS, HW | S, HW | SS, HW | SS, HW | SS, HW | SS |
| 100 | | | | | SS | | | |
| 160 | | | SS | | SS | | | SS |

[1] Horizontal distance from surface expression of fault (up-dip extension).

[2] See handout from interim meeting for definition of Shallow and Deep foci. Shallow focus is centered at 5 km depth (and cannot extend into air). Bottom of deep focus rupture is at 14 km depth. Rupture width from Wells and Coppersmith (1994), 'all mechanisms'.

**Deliverables are**

- values of $\mu$, $\sigma$, $\sigma_{\mu}$, $\sigma_{\sigma}$
- horizontal and vertical components
- strike slip faulting ('SS') and/or normal faulting (hanging wall denoted 'HW', foot wall denoted 'FW'), as shown
- 0.33, 0.5, 1, 2, 5, 10, 20 Hz, pga, pgv

## 1.2 Geometries for 16 Preliminary Cases

<u>Subset for Preliminary Analysis</u>
<u>(16 cases)</u>

| Case | M | depth | x* | SS | $R_{rup}$ | $R_{JB}$ | $R_{seis}$ |
|---|---|---|---|---|---|---|---|
| 1 | 5.0 | shallow** | 1 | SS | 3.2 | 1.0 | 3.2 |
| 2 | 5.0 | shallow | 1 | HW | 3.4 | .9 | 3.4 |
| 3 | 5.0 | deep*** | 5 | SS | 11.3 | 5.0 | 11.3 |
| 4 | 5.0 | deep | 5 | HW | 10.7 | 1.1 | 10.7 |
| 5 | 5.8 | deep | 10 | SS | 12.2 | 10.0 | 12.2 |
| 6 | 5.8 | deep | 20 | HW | 17.3 | 11.9 | 17.3 |
| 7 | 6.5 | shallow | 1 | SS | 1.0 | 1.0 | 3.2 |
| 8 | 6.5 | shallow | 1 | HW | .9 | 0.0 | 3.1 |
| 9 | 6.5 | shallow | -1 | FW | 1.0 | 1.0 | 4.1 |
| 10 | 6.5 | shallow | 5 | HW | 4.3 | 0.0 | 4.4 |
| 11 | 6.5 | shallow | -5 | FW | 5.0 | 5.0 | 7.4 |
| 12 | 6.5 | shallow | 50 | SS | 50.0 | 50.0 | 50.1 |
| 13 | 6.5 | shallow | 50 | HW | 44.1 | 45.3 | 45.3 |
| 14 | 7.0 | shallow | 10 | SS | 10.0 | 10.0 | 10.4 |
| 15 | 7.5 | shallow | 50 | SS | 50.0 | 50.0 | 50.1 |
| 16 | 7.5 | shallow | 50 | HW | 44.2 | 41.9 | 44.2 |

*x = horizontal distance (km) from surface trace of "fault"

** centered at a depth of 5 km

*** bottom edge of rupture at 14 km depth

## 1.3 Site Velocity Profile

The site velocity profile is the profile used in the scenario earthquake study, with the top 300m removed. This is the "repository outcrop" velocity profile. The ground motion estimated for this profile will be referred to as "$YM_{300}$".

The kappa used for this site is based on removing the kappa from the top 300m. Using a reference kappa of 0.02 sec with the low strain damping estimated by Stoke, the kappa in the top 300 m is 0.0014 sec. The resulting kappa for this model is then 0.0186 sec.

Site Velocity Profile

| Layer # | Depth to top (km) | Thickness (km) | $V_S$ (km/s) | $V_P$ (km/s) | Density (g/cm$^3$) | $Q_S$ | $Q_P$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | .70 | 1.9 | 3.2 | 2.4 | 70 | 150 |
| 2 | .70 | .60 | 2.1 | 3.6 | 2.4 | 100 | 200 |
| 3 | 1.3 | 1.50 | 2.9 | 5.0 | 2.5 | 150 | 300 |
| 4 | 2.8 | 2.20 | 3.4 | 5.8 | 2.7 | 400 | 800 |
| 5 | 5.0 | 10.70 | 3.5 | 6.2 | 2.75 | 400 | 800 |
| 6 | 15.7 | 16.00 | 3.8 | 6.5 | 2.9 | 400 | 800 |
| 7 | 31.7 | — | 4.6 | 7.8 | 3.3 | 400 | 800 |

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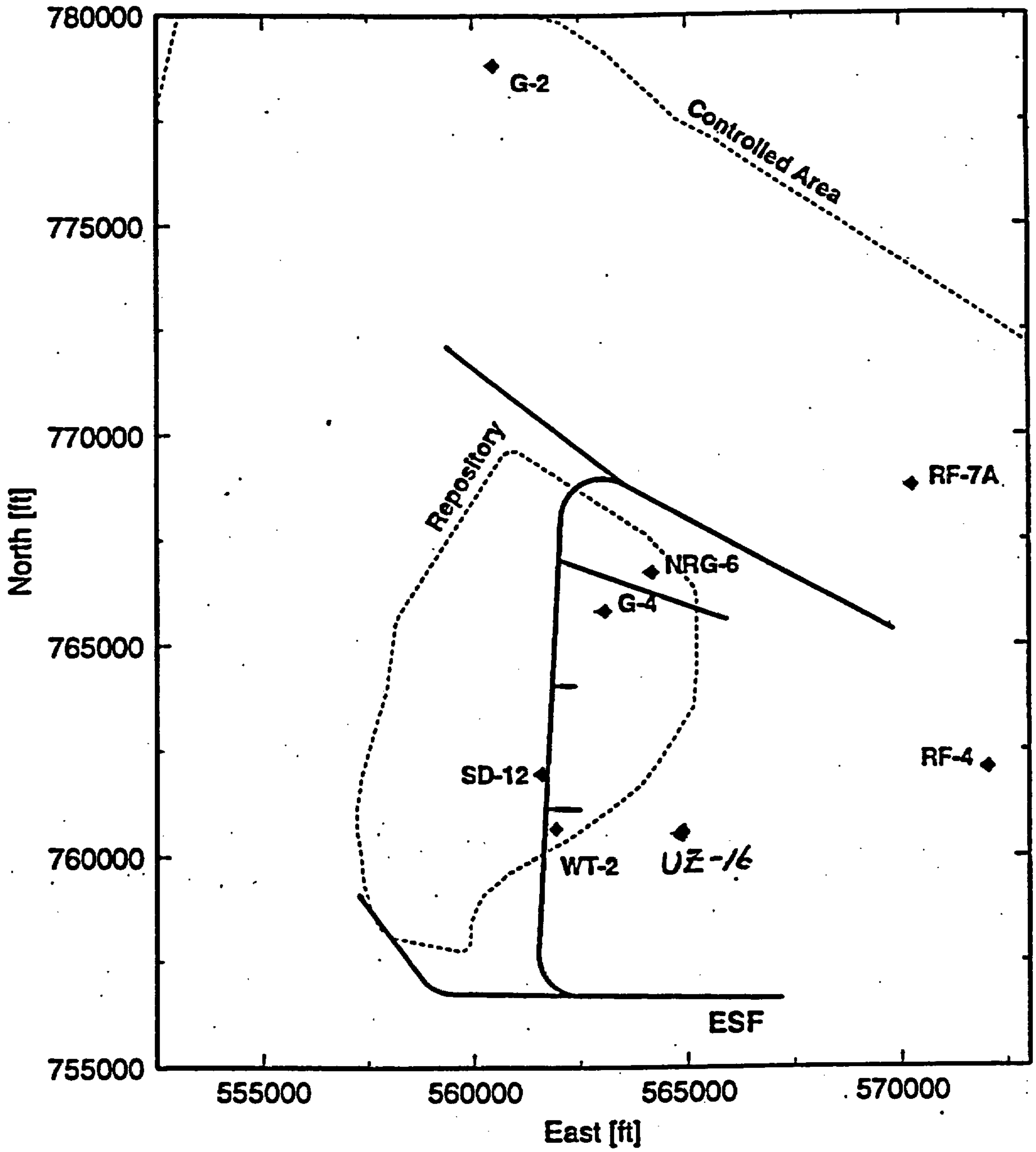
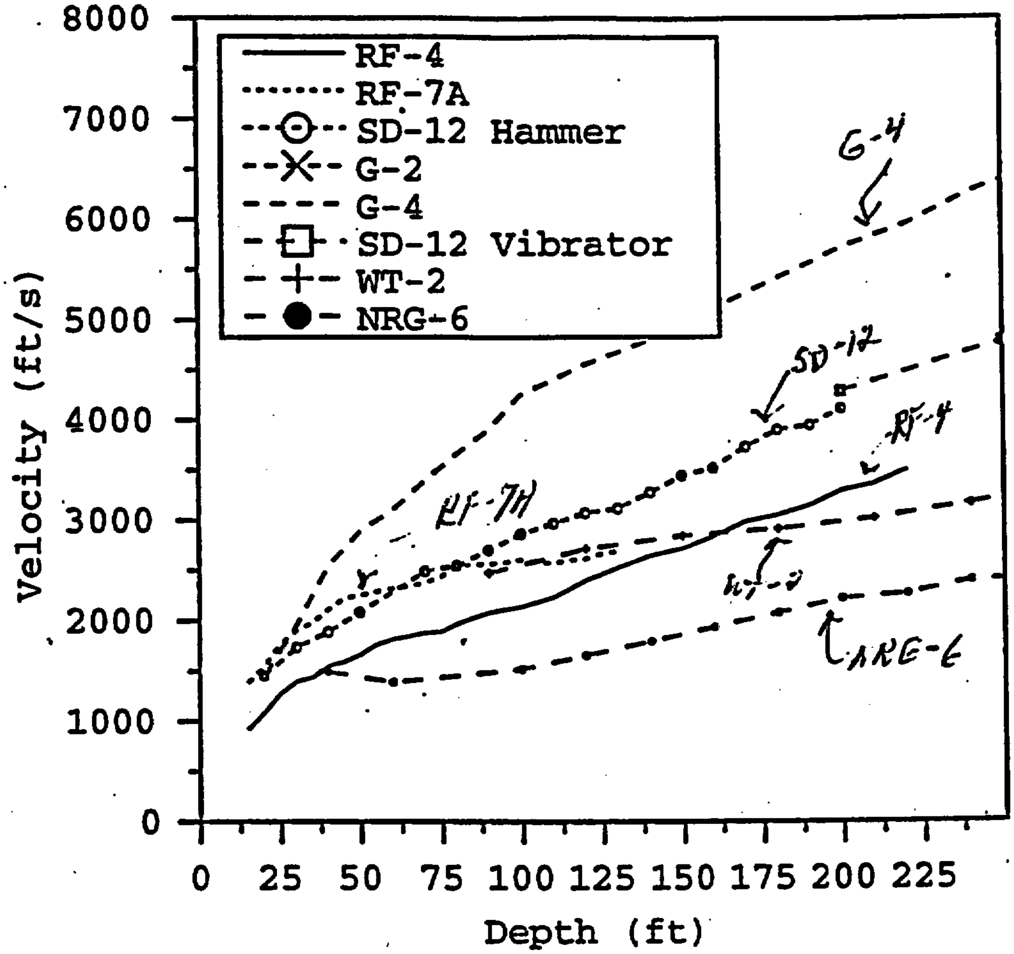



Figure V1. Location of new VSP surveys in wells: RF-4, RF-7A, SD-12, G-2, and G-4. Previous wells with VSP are WT-2 and NRG-6. Coordinates are Nevada State Plane.

## YMP - LBNL
## S-Wave Seismic Velocity
## Average Velocity from VSP




gure V48. Shallow (0 -200 ft.) average S-wave velocity for all wells surveyed by LBNL. Note that the same geologic formations are not at the same depths in each well.

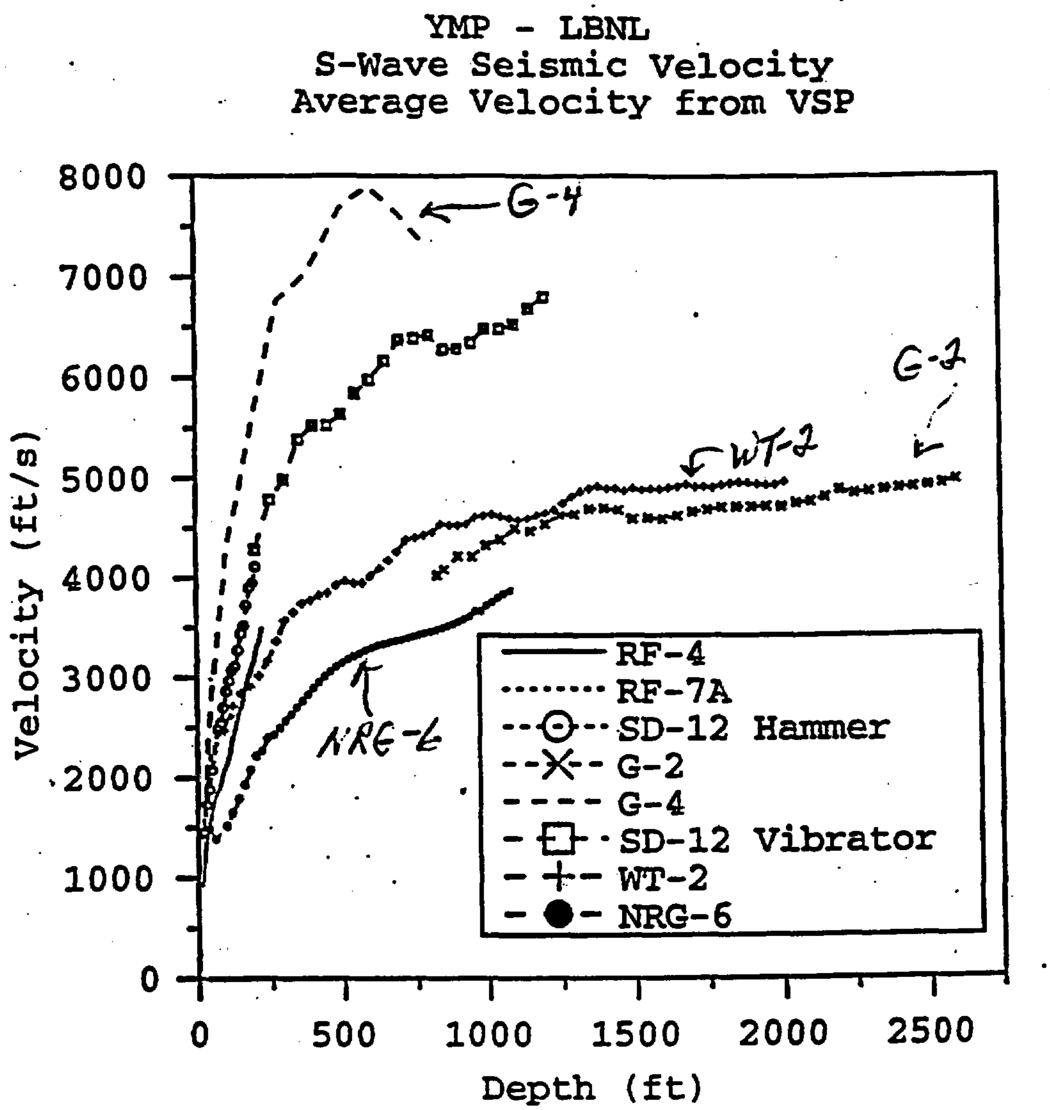



Figure V51. Deep (0-2750 ft.) average S-wave velocity for all wells surveyed by LBNL. Note that the same geologic formations are not at the same depths in each well.

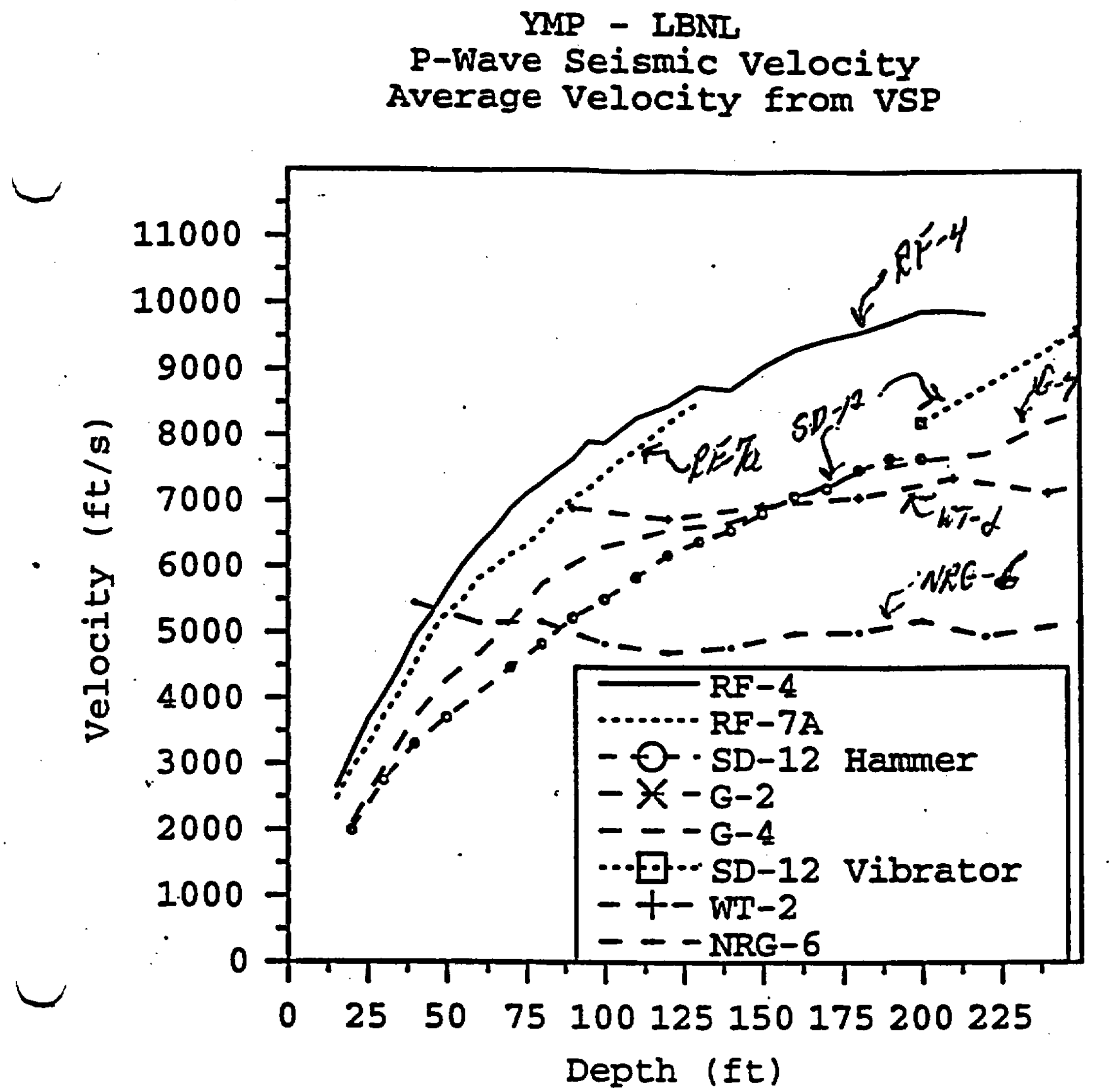



Figure V47. Shallow (0 -200 ft.) average P-wave velocity for all wells surveyed by LBNL. Note that the same geologic formations are not at the same depths in each well.

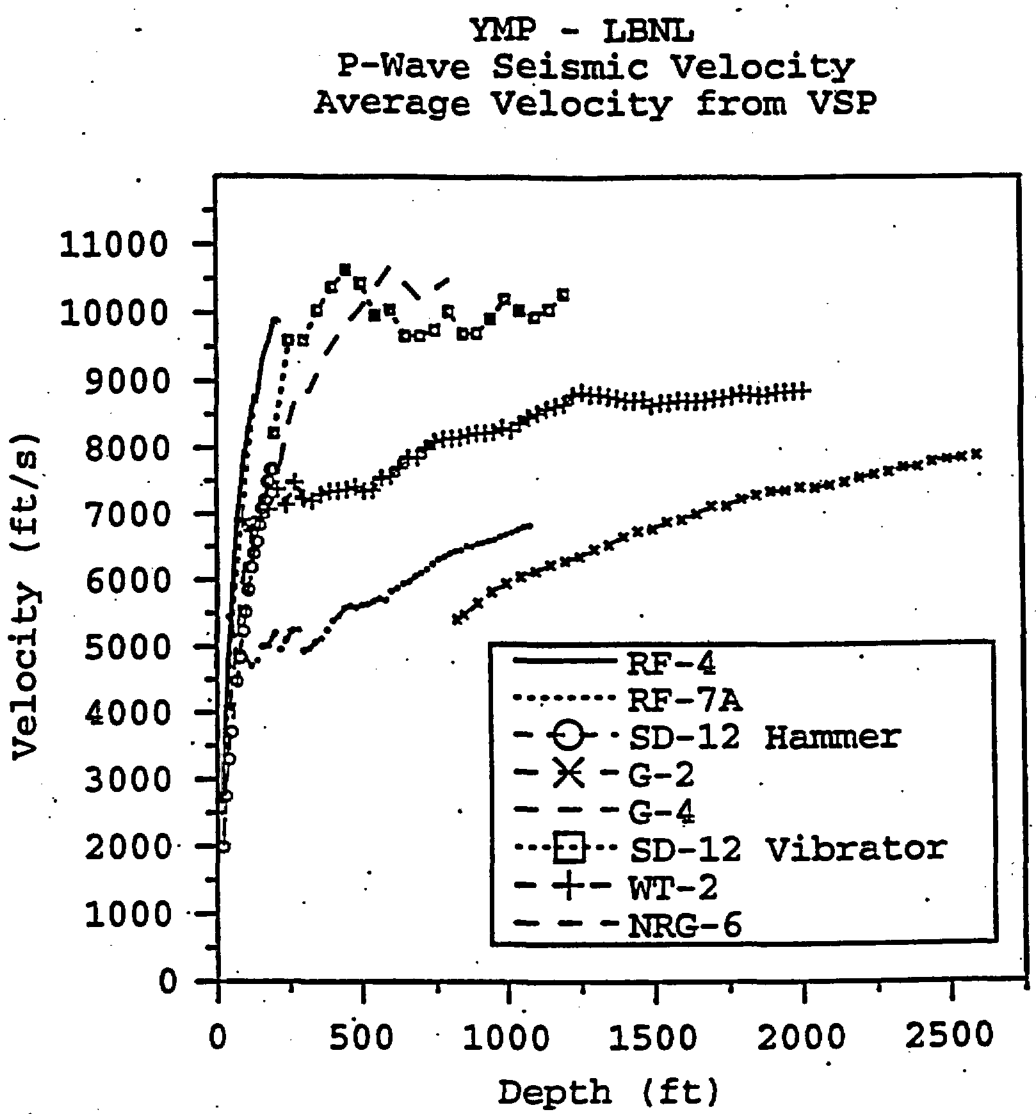



Figure V50. Deep (0-2750 ft.) average P-wave velocity for all wells surveyed by LBNL. Note that the same geologic formations are not at the same depths in each well.

# Section 2:

# Ground Motion Models - General Information

1. Empirical Models: These models and frequencies are provided in program yucatten

| Modeler | Components Available[1] | PGV Available? | Frequencies Available[2] | Spudich Adjustment Available? |
|---|---|---|---|---|
| Abrahamson & Silva '97 (rock) | H, Z | No | 0.33, 0.5, 1., 2., 5., 10., 20., pga | No |
| Boore, Joyner, Fumal '97 ($V_s$) | H | No | 0.5, 1., 2., 5., 10., pga | Yes |
| Boore, Joyner, Fumal '94 (class A) | H | No | 0.5, 1., 2., 5., 10., pga | No |
| Boore, Joyner, Fumal '94 (class B) | H | No | 0.5, 1., 2., 5., 10., pga | No |
| Campbell '97 (soft rock) | H, Z | Yes | 0.33, 0.5, 1., 2., 5., 10., 20., pga | No |
| Campbell '97 (hard rock) | H, Z | Yes | 0.33, 0.5, 1., 2., 5., 10., 20., pga | No |
| Campbell '93-'94[3] (hard rock) | H | No | 0.5, 1., 2., 5., 10., 20., pga | Yes |
| Campbell '90-'94[3] (soft rock) | H, Z[4] | No | 0.5, 1., 2., 5., 10., 20., pga | Yes |
| Campbell '90[3] (soil/soft rock) | H, Z | No | 0.5, 1., 2., 5., 10., 20., pga | Yes |
| Idriss '93[5] (rock/stiff soil) | H | No | 0.33, 0.5, 1., 2., 5., 10., 20., pga | Yes |
| Idriss '97 | H | No | pga | No |
| Joyner-Boore '88 (rock) | H | Yes | None (used for pgv only) | Yes |
| Sadigh et al. '97 (rock) | H, Z | No | 0.33, 0.5, 1., 2., 5., 10., 20., pga | Yes |
| Sabetta and Pugliese '96 (rock) | H, Z | Yes | 0.33, 0.5, 1., 2., 5., 10., pga | Yes |
| Spudich et al. '96 (rock) | H | No | 0.5, 1., 2., 5., 10., pga | N/A |
| McGarr 84 (rock) (see page 4.1.4-1) | H | Yes | PGV only | No |

Notes for Table 1.

[1] H indicates available for horizontal component, Z indicates available for vertical component

[2] Required frequencies are 0.33, 0.5, 1, 2, 5, 10 and 20 Hz

[3] Older Campbell models included because Spudich et al. provided correction factors

[4] Vertical motions provided in Campbell (1990), rock conditions, with no discrimination between hard or soft rock

[5] Idriss '93 is identical to Idriss '91

## 2. Numerical Models

| Modeler | Components Available[1] | PGV Available? | Frequencies Available[2] | Cases Run |
|---|---|---|---|---|
| Anderson | H, Z | Yes | 0.3[3], 0.5, 1, 2, 5, 10, 20, pga | 16 (Preliminary Cases 1-16) |
| Silva Finite Fault | H | Yes | 0.3[3], 0.5, 1, 2, 5, 10, 20, pga | 41 (All Final Cases with M≥5.8) |
| Silva Point Source | H, Z | Yes | 0.33, 0.5, 1, 2, 5, 10, 20, pga | 16 (Preliminary Cases 1-16) |
| Somerville | H, Z | Yes | 0.5, 1, 2, 5, 10 20, pga[4] | 14 (Preliminary Cases 5-16) |

Notes:
[1] H indicates available for horizontal component, Z indicates available for vertical component
[2] Required frequencies are 0.33, 0.5, 1, 2, 5, 10 and 20 Hz
[3] 0.30 Hz instead of 0.33 Hz
[4] No 0.33 Hz available at this time

Data Package Reference (Vol 1):

| Modeler | Median Estimate $\mu$ | Aleatory Variability $\sigma_{Model}$ | Aleatory Variability $\sigma_{Parametric}$ | Total Aleatory Variability $\sigma$ | Epistemic Variability $\sigma_{\mu}$ | Epistemic Variability $\sigma_{\sigma}$ |
|---|---|---|---|---|---|---|
| Zeng & Anderson | 3.4.4-1, 3.4.5-1 to -3 | 3.4.8-2 to 3.4.8-4 | 3.4.4-1, 3.4.5-1 to -3 | | | |
| Silva Finite Fault | 3.3-2, -3, -4 | 3.3.5-1 to 3.3.5-3 | 3.3-5, -6, -7 | | | |
| Silva Point Source | 7.1-2 (eq) & program | 7.2-1 | 7.2-1 | | | |
| Somerville | 3.1.2-2, 3.1.3-1 | 3.1.2-4 | 3.1.2-5 | 3.1.2-3 | 3.1.2-6 | 3.1.2-7 |

3. Blast Models: These models and frequencies are provided in program yucatten

| | Components Available[1] | PGV Available? | Frequencies Available[2] |
|---|---|---|---|
| Bennett Model 1 | H | Yes | 0.5, 1., 2., 5., 10., 20., pga |
| Bennett Model 2 | H | No | 0.5, 1., 2., 5., 10., 20., pga |
| Bennett Model 3 | H | No | 0.5, 1., 2., 5., 10., 20., pga |

Notes:
[1] H indicates available for horizontal component
[2] Required frequencies are 0.33, 0.5, 1, 2, 5, 10 and 20 Hz

## 4. Hybrid Empirical

The hybrid empirical model are provided in the excel spreadsheets "HYBRD_SH.XLS" and "HYBRD_DP.XLS" for the shallow and deep cases, respectively. A description of this model is given in section 6.

The adjustment factors have been parameterized in the FORTRAN program "campFac.for". The factors from this program can be used to scale the ground motion estimates from the empirical attenuation relation.

| | Components Available[1] | PGV Available? | Frequencies Available[2] |
|---|---|---|---|
| Hybrid Empirical | H, Z | Yes | 0.33, 0.5, 1., 2., 5., 10., 20., pga |
| | | | |
| | | | |

## 5. Adjustment Factors

| Factors Adjust for: | Frequencies Available[1] | Issue | Modeler | Black Binder Ref. |
|---|---|---|---|---|
| Source, Crust, Site | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → $YM_{300}$ (Δσ input) | Campbell | |
| Source, Crust, Site | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → $YM_{300}$ (Δσ input) | Silva | |
| Source | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → YM (Δσ input) | Campbell | 8.4.2-1 |
| Source | 0.5, 1, 2, 5, 10, 20 | CA → YM (Δσ input) | Silva | 8.4.1-1 |
| Source | N/A | CA Atten Relations→ Extensional Regimes | Spudich et al. | 8.4.3-1 |
| Crust, Site | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → $YM_{300}$ | Campbell | 8.3.2-1 |
| Crust, Site | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → $YM_{300}$ | Silva | 8.3.1-1 |
| Crust, Site | 0.33, 0.5, 1, 2, 5, 10, 20 | CA → YM | Silva | 8.2.1-2 |
| | | | | |
| YM Site | 0.33, 0.5, 1, 2, 5, 10, 20 | YM → $YM_{300}$ | Silva | 8.1.1-2 |
| Vertical/Horizontal Ratio | 0.33, 0.5, 1, 2, 5, 10, 20 | N/A | Silva | 8.5-1 |
| PGV/PGA Ratio | N/A | YM300 | Campbell | Spreadsheet |
| PGV/PGA Ratio | N/A | YM300 | Silva | 8.6-1 |

Notes:
[1] Required frequencies are 0.33, 0.5, 1, 2, 5, 10 and 20 Hz

## 5. Constraints on Models: Precarious rocks

See black binder Section 11.

## 2.1 Summary of Available Ground Motion Models

| | |
|---|---|
| **1. Finite Fault Numerical Simulation for $YM_{300}$** | |
| Result: | Yucca Mountain ground motion at repository outcrop |
| Proponents: | Somerville (16 cases)<br>Silva<br>Anderson & Zeng |
| Issues: | Random component effect |

| | |
|---|---|
| **2. Empirical** | |
| **(a) Western US models** | |
| Result: | WUS (CA) ground motion at surface |
| Proponents: | Abrahamson & Silva (1997)<br>Boore, Joyner, Fumal (Vs) (1997)<br>Boore, Joyner, Fumal (class A) (1994)<br>Boore, Joyner, Fumal (class B) (1994)<br>Campbell (soft rock) (1997)<br>Campbell (hard rock) (1997)<br>Campbell (soft rock) (1993-94)<br>Campbell (hard rock) (1993-94)<br>Campbell (soft rock) (1990-94)<br>Campbell (hard rock) (1990-94)<br>Idriss (1991)<br>Idriss (1997)<br>Sadigh et al. (1997) |
| Issues: | CA—> $YM_{surface}$ : Q, crust, kappa<br>$CA_{\Delta\sigma}$ —> $YM_{\Delta\sigma}$: (source)<br>$YM_{surface}$—> $YM_{300m}$ |
| **(b) Extensional regime empirical models** | |
| Result: | Extensional ground motion |
| Proponents: | Spudich et al. (1996)<br>McGarr (Extensional regime) (1984) |
| Issues: | Extensional—> $YM_{surface}$: kappa, crust, Q<br>$YM_{surface}$—> $YM_{300m}$ |
| **(c) Attenuation relations from other regions** | |
| Proponent: | Sabetta & Pugliese (1996) - Italian data |
| Issues: | Italy—> $YM_{surface}$ : Q, crust, kappa<br>$Italy_{\Delta\sigma}$ —> $YM_{\Delta\sigma}$<br>$YM_{surface}$—> $YM_{300m}$ |

| 3. Blast Experience Models | |
|---|---|
| **(a) NTS source & NTS attenuation** | |
| Result: | NTS ground motion from blast |
| Proponents: | Bennett |
| Issues: | Blast source vs. earthquake source<br>Shallow depth of blast<br>$YM_{surface}$—> $YM_{300m}$ |
| **(b) NTS attenuation with Sadigh (1993) spectral shape** | |
| Result: | WUS ground motion with blast attenuation rate |
| Proponents: | Bennett |
| Issues: | $WUS_{surface}$—>$YM_{surface}$<br>$YM_{surface}$—> $YM_{300}$ |
| **(c) Little Skull Mtn spectral shape and Sadigh magnitude scaling** | |
| Result: | Little Skull Mtn ground motion with blast attenuation rate |
| Proponents: | Bennett |
| Issues: | $YM_{surface}$—> $YM_{300m}$ |

| 4. Hybrid Empirical | |
|---|---|
| Result: | Yucca Mountain ground motion at $YM_{300}$<br>(YM-specific source, Q, crust, kappa) |
| Proponents: | Campbell |
| Issues: | Stress-drop for YM |

| 5. Point Source Stochastic Model | |
|---|---|
| Result: | Yucca Mountain ground motion at $YM_{300}$<br>(linear site response)<br>(YM-specific source, crust, kappa) |
| Proponents: | Silva |
| Issues: | Median and variability of stress-drop for YM,<br>Definition of equivalent point source distance |

| | |
|---|---|
| **6. Scenario Earthquake Calculations (for models not being updated for $YM_{300}$)** | |
| Result: | Yucca Mountain ground motion at surface (with non linear site response) M6.4 (normal), M6.7(SS), M7.0(SS) |
| Proponents: | Chin<br>Joyner |
| Issues: | $YM_{surface}$ —> $YM_{300m}$<br>magnitude scaling |

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## 2.3 Summary of Proponent Models for Adjustments

| **1. $YM_{surface}$ —> $YM_{300}$**<br>**Surface at Yucca Mountain to Repository Outcrop (300 m)** | |
|---|---|
| **Model 1:** | |
| **Conversion factor:** | **Ratio of $YM_{300}$ / $YM_{surface}$** |
| **Source of factor:** | **1D vertical wave propagation (Silva)** |
| **Component:** | **horizontal** |
| **Tool provided in packet:** | **Plot of ratio. Tabulated values are also provided.** |
| **Accounts for:** | **differences in crustal velocity, kappa, Q** |

| 2. CA —> $YM_{surface}$<br>California to Yucca Mountain (surface)<br>(crust and kappa) | |
|---|---|
| **Model 1:**<br>Conversion factor: | Ratio of $YM_{surface}$/ $CA_{surface}$ |
| Source of factor: | Point source stochastic model (Silva) |
| Component: | horizontal |
| Tool provided in packet: | Plot of ratio. Tabulated values are also provided. |
| Accounts for: | crustal velocity, kappa, Q |

| 3. CA —> $YM_{300}$<br>California to Yucca Mountain (surface)<br>(crust and kappa) | |
|---|---|
| **Model 1:** | |
| Conversion factor: | $YM_{surface} / CA_{surface} * YM_{300} / YM_{surface}$<br>(from cases 1 and 2 above) |
| Source of factor: | Point source stochastic model (Silva) |
| Component: | horizontal |
| Tool provided in packet: | Plot of ratio. Tabulated values are also provided. |
| Accounts for: | crustal velocity, kappa, Q |
| **Method 2:** | |
| Conversion factor: | Ratio of $YM_{300} / CA_{surface}$ |
| Source of factor: | Point source stochastic model (Campbell) |
| Component: | horizontal |
| Tool provided in packet: | Excel file<br>plots of scale factors |
| Effects included: | crustal velocity, kappa, Q |

| 4. $CA_{surface}$ —> $YM_{surface}$<br>California to Yucca Mountain (surface)<br>(stress drop only) | |
|---|---|
| **Model 1:** | |
| Conversion factor: | adjustment factors |
| Source of factor: | Empirical (Spudich) |
| Component: | horizontal, vertical |
| Tool provided in packet: | None. See Spudich report. |
| Accounts for: | observed differences between extensional regime and California models (implicitly also includes possible differences in crust and kappa) |
| **Model 2:** | |
| Conversion factor: | equation |
| Source of factor: | point source stochastic model (Silva) |
| Component: | horizontal |
| Tool provided in packet: | equation |
| Accounts for: | differences in median $\Delta\sigma$ between California and Yucca Mountain |
| **Model 3:** | |
| Conversion factor: | equation |
| Source of factor: | point source stochastic model (Campbell) (Implied from hybrid empirical factors) |
| Component: | horizontal |
| Tool provided in packet: | equation |
| Accounts for: | differences in median $\Delta\sigma$ between California and Yucca Mountain |

## Section 3.

## Finite Fault Numerical Simulations for YM300

## Section 3.1

## Somerville Finite Fault Simulations

3.1.1 Somerville - 16 cases

# YUCCA MOUNTAIN PROBABILISTIC SEISMIC HAZARD ANALYSIS

## Documentation of Ground Motions for Specified Geometries

Paul Somerville, Woodward-Clyde

Ground motions generated Jan. 31, 1997; documented Feb. 13, 1997

### Broadband Simulation Procedure

See Appendix 1.

### Velocity Model

Velocity model has shear wave velocity at the surface of 1.9 km/sec. "Amplification factors" are contained exactly in the Green's functions used in the simulations.

### Rupture Area

Relation between seismic moment and rupture area, based on slip models of 11 crustal earthquakes in tectonically active regions:

$A = 2.05 \times 10^{-15} \times Mo^{2/3}$ (Somerville et. al., 1993).

This relation is practically identical to Wells and Coppersmith (1994), and corresponds to an average static stress drop of 35 bars. Variations in slip on the fault produce variable local stress drop.

### Rise Time

The relation between rise time and seismic moment, derived from the same set of 11 earthquakes, is:

$Tr = 1.72 \times 10^{-9} \times Mo^{1/3}$ (Somerville et. al., 1993).

### Slip Models

Slip models were generated using a method developed by Abrahamson based on these 11 earthquakes and described in Somerville et al. (1993). The five slip models used for each magnitude are shown in the attached figures. The slip models were tapered with a cosine bell as follows: over the top 50% of the downdip width; over the bottom 10% of the downdip width; and over 5% of the length at each end.

Kappa - 0.02

Q - not included - only affects R=50 km, 5 Hz and above - we may recalculate these

### Fault and Station Geometry and Correction for Rupture Directivity

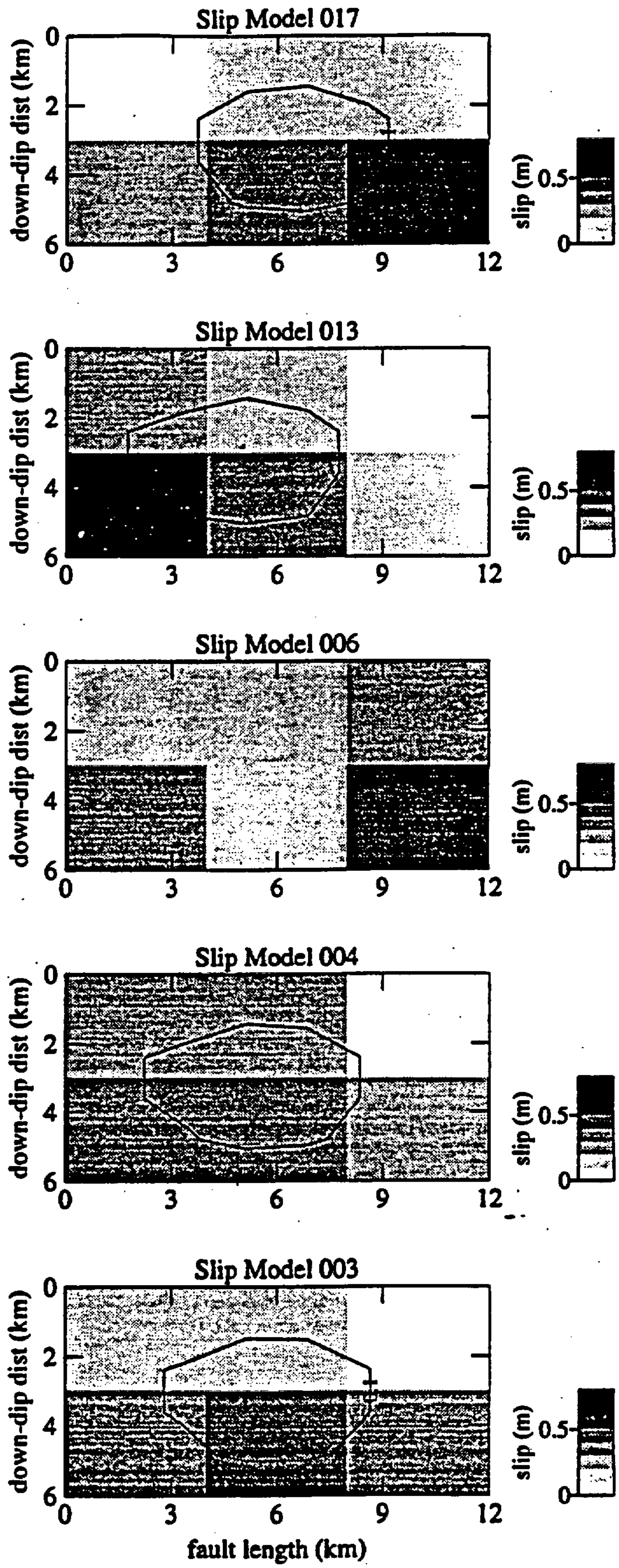
The stations are located 0.25 of the fault length from the end of the fault. The three hypocenters used for each slip model are located as follows: one at the middle of the fault and one 0.17 of the fault length from either end. The three hypocenters sample quite a large range of directivity effects. At periods of 1 and 2 seconds, the spectra are corrected for directivity effects using the model of Somerville et al., Figure 8 (Seismological Research Letters, 68, p. 199-222, 1997) to give a value that represents the average over directivity effects. The aleatory variability in the median estimate of the response spectrum is increased at periods of 1 and 2 seconds to include larger parametric variability; one of these contributions is from directivity effects, as documented in Somerville et al., Figure 8.

### Estimation of Aleatory Variability

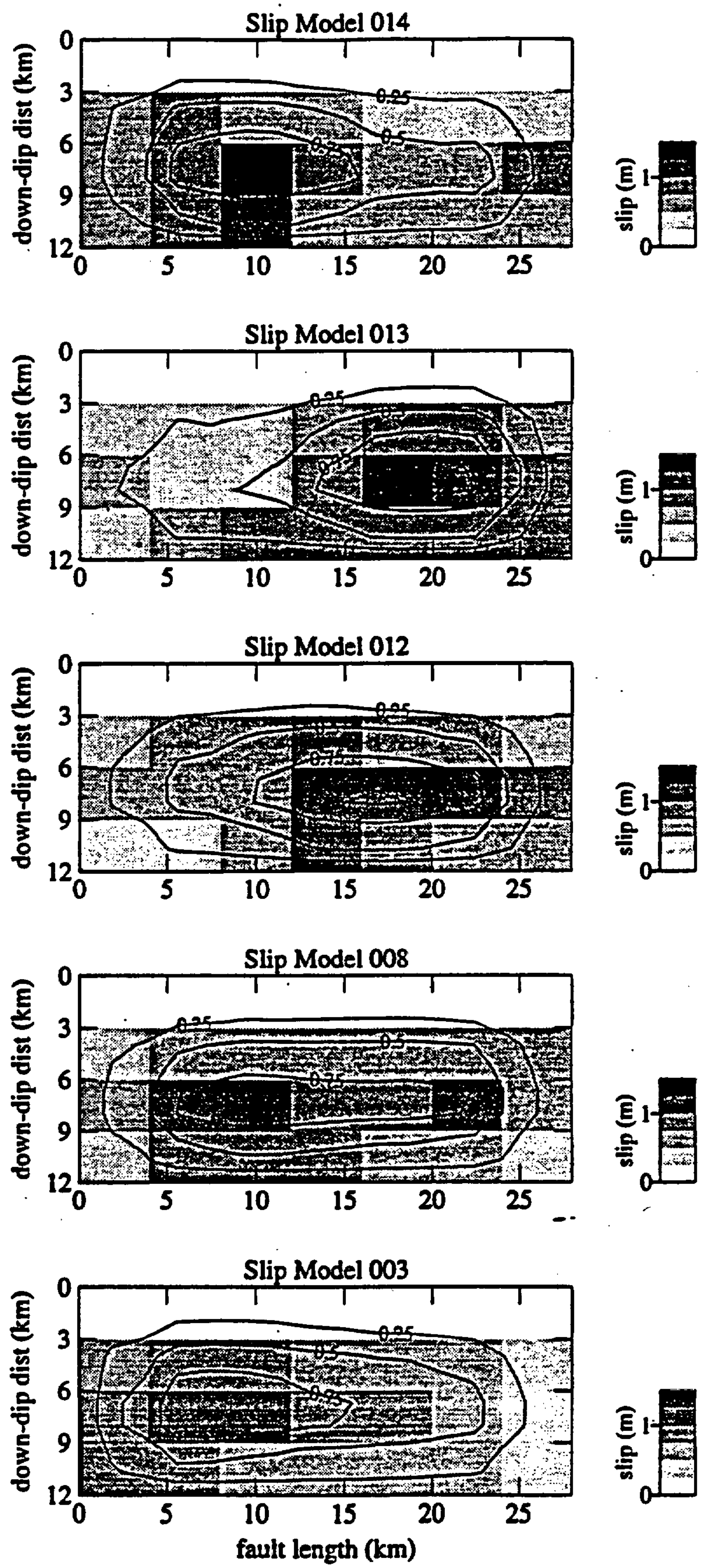
| Aleatory-Category | Sub-category | pga, 20, 10, 5, 2Hz | 1 Hz and pgv | | 0.5 Hz | |
|---|---|---|---|---|---|---|
| | | | strike-slip | dip-slip | strike-slip | dip-slip |
| Parametric | Stressdrop* | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| | Directivity | 0.0 | 0.18 | 0.05 | 0.34 | 0.10 |
| | Other | 0.20 | 0.40 | 0.40 | 0.40 | 0.40 |
| | Total | 0.35 | 0.52 | 0.49 | 0.60 | 0.50 |
| Modeling | | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Total | | 0.49 | 0.63 | 0.60 | 0.69 | 0.61 |

* static stress drop, varied by varying the rupture area for a given seismic moment

# TopShear1.9-M5.8-Dip90



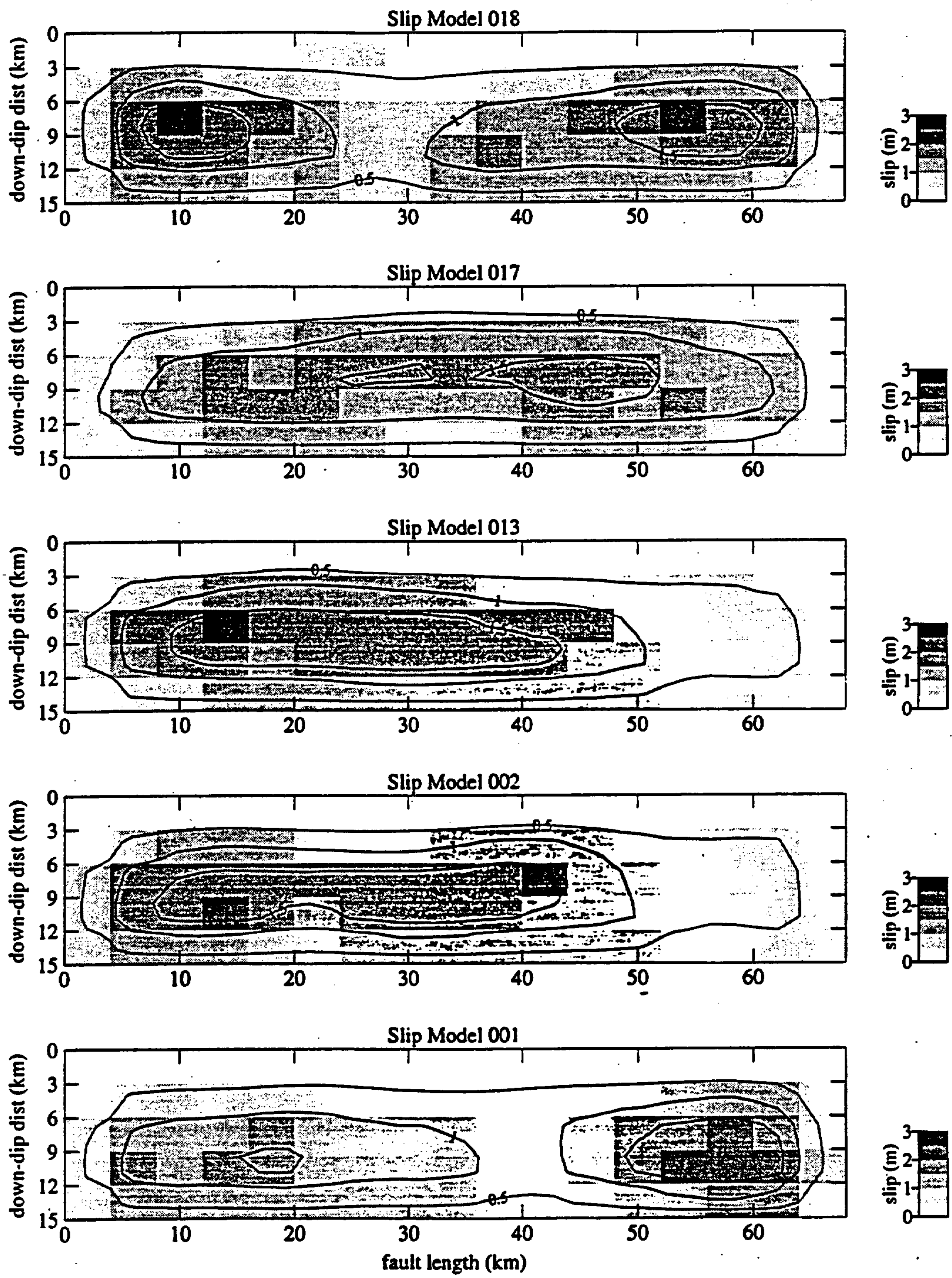
# TopShear1.9-M6.5-Dip90





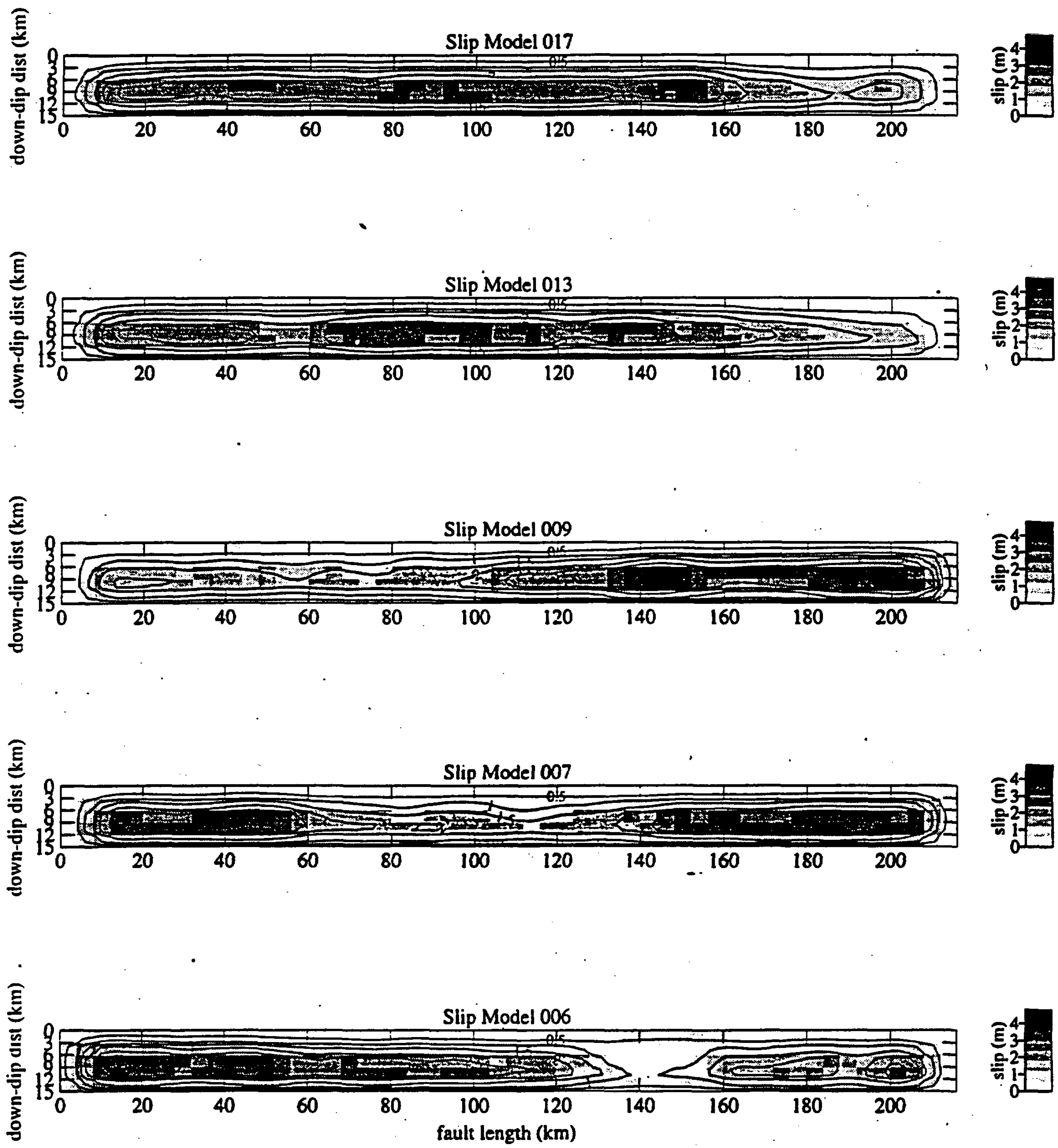

Thu Feb 13 13:47:11 PST 1997
slipPlots

# TopShear1.9-M7.0-Dip90




3.1.1-5

# TopShear1.9-M7.5-Dip90






Thu Feb 13 13:47:30 PST 1997
SlipPlots

Fault Parameters used in Broadband Simulations

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Due Date | 1/31/97 | | 1/31/97 | | 1/31/97 | | 1/31/97 | | 1/31/97 | | 1/31/97 | |
| M | 5 (not run) | | 5.8 | | 6.5 | | 7 | | 7.5 | | 8 (not run) | |
| Mo | $3.55 \times 10^{23}$ | | $5.62 \times 10^{24}$ | | $6.31 \times 10^{25}$ | | $3.55 \times 10^{26}$ | | $2.0 \times 10^{27}$ | | $1.12 \times 10^{28}$ | |
| Rise Time | 0.12 | | 0.31 | | 0.68 | | 1.22 | | 2.17 | | 3.85 | |
| Area | 13 | | 65 (72) | | 324 (336) | | 1023 (1020) | | 3236 (3240) | | 10233 (10200) | |
| Length - km/ elements | 4 / 1 | | 12 / 3 | | 28 / 7 | | 68 /17 | | 216 / 54 | | 680 /170 | |
| Width - km / elements | 3 / 1 | | 6 / 2 | | 12 / 4 | | 15 / 5 | | 15 / 5 | | 15 / 5 | |
| Downdip distance of hypocenter | 1.5 | | 4.5 | | 9 | | 11.25 | | 11.25 | | 11.25 | |
| Horizontal distance of hypocenter from center | -1.33,0,+1.33 | | -4.0, 0, +4.0 | | -9.3,0,+9.3 | | -22.67, 0, +22.67 | | -72, 0,+72 | | -226.8, 0,+226.8 | |
| Distance along stk of hypo | | | 2., 6. 10. | | 4.7, 14.0, 23.3 | | 11.33, 34., 56.67 | | 36, 108, 180 | | | |
| Dip/Rake | 60 / 90 | 90 / 0 | 60 / 90 | 90 / 0 | 60 / 90 | 90 / 0 | 60 / 90 | 90 / 0 | 60 / 90 | 90 / 0 | 60 / 90 | 90 / 0 |
| Depth of top | | | 2.6<br>7.79 | 3.0<br>9.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Depth to bottom | | | 7.79<br>13 | 9<br>15 | 10.39 | 12 | 13 | 15 | 13 | 15 | | |
| Depth of hypocenter | | | 6.50<br>11.69 | 7.5<br>13.5 | 7.79 | 9.0 | 9.74 | 11.25 | 9.74 | 11.25 | 9.74 | 11.25 |
| Shear Velocity | | | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Rupture Velocity | | | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| Station Locations | Station distances east of the projection of the fault plane at the surface: -50,-20,-10,-5,-1,1,5,10,20,50 | | | | | | | | | | | |
| N of top center | | | 3 | 3 | 7 | 7 | 17 | 17 | 54 | 54 | 170 | 170 |
| E of top center | | | | | | | | | | | | |

## Section 3.1.2

## Tabluated Results for the Horizontal Component (Somerville Simulations, Cases 1-16)

**Tabulation of Ground Motion Parameters**

The following ground motion parameters are provided in the following tables:

Median Sa - Horizontal Component

Median Sa - Vertical Component

Combined Modeling and Parametric Components of Aleatory Variability about Median Sa- H

Modeling Component of Aleatory Variability about Median Sa- Horizontal

Parametric Component of Aleatory Variability about Median Sa- Horizontal

Epistemic Uncertainty in Median Sa- Horizontal

Epistemic Uncertainty in Combined Aleatory Variability about Median Sa- Horizontal

3.1.2-2

Woodward-Clyde: Somerville

| Median Sa - Horizontal Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_W$ 5.8 Deep | | $M_W$ 6.5 | | | | | | | $M_W$ 7.0 | $M_W$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | .01730 | 0.0088 | 0.1530 | 0.0708 | 0.0819 | 0.0899 | 0.0605 | 0.0103 | 0.0059 | 0.0859 | 0.0174 | 0.0115 |
| 1.0 | 0.0563 | 0.0373 | 0.4130 | 0.2343 | 0.2348 | 0.3833 | 0.1983 | 0.0276 | 0.0176 | 0.2290 | 0.0688 | 0.0594 |
| 2.0 | 0.1309 | 0.0966 | 0.7771 | 0.5994 | 0.5993 | 0.7874 | 0.4337 | 0.0420 | 0.0499 | 0.6374 | 0.1699 | 0.1710 |
| 5.0 | 0.1764 | 0.1549 | 1.0876 | 0.9442 | 0.9421 | 1.2219 | 0.6278 | 0.0610 | 0.0788 | 0.7569 | 0.2602 | 0.2727 |
| 10.0 | 0.1776 | 0.1529 | 1.1180 | 1.0291 | 1.0311 | 1.2583 | 0.5670 | 0.0717 | 0.0726 | 0.8162 | 0.2240 | 0.2339 |
| 20.0 | 0.1385 | 0.1236 | 0.8230 | 0.6709 | 0.6678 | 1.0379 | 0.4871 | 0.0565 | 0.0534 | 0.5944 | 0.1814 | 0.1629 |
| PGA | 0.0889 | 0.0775 | 0.5636 | 0.4647 | 0.4598 | 0.6417 | 0.2873 | 0.0328 | 0.0336 | 0.3958 | 0.1007 | 0.0966 |
| PGV | 5.9900 | 4.1394 | 46.760 | 26.3591 | 27.4479 | 35.8396 | 20.1576 | 2.8650 | 2.2562 | 25.430 | 6.5440 | 4.8642 |

Woodward-Clyde: Somerville

**Combined Modeling and Parametric Components of Aleatory Variability about Median Sa - Horizontal Component**

| Frequency Hz | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.69 | 0.61 | 0.69 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.69 | 0.61 | 0.61 |
| 1.0 | 0.63 | 0.60 | 0.63 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.63 | 0.60 | 0.60 |
| 2.0 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| 5.0 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| 10.0 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| 20.0 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| PGA | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| PGV | 0.63 | 0.60 | 0.63 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.63 | 0.60 | .060 |

Woodward-Clyde: Somerville

| Modeling Component of Aleatory Variability about Median Sa - Horizontal Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 1.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 2.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 5.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 10.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 20.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| PGA | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| PGV | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |

Woodward-Clyde: Somerville

| Parametric Component of Aleatory Variability about Median Sa - Horizontal Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_W$ 5.8 Deep | | $M_W$ 6.5 | | | | | | | $M_W$ 7.0 | $M_W$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.60 | 0.50 | 0.60 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.60 | 0.50 | 0.50 |
| 1.0 | 0.52 | 0.49 | 0.52 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.52 | 0.49 | 0.49 |
| 2.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 5.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 10.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| 20.0 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| PGA | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| PGV | 0.52 | 0.49 | 0.52 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.52 | 0.49 | 0.49 |

3.1.2-5

3.1.2-6

Woodward-Clyde: Somerville

| Epistemic Uncertainty in Median Sa - Horizontal Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_W$ 5.8 Deep | | $M_W$ 6.5 | | | | | | | $M_W$ 7.0 | $M_W$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 1.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 2.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 5.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 10.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 20.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| PGA | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| PGV | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

Woodward-Clyde: Somerville

| Epistemic Uncertainty in Aleatory Variability about Median Sa (+/-) - Horizontal Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_W$ 5.8 Deep | | $M_W$ 6.5 | | | | | | | $M_W$ 7.0 | $M_W$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| 1.0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| 2.0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| 5.0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| 10.0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| 20.0 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| PGA | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| PGV | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |

## Section 3.1.3

**Tabluated Results for the Vertical Component (Somerville Simulations, Cases 1-16)**

Woodward-Clyde: Somerville

| Median Sa - Vertical Component | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency Hz | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
| | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.5 | 0.0075 | 0.0048 | 0.0534 | 0.0661 | 0.0552 | 0.0515 | 0.0505 | 0.0035 | 0.0052 | 0.0282 | 0.0056 | 0.0076 |
| 1.0 | 0.0178 | 0.0179 | 0.1153 | 0.1309 | 0.1293 | 0.1449 | 0.1371 | 0.0059 | 0.0122 | 0.0890 | 0.0317 | 0.0283 |
| 2.0 | 0.0679 | 0.0512 | 0.2876 | 0.3819 | 0.3808 | 0.3927 | 0.2999 | 0.0228 | 0.0428 | 0.3420 | 0.0912 | 0.0797 |
| 5.0 | 0.0828 | 0.0769 | 0.5503 | 0.5391 | 0.5393 | 0.5936 | 0.3246 | 0.0270 | 0.0306 | 0.4553 | 0.1261 | 0.1176 |
| 10.0 | 0.1036 | 0.0990 | 0.8969 | 0.8949 | 0.8947 | 0.5713 | 0.4779 | 0.0345 | 0.0444 | 0.4909 | 0.1325 | 0.1313 |
| 20.0 | 0.0741 | 0.0790 | 0.5877 | 0.5470 | 0.5509 | 0.5943 | 0.3181 | 0.0269 | 0.0335 | 0.3969 | 0.0934 | 0.0977 |
| PGA | 0.0425 | 0.0472 | 0.3306 | 0.3299 | 0.3251 | 0.3075 | 0.1985 | 0.0172 | 0.0218 | 0.2186 | 0.0530 | 0.0554 |
| PGV | 2.5437 | 2.4366 | 12.8034 | 21.0499 | 18.6963 | 20.279 | 13.0190 | 0.7055 | 1.8854 | 10.838 | 2.3347 | 2.4583 |

3.1.3-1

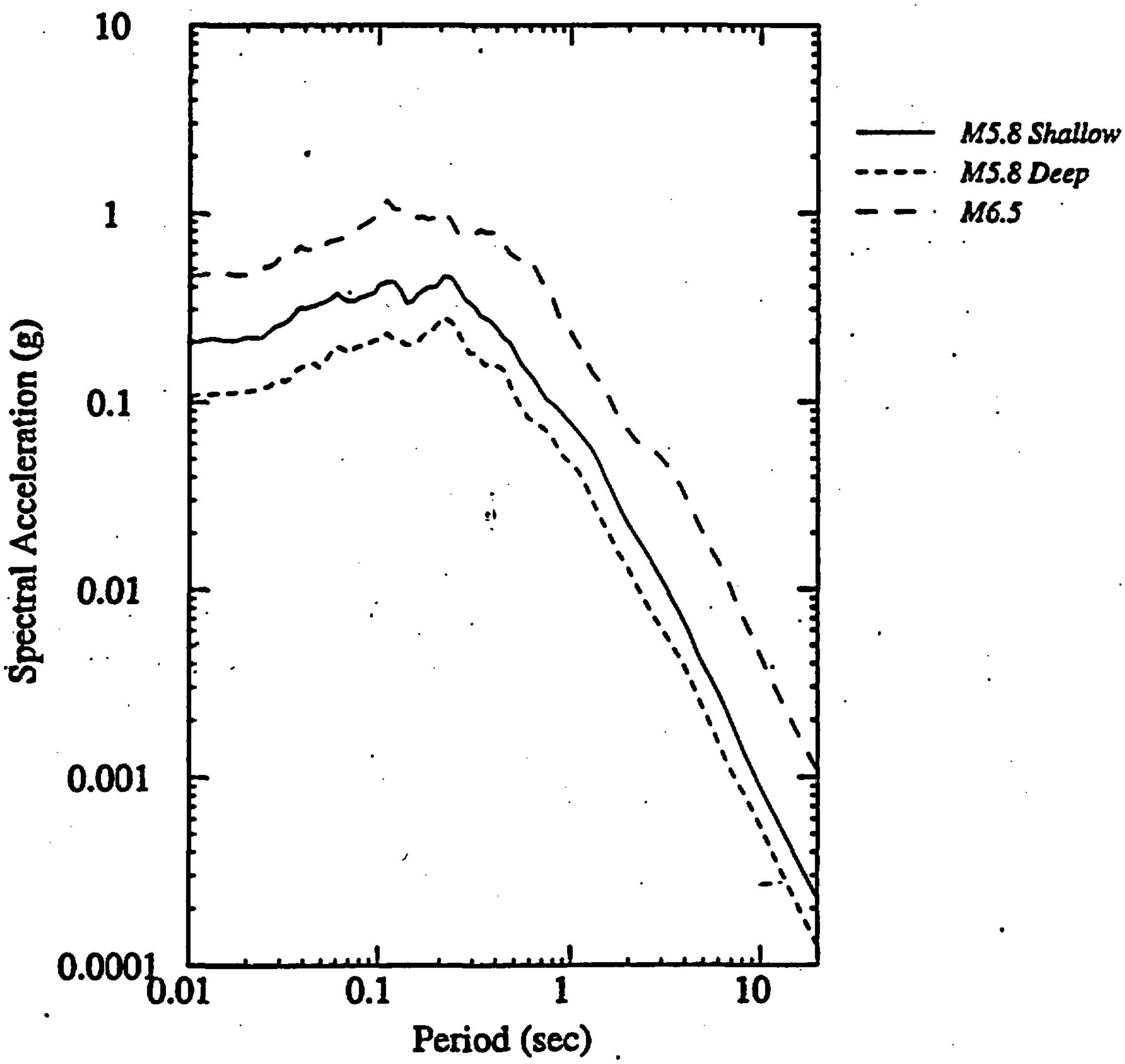
## Section 3.1.4

## Plots of Results for the Horizontal Component (Somerville Simulations, Cases 1-16)

## Display of Response Spectra

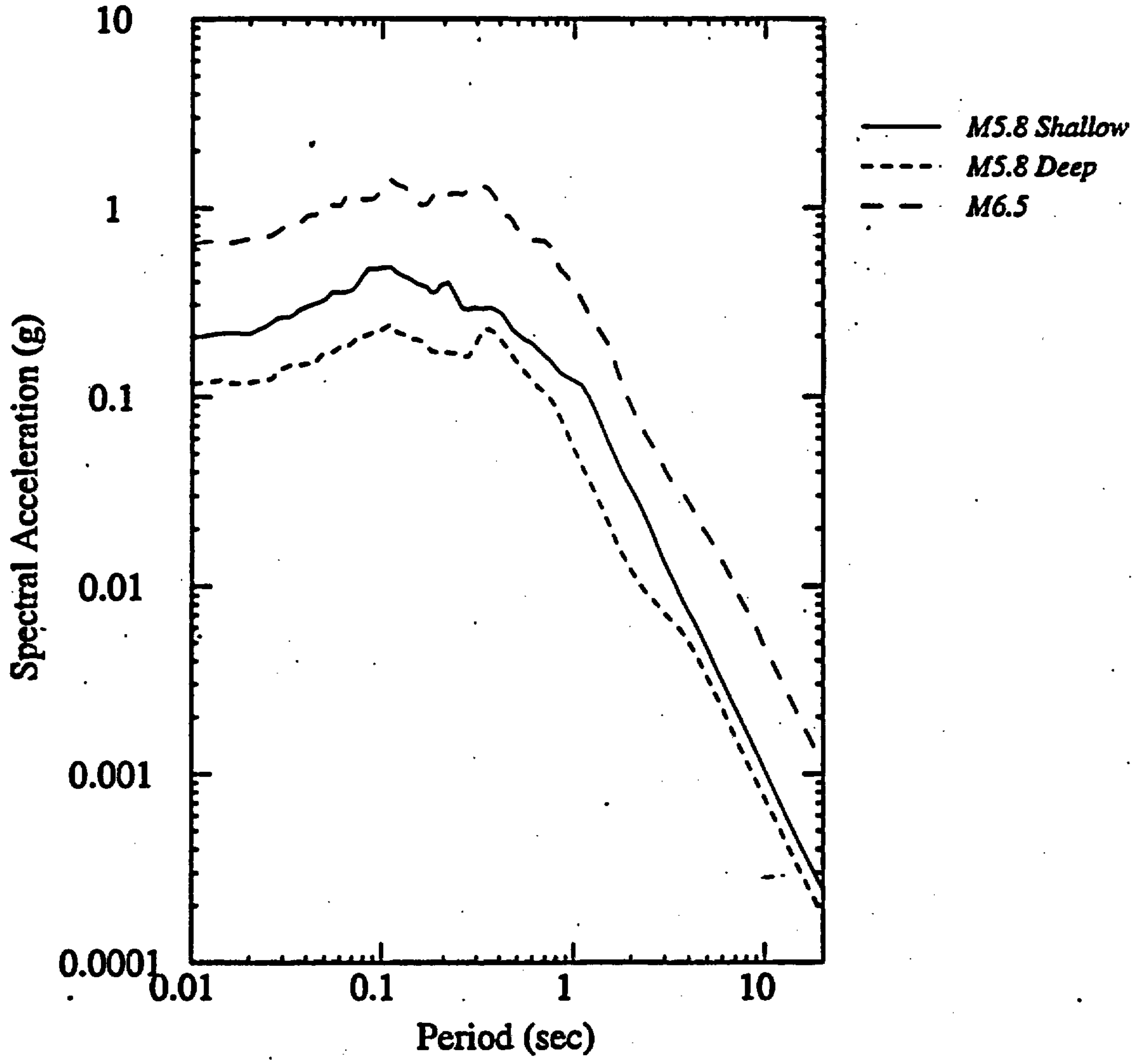
- Unlike tabulated values, we have not corrected these spectra for rupture directivity
- Station code: letter e or w indicates hanging wall or foot wall
  three digit number indicates horizontal distance to fault outcrop.

## Yucca Broadband Results, All Magnitudes,Dip 60.0
## Station e001; Component h

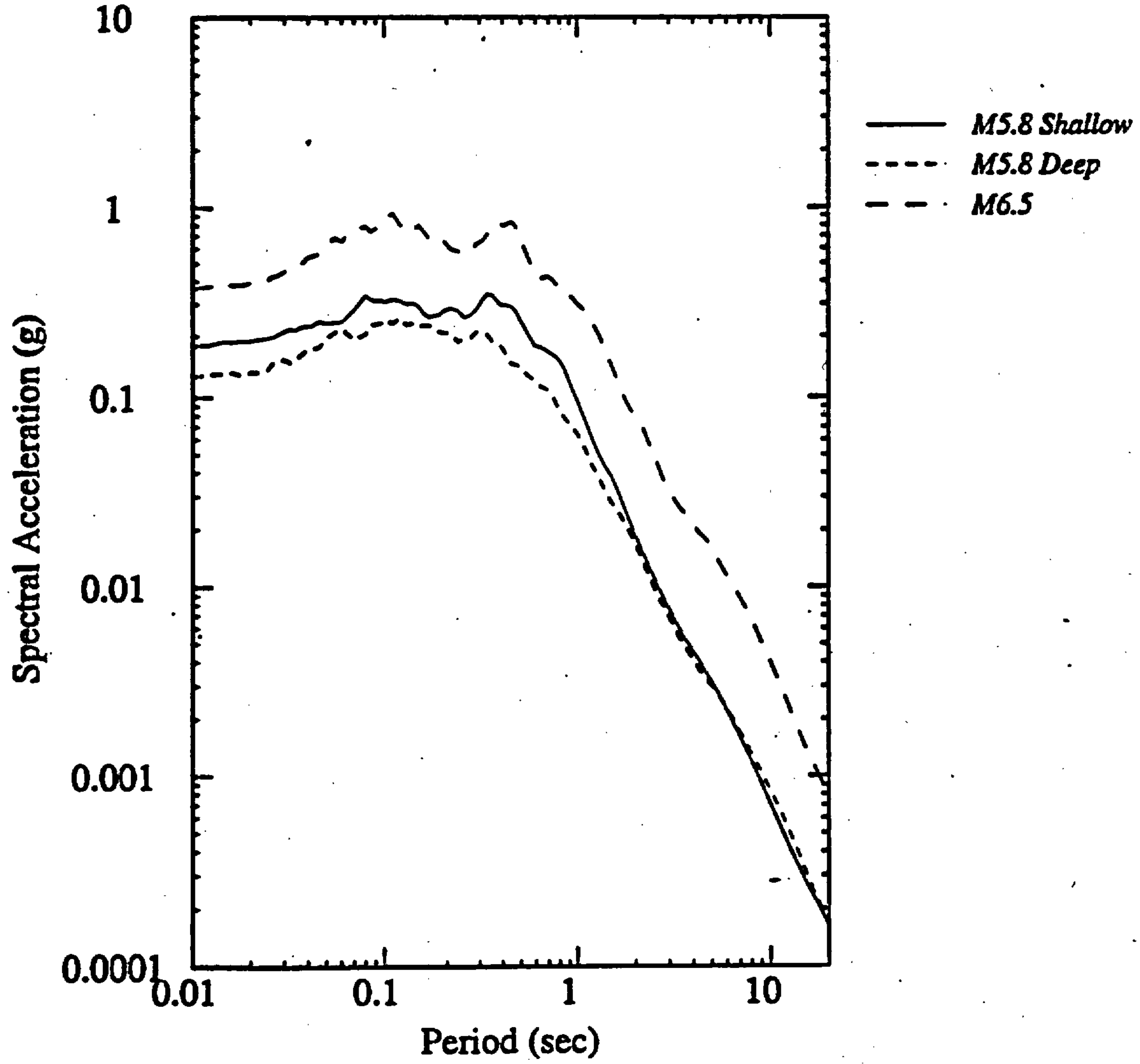



: Thu Jan 30 14:40:01 PST 1997
ncy/Yucca/BroadBand/mplot_spectra_mm2.csh

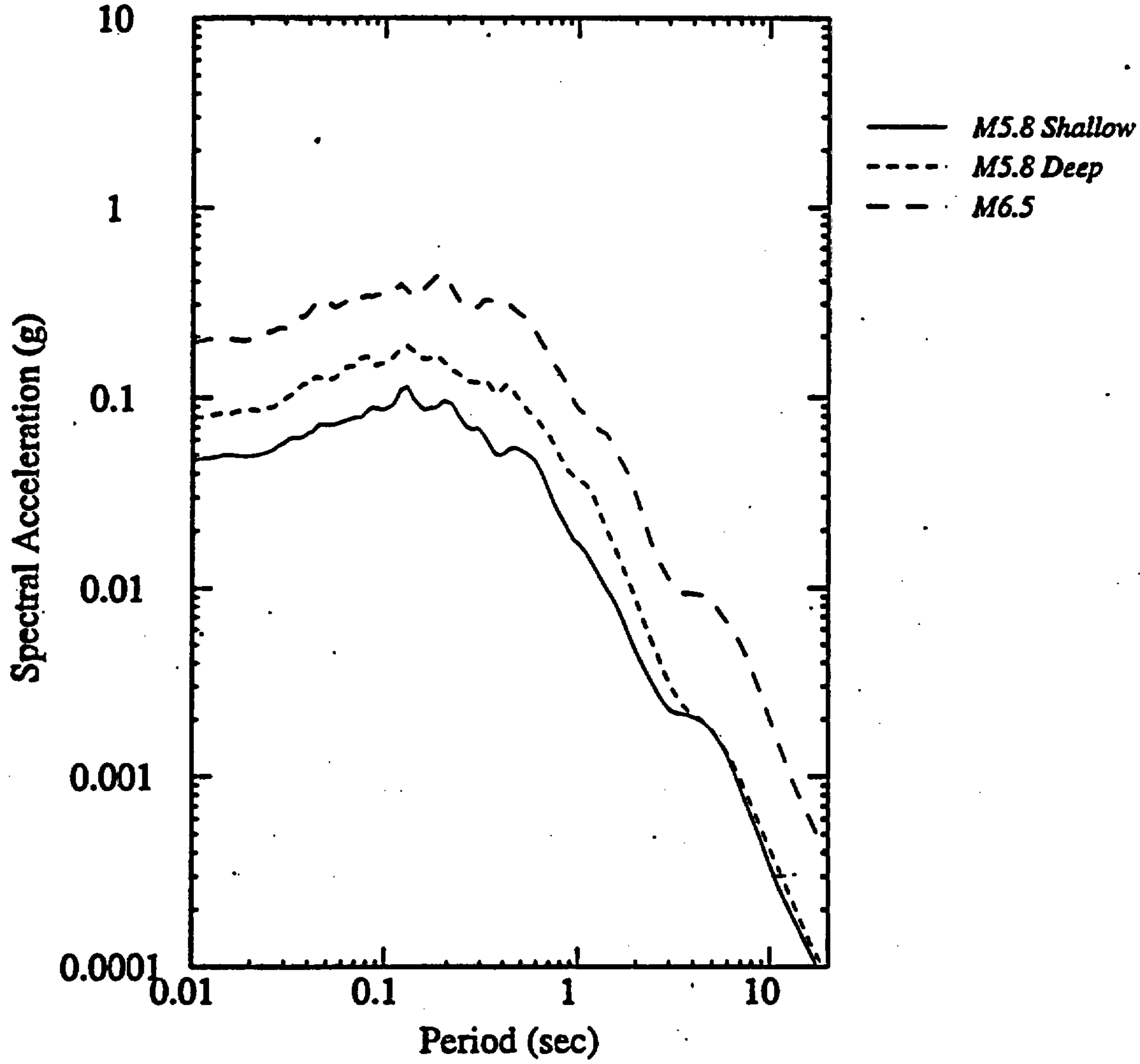
## Yucca Broadband Results, All Magnitudes,Dip 60.0
## Station e005, Component h



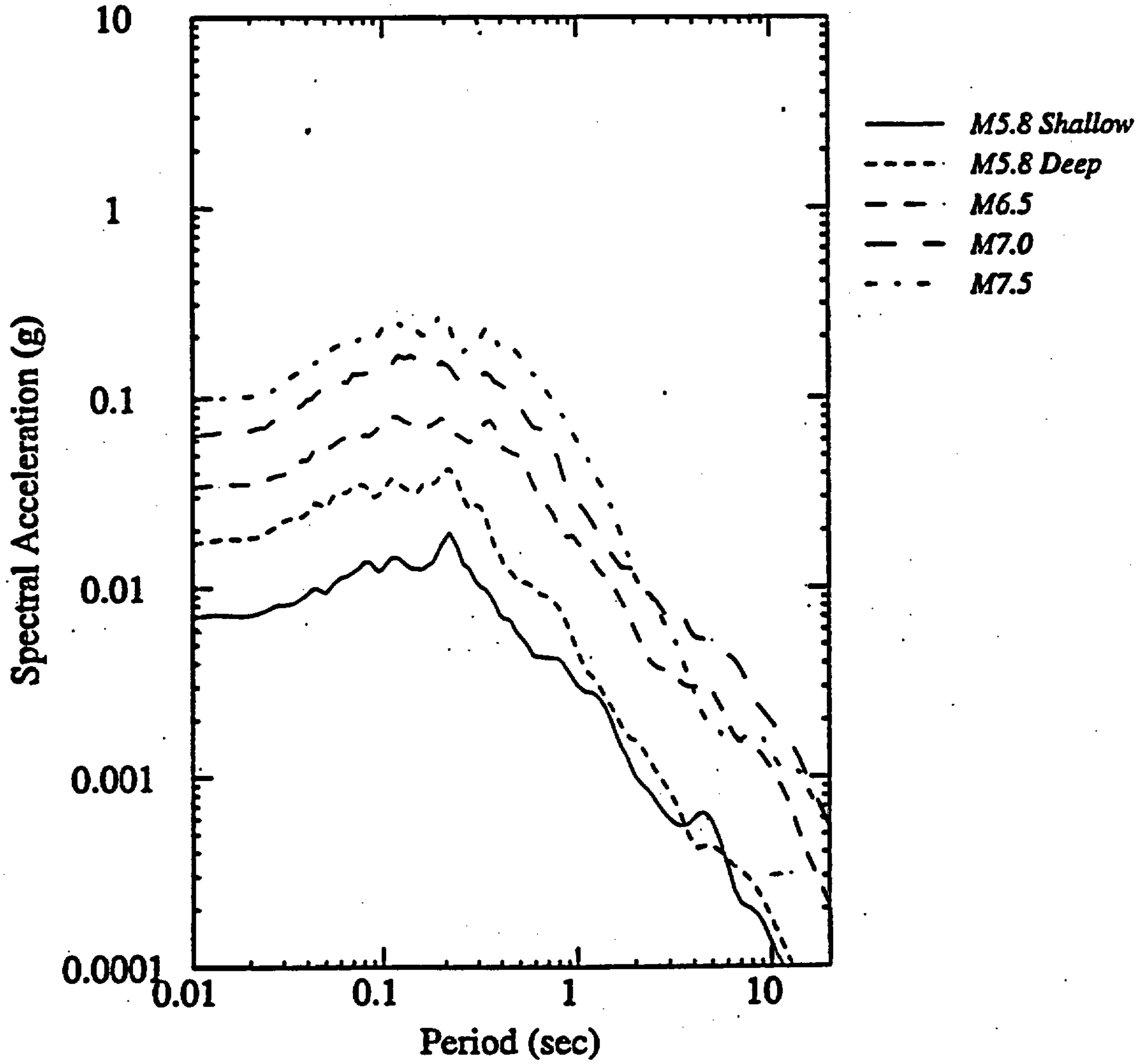
## Yucca Broadband Results, All Magnitudes,Dip 60.0
## Station e010, Component h



Yucca Broadband Results, All Magnitudes,Dip 60.0
Station e020, Component h

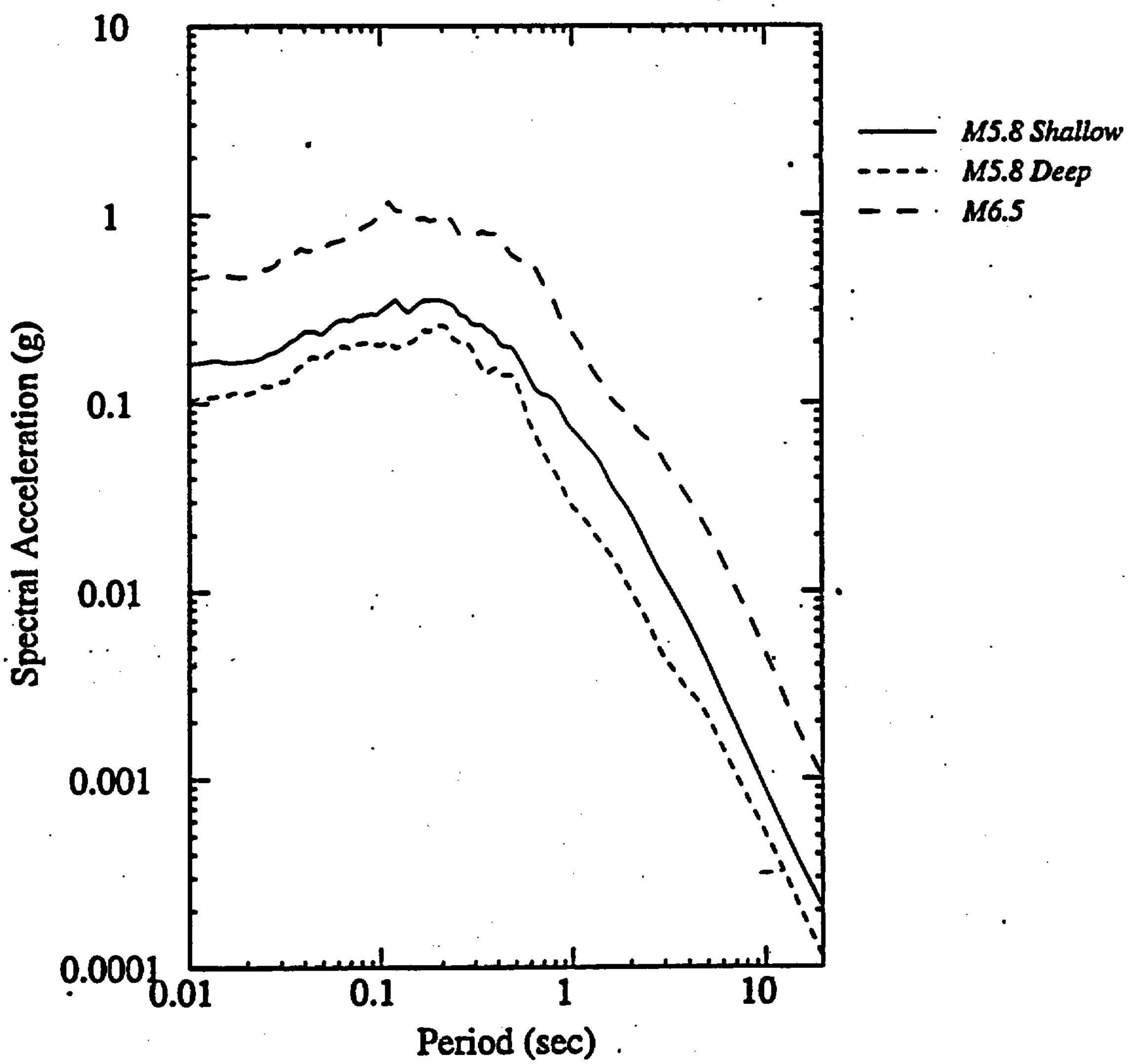


Yucca Broadband Results, All Magnitudes,Dip 60.0
Station e050, Component h



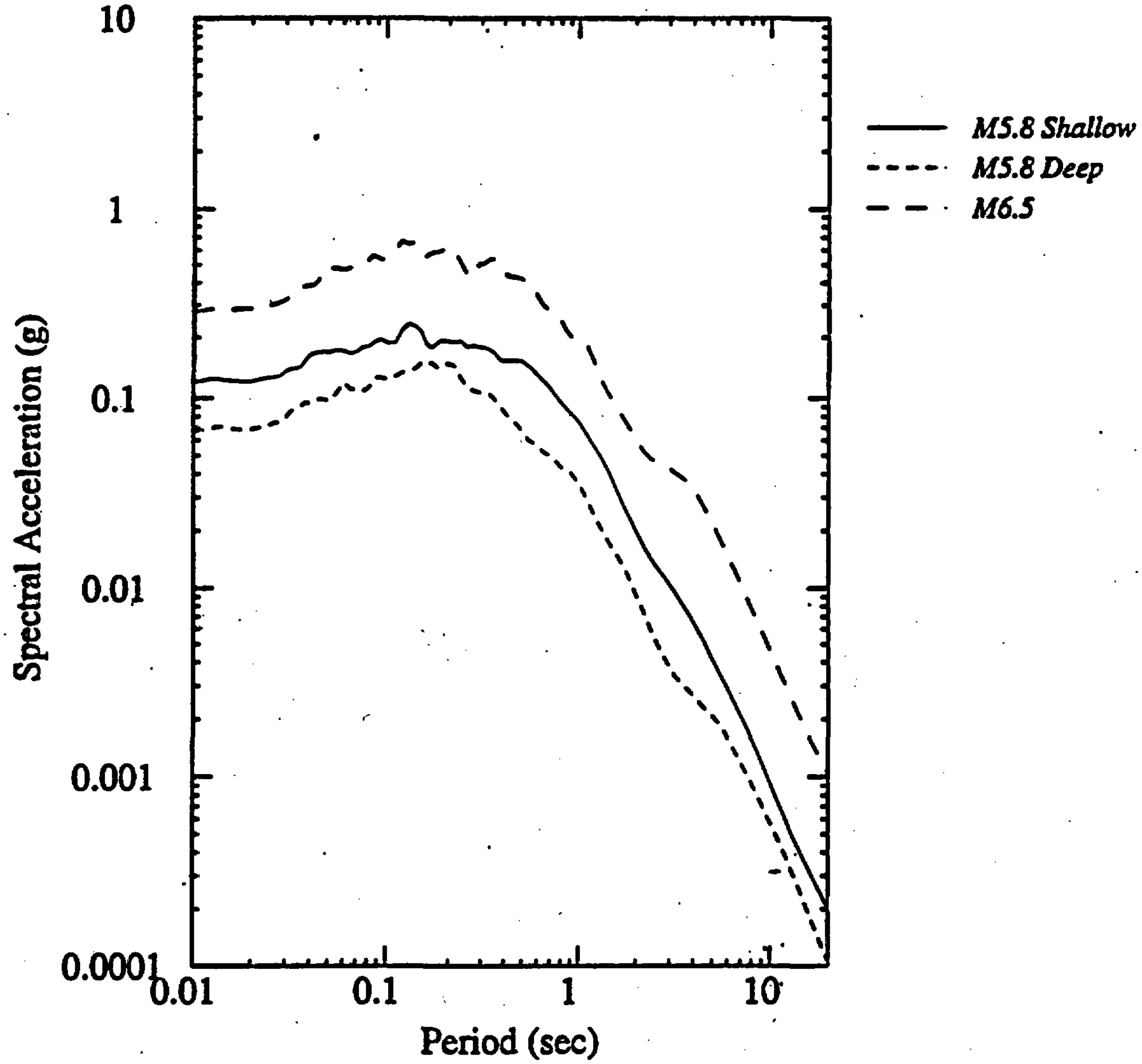

: Thu Jun 30 14:41:10 PST 1997
ancy/Yucca/BroadBand/mplot_spectra_mm2.mh

Yucca Broadband Results, All Magnitudes,Dip 60.0
Station w001, Component h



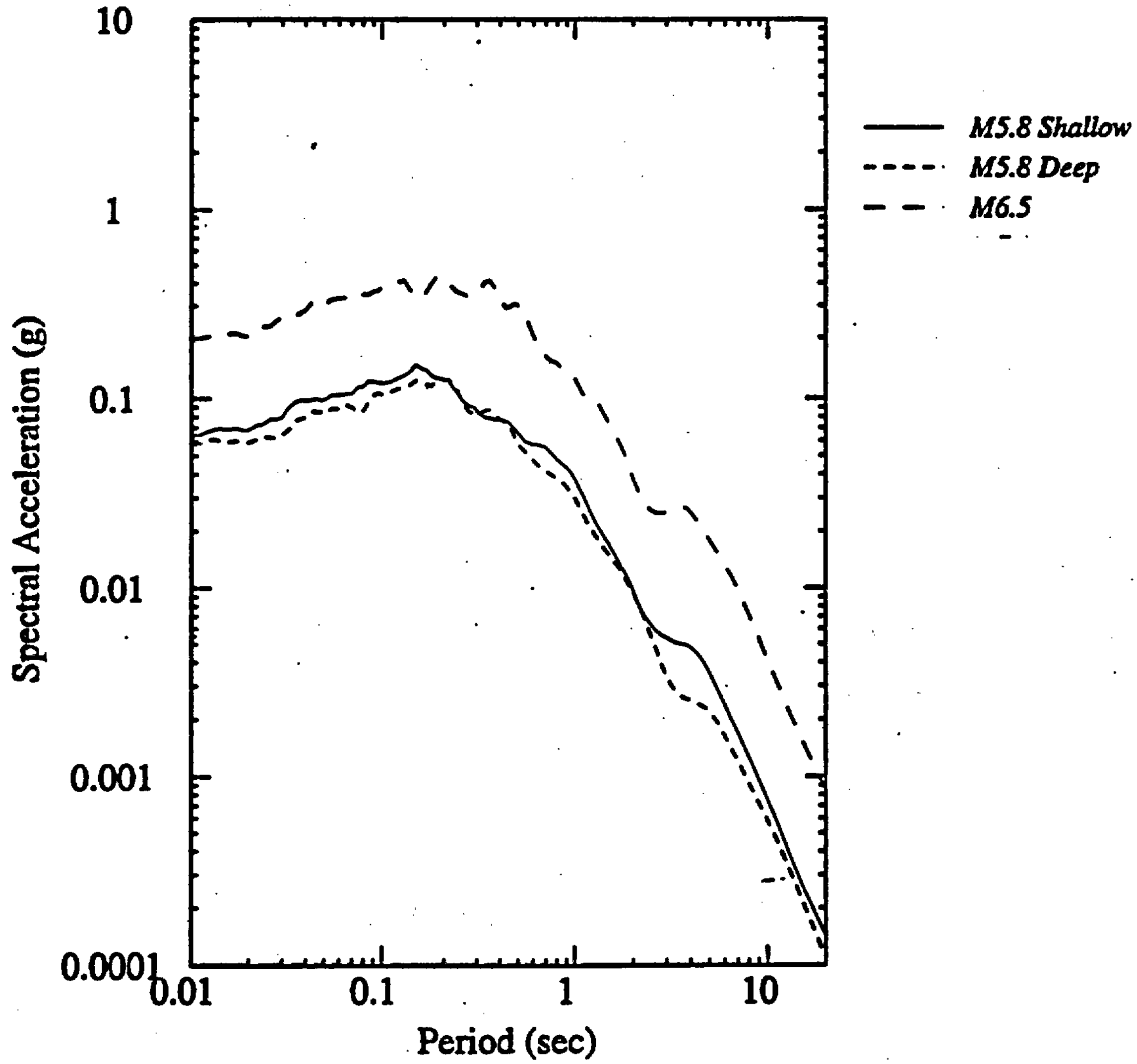

: Thu Jan 30 14:41:26 PST 1997
ncy/Yucca/BroadBand/mplot_spectra_sum2.csh

# Yucca Broadband Results, All Magnitudes,Dip 60.0
## Station w005, Component h



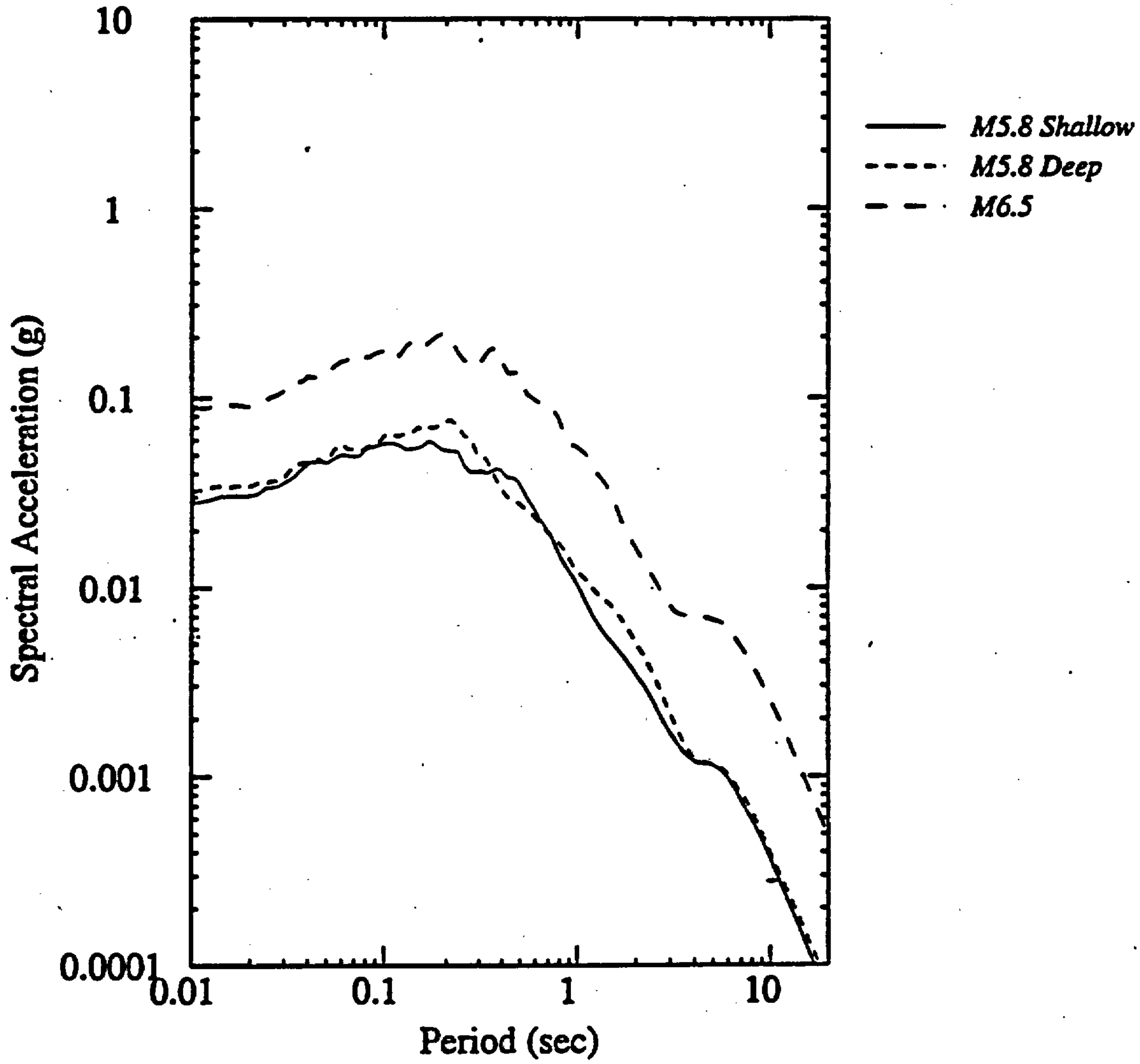

Thu Jan 30 14:41:43 PST 1997
:y/Yucca/BroadBand/mplot_spectra_mm2.mh

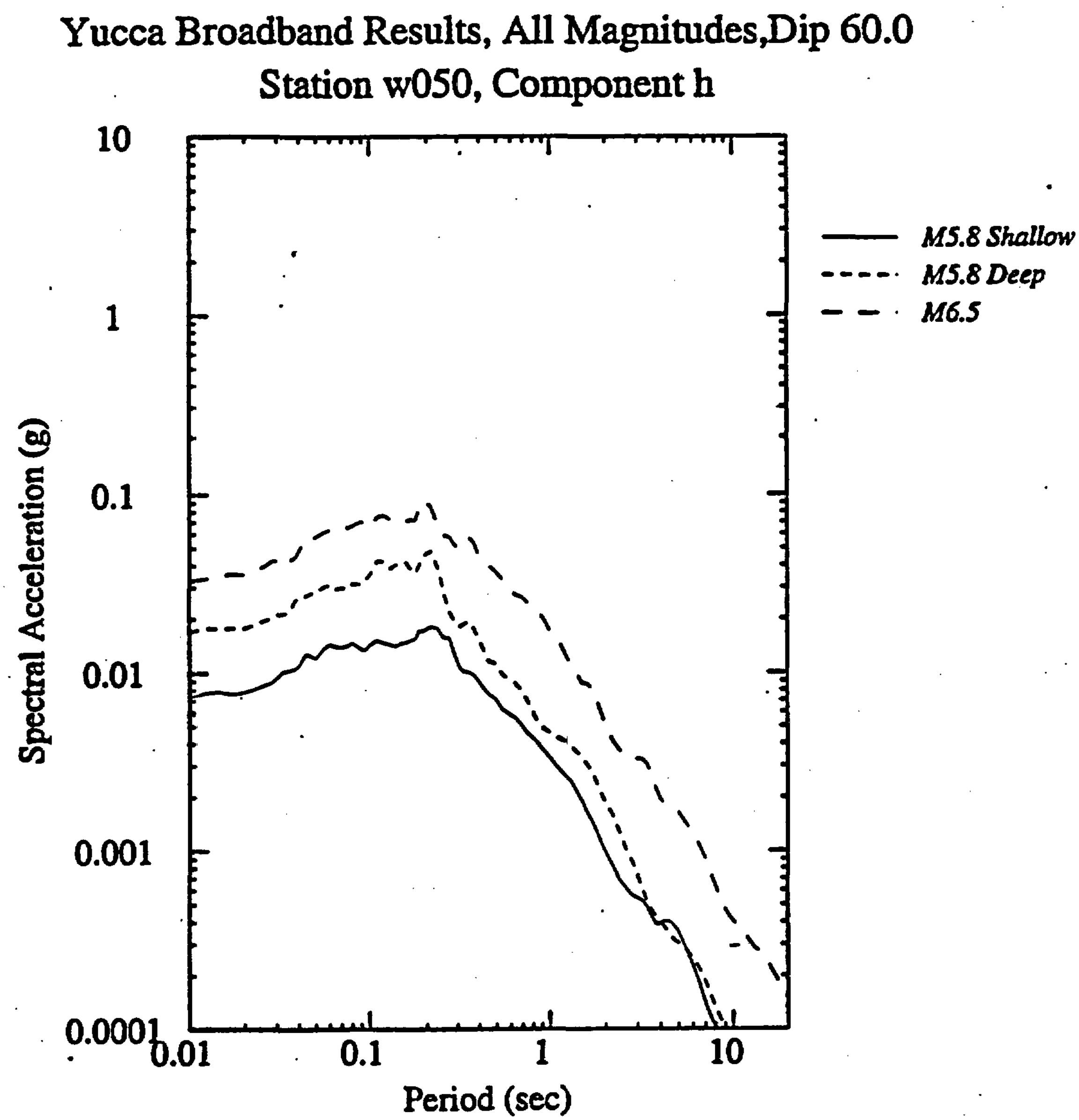
Yucca Broadband Results, All Magnitudes,Dip 60.0
Station w010, Component h




3: Thu Jan 30 14:42:00 PST 1997
ency/Yucca/BroadBand/mplot_spectra_sum2.csh

## Yucca Broadband Results, All Magnitudes,Dip 60.0
## Station w020, Component h

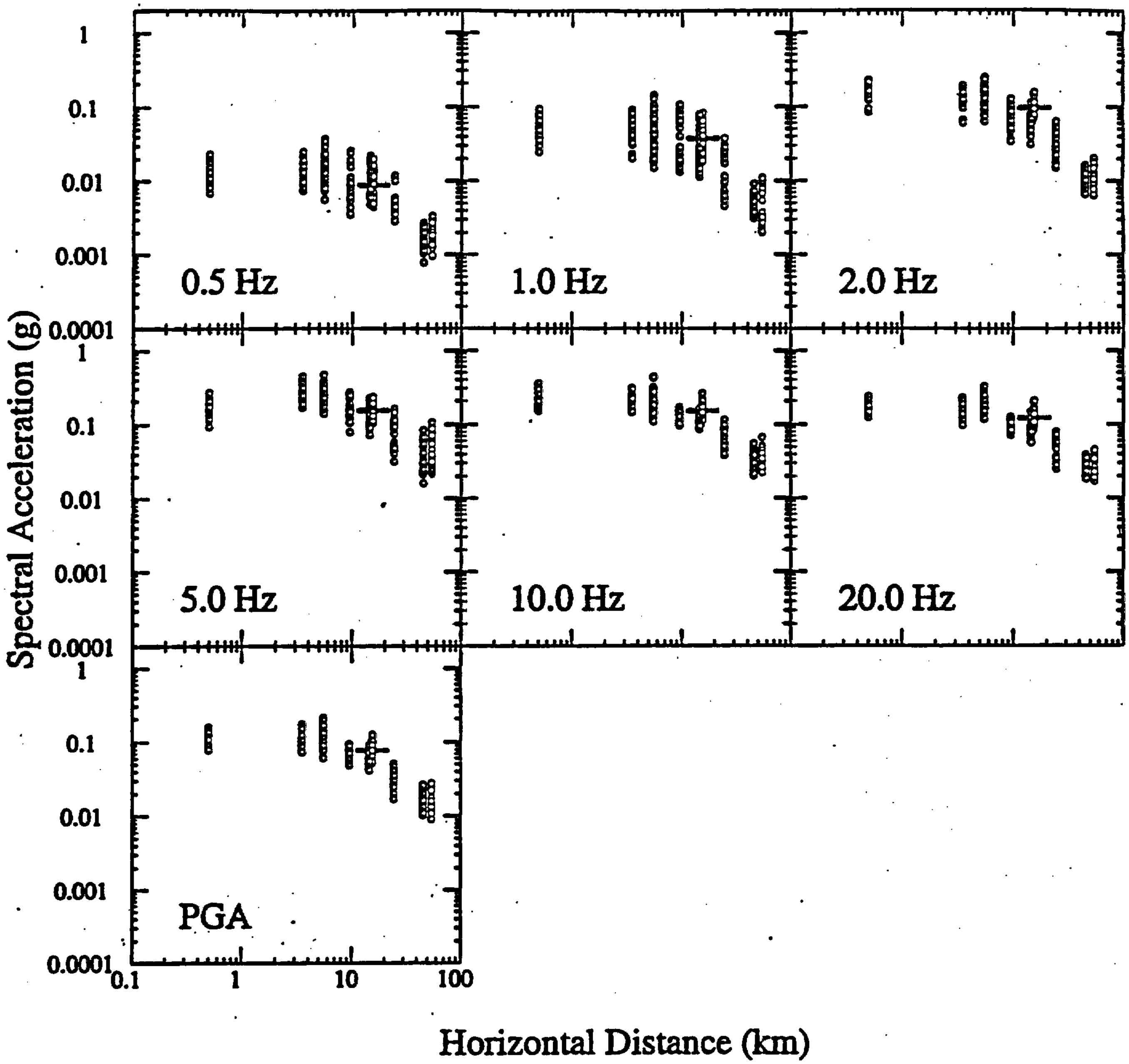




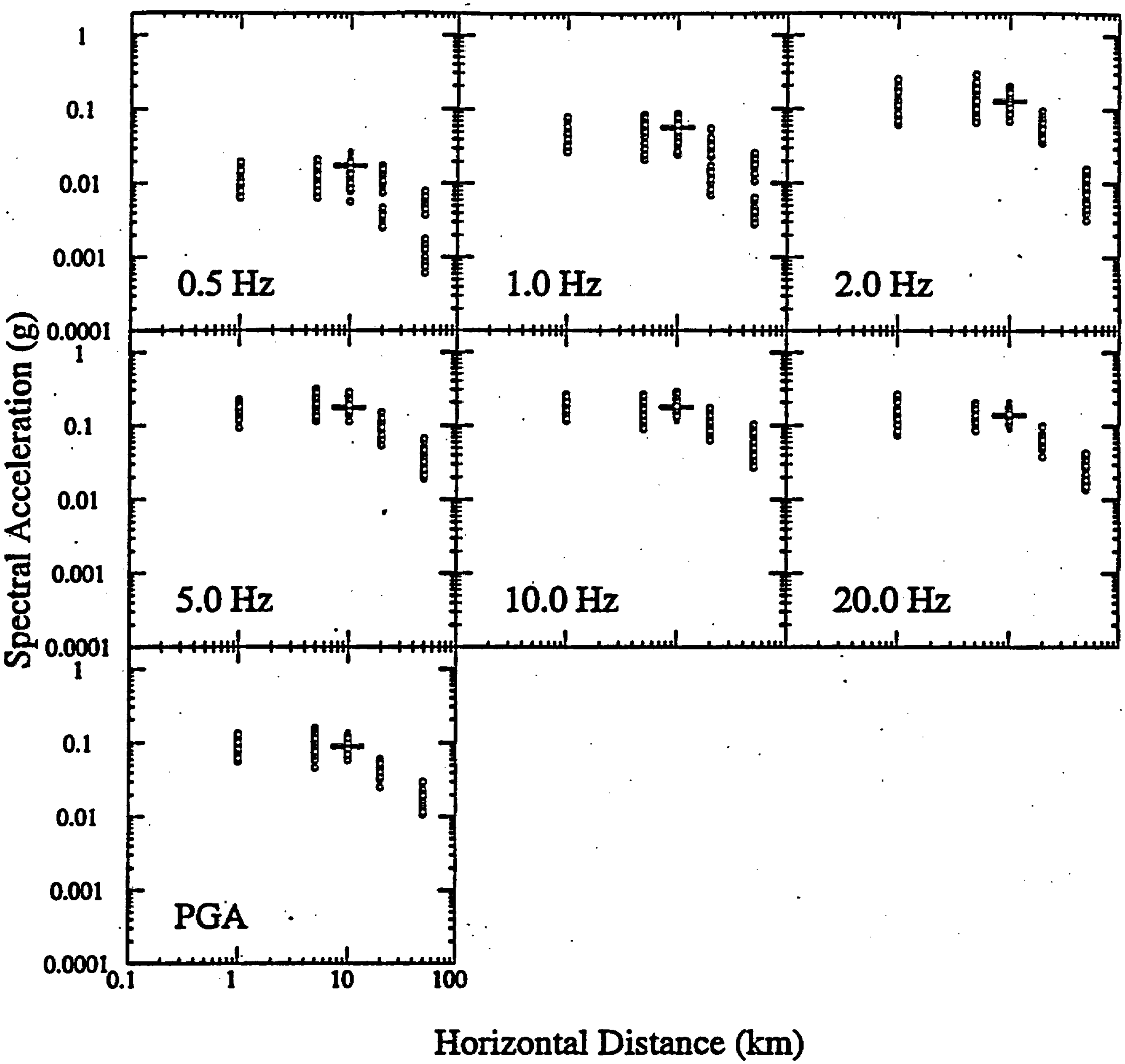

Thu Jan 30 14:42:34 PST 1997

**Display of Attenuation for M 5.8 and M 6.5 for Discrete Periods**

- o Unlike tabulated values, we have not corrected these spectra for rupture directivity
- o M5.8d means magnitude 5.8 deep; M5.8s means magnitude 5.8 shallow
- o Two dip angles, 60 and 90 degrees, are shown.
- o Many more results are shown than required for the exercise
- o Values required for exercise, shown as horizontal bars, are averages over 15 simulations whose complete range is shown as vertical lines of circles.
- o Hanging wall and foot wall values are not distinguished.



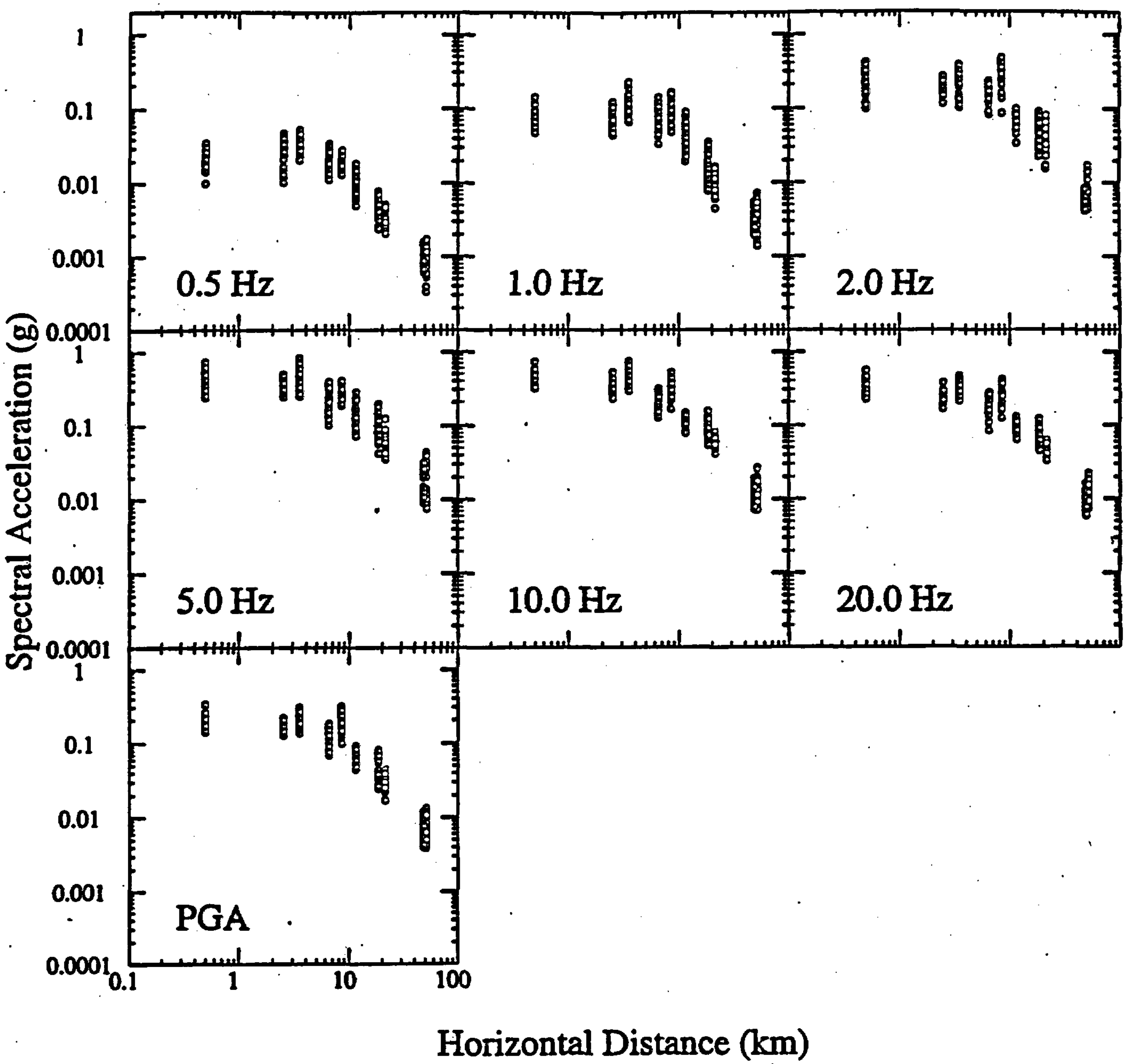

*M5.8d, Dip 60.0, Horizontal Components*



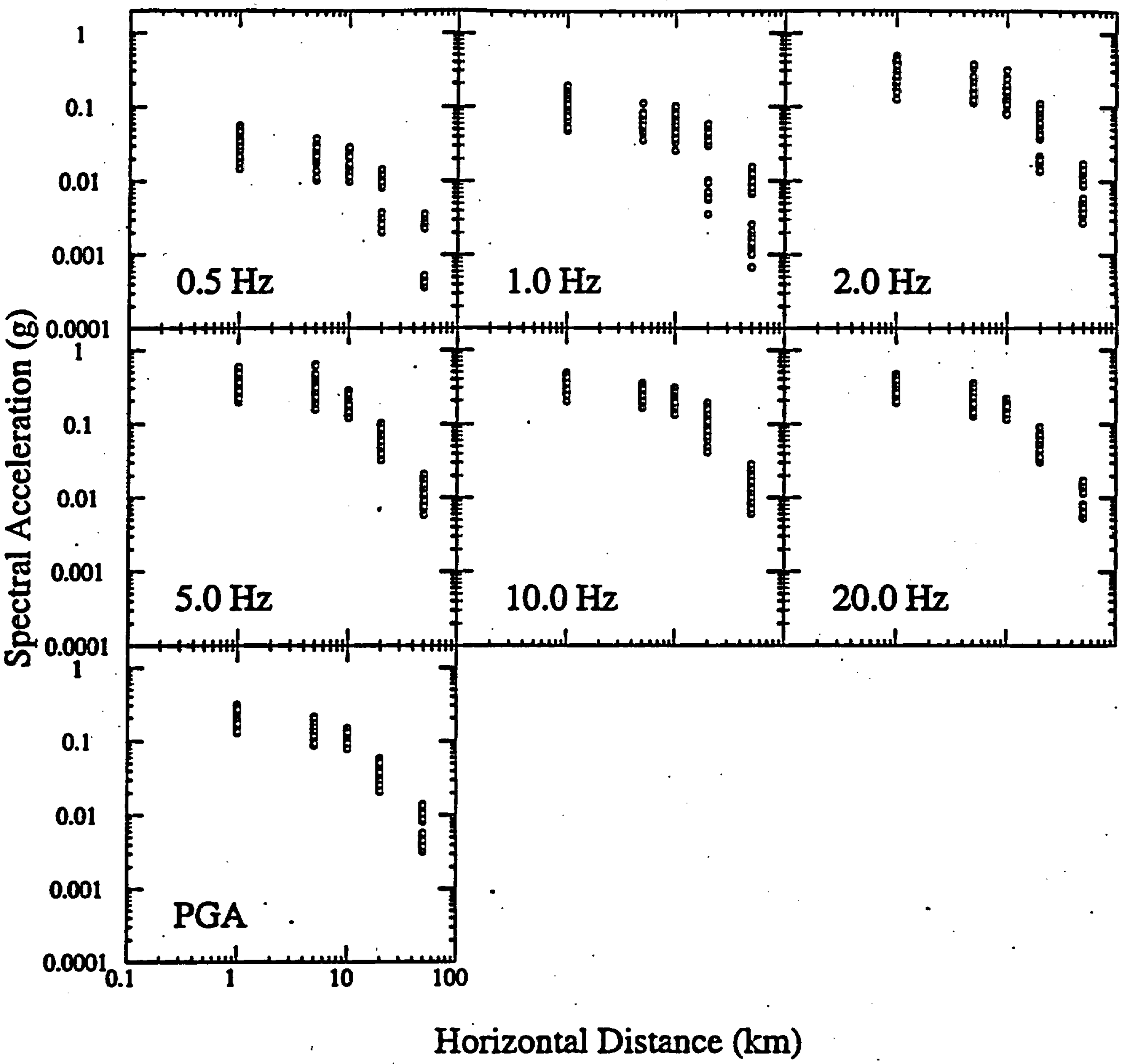

*M5.8d, Dip 90.0, Horizontal Components*



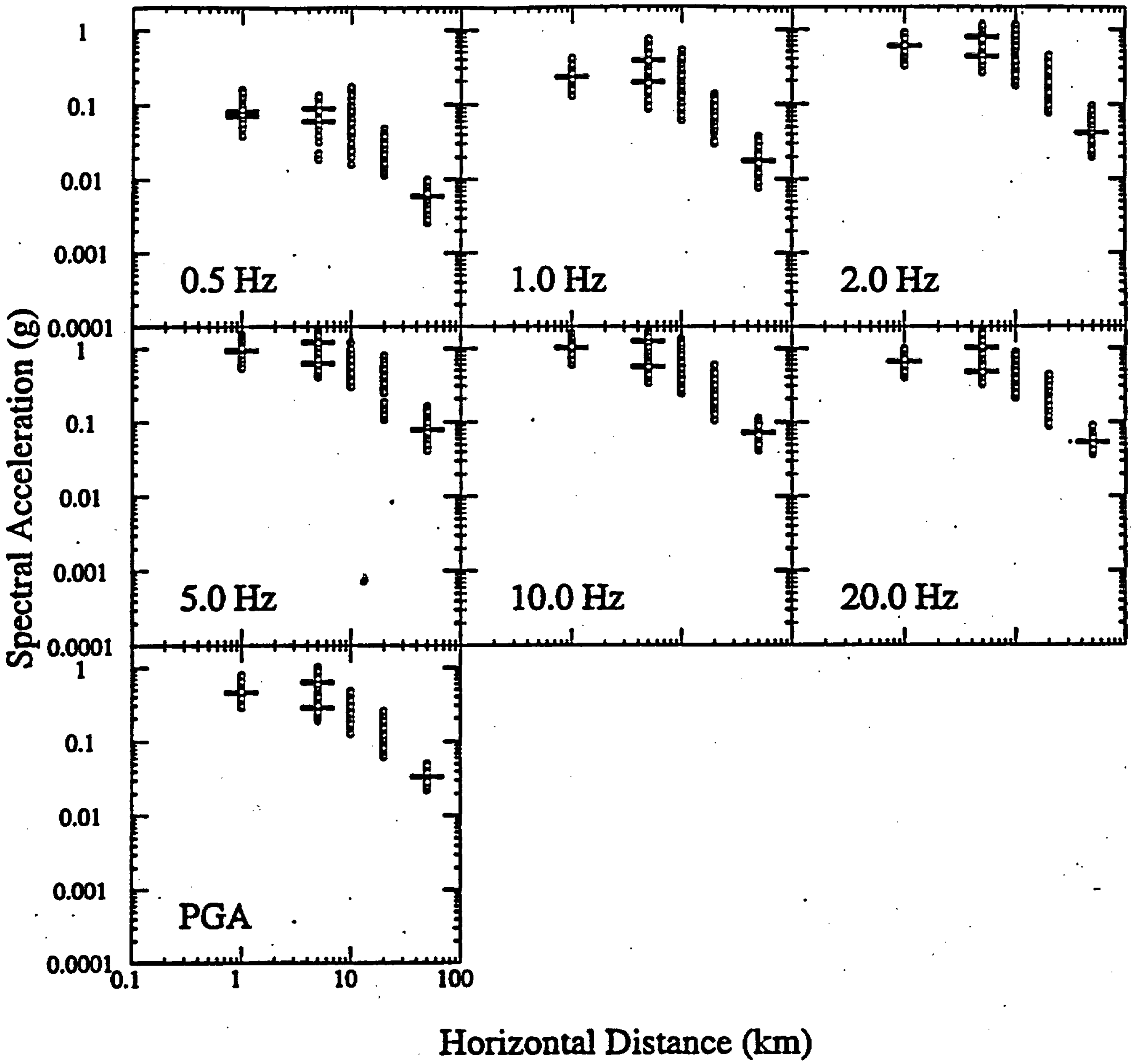
0: Fri Jan 31 16:40:04 PST 1997
.ancy/Yucca/BroadBand/Amen/Amplot_m5.8d_90_h.exh




*M5.8s, Dip 60.0, Horizontal Components*

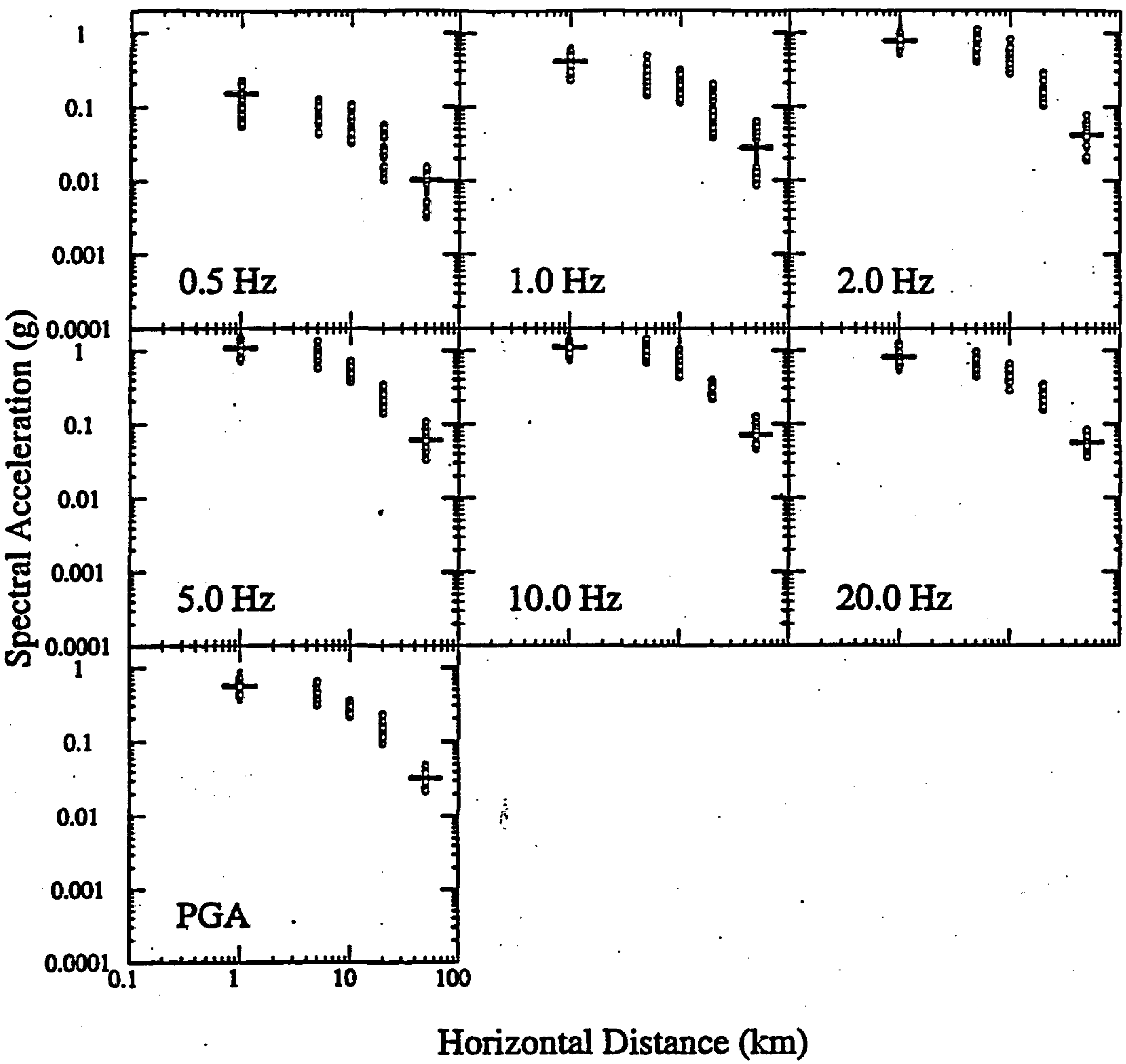



*M5.8s, Dip 90.0, Horizontal Components*




*M6.5, Dip 60.0, Horizontal Components*

Fri Jan 31 17:17:43 PST 1997




*M6.5, Dip 90.0, Horizontal Components*

# Section 3.2

## Silva Finite Fault Simulations for "Scenario Eqk Report" Events

## 3.2 Silva - Scenario earthquake simulations

Silva has repeated the scenario earthquake simulations for the normal faulting cases (N01, N03, N04, N07, N08) using the velocity structure for $YM_{300}$. These cases and site locations are given in the scenario earthquake report (see Tables 8.4, 8.5, and 8.6 and Figure 8-2 in the scenario earthquake report). N01 is the reference M6.4 event. N03 and N04 are for variations in the dip. N07 and N08 are for variations in the static stress drop. These variations of the simulations are parameterized in terms of the parameteric variability in the following tables.

**Numerical Simulation (Silva) (Model 1)**
**(.5, 1, 2, 5, 10, 20 hz)**

| Numerical Simulation (Silva) (Model 1) Freq = .5 hz | | | | | |
|---|---|---|---|---|---|
| | | | Parametric Aleatory | | |
| Site | N01 Median | Modeling Aleatory | dip | static Δσ | hypo, slip |
| 1 | 0.13913 | .71 | .17 | | 0.54743 |
| 2 | 0.14643 | .71 | .17 | | 0.55421 |
| 3 | 0.10953 | .71 | .17 | | 0.47319 |
| 4 | 0.12778 | .71 | .17 | | 0.42962 |
| 5 | 0.07350 | .71 | .17 | | 0.40146 |
| 6 | 0.02415 | .71 | .17 | | 0.39609 |
| 7 | 0.11957 | .71 | .17 | | 0.53078 |
| 8 | 0.10452 | .71 | .17 | | 0.46069 |
| 9 | 0.08191 | .71 | .17 | | 0.35055 |
| 10 | 0.08023 | .71 | .17 | | 0.38889 |
| 11 | 0.02690 | .71 | .17 | | 0.40705 |
| 12 | 0.01280 | .71 | .17 | | 0.43094 |
| 13 | 0.10086 | .71 | .17 | | 0.29140 |
| 14 | 0.04954 | .71 | .17 | | 0.48379 |

| Numerical Simulation (Silva) (Model 1) Freq = 1 hz | | | | | |
|---|---|---|---|---|---|
| | | | Parametric Aleatory | | |
| Site | N01 Median | Modeling Aleatory | dip | static Δσ | hypo, slip |
| 1 | 0.35004 | .80 | .16 | | 0.34571 |
| 2 | 0.39094 | .80 | .16 | | 0.33591 |
| 3 | 0.23563 | .80 | .16 | | 0.43233 |
| 4 | 0.31213 | .80 | .16 | | 0.37923 |
| 5 | 0.17045 | .80 | .16 | | 0.30868 |
| 6 | 0.06655 | .80 | .16 | | 0.32547 |
| 7 | 0.30388 | .80 | .16 | | 0.36033 |
| 8 | 0.25819 | .80 | .16 | | 0.30185 |
| 9 | 0.16677 | .80 | .16 | | 0.36872 |
| 10 | 0.19120 | .80 | .16 | | 0.31216 |
| 11 | 0.08736 | .80 | .16 | | 0.33607 |
| 12 | 0.03648 | .80 | .16 | | 0.30931 |
| 13 | 0.28418 | .80 | .16 | | 0.32199 |
| 14 | 0.14260 | .80 | .16 | | 0.33259 |

| Numerical Simulation (Silva) (Model 1) Freq = 2 hz | | | | | |
|---|---|---|---|---|---|
| Site | N01 Median | Modeling Aleatory | Parametric Aleatory | | |
| | | | dip | static Δσ | hypo, slip |
| 1 | 0.73426 | .63 | .15 | | 0.39386 |
| 2 | 0.74013 | .63 | .15 | | 0.32529 |
| 3 | 0.51328 | .63 | .15 | | 0.27372 |
| 4 | 0.70924 | .63 | .15 | | 0.33703 |
| 5 | 0.36160 | .63 | .15 | | 0.33499 |
| 6 | 0.11393 | .63 | .15 | | 0.27005 |
| 7 | 0.62649 | .63 | .15 | | 0.31392 |
| 8 | 0.47390 | .63 | .15 | | 0.27505 |
| 9 | 0.36578 | .63 | .15 | | 0.26138 |
| 10 | 0.36964 | .63 | .15 | | 0.27023 |
| 11 | 0.13274 | .63 | .15 | | 0.23224 |
| 12 | 0.06164 | .63 | .15 | | 0.32265 |
| 13 | 0.48597 | .63 | .15 | | 0.27715 |
| 14 | 0.21157 | .63 | .15 | | 0.27634 |

| Numerical Simulation (Silva) (Model 1) Freq = 5 hz | | | | | |
|---|---|---|---|---|---|
| Site | N01 Median | Modeling Aleatory | Parametric Aleatory | | |
| | | | dip | static Δσ | hypo, slip |
| 1 | 1.46383 | .35 | .13 | | 0.35173 |
| 2 | 1.51426 | .35 | .13 | | 0.27804 |
| 3 | 0.89306 | .35 | .13 | | 0.30130 |
| 4 | 1.42467 | .35 | .13 | | 0.31540 |
| 5 | 0.63101 | .35 | .13 | | 0.23787 |
| 6 | 0.18603 | .35 | .13 | | 0.26232 |
| 7 | 1.18949 | .35 | .13 | | 0.28787 |
| 8 | 1.01035 | .35 | .13 | | 0.29464 |
| 9 | 0.72373 | .35 | .13 | | 0.29915 |
| 10 | 0.73908 | .35 | .13 | | 0.26408 |
| 11 | 0.22513 | .35 | .13 | | 0.22378 |
| 12 | 0.11319 | .35 | .13 | | 0.19990 |
| 13 | 0.92230 | .35 | .13 | | 0.30005 |
| 14 | 0.38599 | .35 | .13 | | 0.21240 |

| Numerical Simulation (Silva) (Model 1) Freq = 10 hz | | | | | |
|---|---|---|---|---|---|
| Site | N01 Median | Modeling Aleatory | Parametric Aleatory | | |
| | | | dip | static Δσ | hypo, slip |
| 1 | 1.79633 | .38 | .12 | | 0.31252 |
| 2 | 1.88558 | .38 | .12 | | 0.29524 |
| 3 | 1.18375 | .38 | .12 | | 0.34209 |
| 4 | 1.72773 | .38 | .12 | | 0.28160 |
| 5 | 0.71683 | .38 | .12 | | 0.26558 |
| 6 | 0.19186 | .38 | .12 | | 0.24728 |
| 7 | 1.38717 | .38 | .12 | | 0.26503 |
| 8 | 1.18530 | .38 | .12 | | 0.24705 |
| 9 | 0.84814 | .38 | .12 | | 0.30985 |
| 10 | 0.87158 | .38 | .12 | | 0.26473 |
| 11 | 0.24765 | .38 | .12 | | 0.18644 |
| 12 | 0.11744 | .38 | .12 | | 0.14901 |
| 13 | 1.08335 | .38 | .12 | | 0.20530 |
| 14 | 0.41901 | .38 | .12 | | 0.22381 |

| Numerical Simulation (Silva) (Model 1) Freq = 20 hz | | | | | |
|---|---|---|---|---|---|
| Site | N01 Median | Modeling Aleatory | Parametric Aleatory | | |
| | | | dip | static Δσ | hypo, slip |
| 1 | 1.68699 | .33 | .10 | | 0.36341 |
| 2 | 1.74833 | .33 | .10 | | 0.27719 |
| 3 | 1.04367 | .33 | .10 | | 0.29164 |
| 4 | 1.58250 | .33 | .10 | | 0.26958 |
| 5 | 0.60689 | .33 | .10 | | 0.24424 |
| 6 | 0.16858 | .33 | .10 | | 0.20560 |
| 7 | 1.33397 | .33 | .10 | | 0.29648 |
| 8 | 1.07103 | .33 | .10 | | 0.25996 |
| 9 | 0.69699 | .33 | .10 | | 0.27289 |
| 10 | 0.77563 | .33 | .10 | | 0.21505 |
| 11 | 0.22336 | .33 | .10 | | 0.15381 |
| 12 | 0.09404 | .33 | .10 | | 0.14757 |
| 13 | 0.96551 | .33 | .10 | | 0.20608 |
| 14 | 0.38247 | .33 | .10 | | 0.17374 |

| Numerical Simulation (Silva) (Model 1)<br>Freq = 100 hz | | | | | |
|---|---|---|---|---|---|
| Site | N01<br>Median | Modeling<br>Aleatory | Parametric Aleatory | | |
| | | | dip | static Δσ | hypo, slip |
| 1 | 0.83123 | .33 | .10 | | 0.32954 |
| 2 | 0.87771 | .33 | .10 | | 0.29222 |
| 3 | 0.51831 | .33 | .10 | | 0.28893 |
| 4 | 0.78583 | .33 | .10 | | 0.26911 |
| 5 | 0.32327 | .33 | .10 | | 0.24932 |
| 6 | 0.09135 | .33 | .10 | | 0.21946 |
| 7 | 0.66525 | .33 | .10 | | 0.29090 |
| 8 | 0.54228 | .33 | .10 | | 0.24685 |
| 9 | 0.36586 | .33 | .10 | | 0.29009 |
| 10 | 0.39493 | .33 | .10 | | 0.22810 |
| 11 | 0.11671 | .33 | .10 | | 0.15827 |
| 12 | 0.05264 | .33 | .10 | | 0.15167 |
| 13 | 0.49546 | .33 | .10 | | 0.22342 |
| 14 | 0.19915 | .33 | .10 | | 0.17691 |

## Section 3.3

## Silva Finite Fault Simulations

## 3.3.1 Silva - 41 YM Cases

Silva computed all cases required for the project with magnitude ≥ 5.8. These cases are all those shown on page 1.1-4 excepting the magnitude 5.0 cases.

Median Sa-Horizontal Component (g): REV. 0



3.3.1-1

| Frequency* (Hz) | $M_W$ 5.8 | | | | | | | | $M_W$ 5.8 Deep | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | FW | SS | HW | FW | SS | HW | HW | FW | SS | HW |
| | 1km | 5km | 5km | 10km | 10km | 10km | 50km | 50km | 5km | 5km | 10km | 20km |
| 0.30 | 0.032 | 0.026 | 0.014 | 0.010 | 0.013 | 0.007 | 0.001 | 0.001 | 0.018 | 0.012 | 0.011 | 0.007 |
| 0.50 | 0.078 | 0.075 | 0.046 | 0.031 | 0.046 | 0.025 | 0.005 | 0.004 | 0.061 | 0.040 | 0.030 | 0.022 |
| 1.00 | 0.303 | 0.275 | 0.155 | 0.135 | 0.224 | 0.075 | 0.017 | 0.015 | 0.192 | 0.121 | 0.120 | 0.106 |
| 2.00 | 0.702 | 0.679 | 0.305 | 0.300 | 0.442 | 0.174 | 0.028 | 0.022 | 0.392 | 0.259 | 0.249 | 0.233 |
| 5.00 | 1.095 | 1.040 | 0.489 | 0.489 | 0.710 | 0.270 | 0.040 | 0.039 | 0.593 | 0.375 | 0.412 | 0.343 |
| 10.00 | 1.308 | 1.146 | 0.529 | 0.471 | 0.692 | 0.275 | 0.034 | 0.027 | 0.632 | 0.393 | 0.409 | 0.340 |
| 20.00 | 0.909 | 0.810 | 0.379 | 0.364 | 0.517 | 0.200 | 0.023 | 0.020 | 0.448 | 0.275 | 0.296 | 0.236 |
| 100.00 | 0.598 | 0.537 | 0.255 | 0.244 | 0.348 | 0.137 | 0.018 | 0.015 | 0.307 | 0.193 | 0.203 | 0.165 |
| PGV** (cm/sec) | 35.62 | 32.23 | 16.46 | 14.69 | 8.75 | 8.75 | 1.42 | 1.93 | 20.31 | 13.10 | 12.71 | 10.43 |

*5% damped pseudo absolute response spectra

**Equivalent to PGA

3.3.1-2

Pacific Engineering: Silva Finite Fault — March 14, 1997

Median Sa-Horizontal Component (g): — REV. 0



| Frequency* (Hz) | $M_W$ 6.5 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | FW | SS | HW | FW | SS | HW | FW | SS | HW | FW | SS | HW | SS | SS |
| | 1km | 1km | 1km | 5km | 5km | 5km | 10km | 10km | 10km | 20km | 20km | 20km | 50km | 50km | 100km | 160km |
| 0.30 | 0.056 | 0.058 | 0.048 | 0.045 | 0.055 | 0.032 | 0.031 | 0.043 | 0.020 | 0.014 | 0.018 | 0.009 | 0.008 | 0.004 | 0.005 | 0.004 |
| 0.50 | 0.174 | 0.150 | 0.129 | 0.135 | 0.144 | 0.084 | 0.086 | 0.129 | 0.053 | 0.048 | 0.062 | 0.031 | 0.019 | 0.013 | 0.014 | 0.008 |
| 1.00 | 0.508 | 0.477 | 0.402 | 0.404 | 0.450 | 0.266 | 0.258 | 0.378 | 0.159 | 0.133 | 0.188 | 0.090 | 0.066 | 0.046 | 0.043 | 0.020 |
| 2.00 | 0.875 | 0.905 | 0.728 | 0.690 | 0.836 | 0.463 | 0.469 | 0.677 | 0.297 | 0.265 | 0.358 | 0.169 | 0.102 | 0.082 | 0.063 | 0.029 |
| 5.00 | 1.316 | 1.492 | 1.217 | 1.093 | 1.425 | 0.775 | 0.709 | 1.090 | 0.485 | 0.423 | 0.568 | 0.277 | 0.160 | 0.120 | 0.074 | 0.032 |
| 10.00 | 1.337 | 1.491 | 1.157 | 1.060 | 1.379 | 0.730 | 0.699 | 1.075 | 0.466 | 0.386 | 0.521 | 0.239 | 0.134 | 0.108 | 0.056 | 0.020 |
| 20.00 | 0.980 | 1.036 | 0.835 | 0.761 | 0.990 | 0.517 | 0.492 | 0.753 | 0.320 | 0.249 | 0.344 | 0.158 | 0.085 | 0.067 | 0.037 | 0.015 |
| 100.00 | 0.619 | 0.668 | 0.535 | 0.494 | 0.633 | 0.338 | 0.323 | 0.491 | 0.213 | 0.173 | 0.238 | 0.113 | 0.065 | 0.050 | 0.032 | 0.013 |
| PGV** (cm/sec) | 45.51 | 45.25 | 37.23 | 36.17 | 43.39 | 25.01 | 23.48 | 34.82 | 14.96 | 12.06 | 16.48 | 8.12 | 5.19 | 3.67 | 3.23 | 1.61 |

*5% damped pseudo absolute response spectra

**Equivalent to PGA

3.3.1-3

Pacific Engineering: Silva Finite Fault — March 14, 1997

Median Sa-Horizontal Component (g): — REV. 0



| Frequency* (Hz) | $M_w$ 7.0 | | | | | | $M_w$ 7.5 | | | | | M 8.0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | SS | HW | FW | SS | HW | SS | SS | HW | SS | HW | SS | SS |
| | 1 km | 10 km | 10 km | 10 km | 50 km | 50 km | 1 km | 10 km | 10 km | 50 km | 50 km | 50 km | 160 km |
| 0.30 | 0.085 | 0.060 | 0.066 | 0.036 | 0.017 | 0.018 | 0.096 | 0.072 | 0.066 | 0.031 | 0.030 | 0.036 | 0.022 |
| 0.50 | 0.217 | 0.145 | 0.166 | 0.096 | 0.040 | 0.040 | 0.203 | 0.160 | 0.160 | 0.061 | 0.061 | 0.062 | 0.034 |
| 1.00 | 0.484 | 0.336 | 0.413 | 0.222 | 0.090 | 0.106 | 0.454 | 0.326 | 0.356 | 0.123 | 0.130 | 0.115 | 0.057 |
| 2.00 | 0.873 | 0.615 | 0.710 | 0.389 | 0.151 | 0.171 | 0.847 | 0.575 | 0.587 | 0.200 | 0.210 | 0.202 | 0.082 |
| 5.00 | 1.541 | 1.035 | 1.269 | 0.642 | 0.223 | 0.251 | 1.395 | 0.966 | 0.992 | 0.272 | 0.290 | 0.265 | 0.075 |
| 10.00 | 1.575 | 1.001 | 1.261 | 0.617 | 0.185 | 0.216 | 1.348 | 0.903 | 0.932 | 0.216 | 0.232 | 0.195 | 0.046 |
| 20.00 | 1.030 | 0.644 | 0.838 | 0.396 | 0.114 | 0.132 | 0.862 | 0.565 | 0.585 | 0.133 | 0.143 | 0.123 | 0.035 |
| 100.00 | 0.663 | 0.426 | 0.534 | 0.266 | 0.088 | 0.100 | 0.567 | 0.383 | 0.393 | 0.106 | 0.113 | 0.101 | 0.033 |
| PGV** (cm/sec) | 47.24 | 31.14 | 38.04 | 19.97 | 7.57 | 8.21 | 40.50 | 28.93 | 29.52 | 10.09 | 10.39 | 9.96 | 5.01 |

*5% damped pseudo absolute response spectra

**Equivalent to PGA

| Frequency* (Hz) | $M_W$ 5.8 | | | | | | | | $M_W$ 5.8 Deep | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | FW | SS | HW | FW | SS | HW | HW | FW | SS | HW |
| | 1km | 5km | 5km | 10km | 10km | 10km | 50km | 50km | 5km | 5km | 10km | 20km |
| 0.30 | 0.303 | 0.387 | 0.354 | 0.339 | 0.261 | 0.373 | 0.276 | 0.351 | 0.347 | 0.374 | 0.301 | 0.333 |
| 0.50 | 0.490 | 0.474 | 0.398 | 0.479 | 0.437 | 0.322 | 0.280 | 0.344 | 0.406 | 0.377 | 0.389 | 0.466 |
| 1.00 | 0.453 | 0.437 | 0.414 | 0.418 | 0.352 | 0.401 | 0.303 | 0.337 | 0.447 | 0.421 | 0.337 | 0.366 |
| 2.00 | 0.375 | 0.323 | 0.296 | 0.299 | 0.262 | 0.345 | 0.288 | 0.227 | 0.337 | 0.353 | 0.283 | 0.286 |
| 5.00 | 0.219 | 0.214 | 0.188 | 0.225 | 0.211 | 0.194 | 0.230 | 0.185 | 0.192 | 0.218 | 0.218 | 0.164 |
| 10.00 | 0.259 | 0.254 | 0.238 | 0.218 | 0.183 | 0.199 | 0.172 | 0.137 | 0.206 | 0.180 | 0.171 | 0.132 |
| 20.00 | 0.226 | 0.233 | 0.210 | 0.238 | 0.207 | 0.201 | 0.166 | 0.134 | 0.188 | 0.166 | 0.159 | 0.117 |
| 100.00** | 0.223 | 0.227 | 0.202 | 0.232 | 0.200 | 0.203 | 0.175 | 0.136 | 0.198 | 0.181 | 0.149 | 0.122 |
| PGV (cm/sec) | 0.232 | 0.243 | 0.236 | 0.234 | 0.208 | 0.208 | 0.212 | 0.248 | 0.213 | 0.204 | 0.134 | 0.143 |

*5% damped pseudo absolute response spectra

**Equivalent to PGA

***Total Modeling Sigma: Computed over 15 earthquakes of M 5.8 to 7.4 at 487 sites and a fault distance range of about 1 to 500 km

3.3.1-4

| Frequency* (Hz) | $M_W$ 6.5 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | FW | SS | HW | FW | SS | HW | FW | SS | HW | FW | SS | HW | SS | SS |
| | 1km | 1km | 1km | 5km | 5km | 5km | 10km | 10km | 10km | 20km | 20km | 20km | 50km | 50km | 100km | 160km |
| 0.30 | 0.414 | 0.460 | 0.460 | 0.415 | 0.476 | 0.433 | 0.428 | 0.467 | 0.407 | 0.326 | 0.305 | 0.361 | 0.354 | 0.359 | 0.313 | 0.393 |
| 0.50 | 0.378 | 0.382 | 0.394 | 0.419 | 0.394 | 0.427 | 0.442 | 0.480 | 0.371 | 0.382 | 0.403 | 0.429 | 0.305 | 0.300 | 0.221 | 0.209 |
| 1.00 | 0.389 | 0.477 | 0.464 | 0.414 | 0.425 | 0.434 | 0.448 | 0.463 | 0.400 | 0.322 | 0.306 | 0.350 | 0.380 | 0.242 | 0.239 | 0.223 |
| 2.00 | 0.375 | 0.431 | 0.428 | 0.373 | 0.427 | 0.429 | 0.378 | 0.380 | 0.335 | 0.304 | 0.346 | 0.326 | 0.299 | 0.215 | 0.161 | 0.196 |
| 5.00 | 0.337 | 0.433 | 0.415 | 0.339 | 0.415 | 0.365 | 0.328 | 0.350 | 0.314 | 0.307 | 0.318 | 0.322 | 0.240 | 0.172 | 0.134 | 0.136 |
| 10.00 | 0.324 | 0.436 | 0.421 | 0.350 | 0.425 | 0.388 | 0.312 | 0.349 | 0.270 | 0.271 | 0.265 | 0.288 | 0.230 | 0.143 | 0.125 | 0.112 |
| 20.00 | 0.320 | 0.436 | 0.427 | 0.336 | 0.415 | 0.382 | 0.323 | 0.369 | 0.292 | 0.288 | 0.278 | 0.287 | 0.230 | 0.104 | 0.110 | 0.113 |
| 100.00** | 0.311 | 0.434 | 0.424 | 0.333 | 0.413 | 0.378 | 0.322 | 0.356 | 0.290 | 0.277 | 0.290 | 0.294 | 0.222 | 0.106 | 0.111 | 0.112 |
| PGV (cm/sec) | 0.309 | 0.401 | 0.392 | 0.334 | 0.387 | 0.355 | 0.343 | 0.381 | 0.310 | 0.262 | 0.271 | 0.295 | 0.214 | 0.140 | 0.142 | 0.164 |

3.3.1-5

*5% damped pseudo absolute response spectra

**Equivalent to PGA

***Total Modeling Sigma: Computed over 15 earthquakes of M 5.8 to 7.4 at 487 sites and a fault distance range of about 1 to 500 km

Pacific Engineering: Silva Finite Fault — March 14, 1997

Total Parametric Variability about Median Sa - Horizontal Component: — REV. 0



| Frequency* (Hz) | $M_w$ 7.0 | | | | | | $M_w$ 7.5 | | | | | M 8.0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | SS | HW | FW | SS | HW | SS | SS | HW | SS | HW | SS | SS | *** |
| | 1km | 10km | 10km | 10km | 50km | 50km | 1km | 10km | 10km | 50km | 50km | 50km | 160km | |
| 0.30 | 0.497 | 0.407 | 0.508 | 0.438 | 0.317 | 0.338 | 0.633 | 0.531 | 0.609 | 0.343 | 0.303 | 0.377 | 0.350 | 0.86 |
| 0.50 | 0.442 | 0.415 | 0.469 | 0.399 | 0.300 | 0.299 | 0.676 | 0.586 | 0.644 | 0.344 | 0.266 | 0.422 | 0.365 | 0.79 |
| 1.00 | 0.482 | 0.440 | 0.482 | 0.416 | 0.261 | 0.265 | 0.731 | 0.604 | 0.718 | 0.325 | 0.291 | 0.462 | 0.440 | 0.69 |
| 2.00 | 0.456 | 0.406 | 0.399 | 0.394 | 0.247 | 0.256 | 0.742 | 0.641 | 0.723 | 0.305 | 0.265 | 0.565 | 0.505 | 0.66 |
| 5.00 | 0.454 | 0.394 | 0.382 | 0.351 | 0.233 | 0.222 | 0.766 | 0.722 | 0.756 | 0.361 | 0.311 | 0.675 | 0.596 | 0.60 |
| 10.00 | 0.452 | 0.411 | 0.418 | 0.385 | 0.249 | 0.223 | 0.823 | 0.761 | 0.818 | 0.400 | 0.352 | 0.718 | 0.578 | 0.57 |
| 20.00 | 0.452 | 0.408 | 0.414 | 0.387 | 0.250 | 0.227 | 0.843 | 0.772 | 0.826 | 0.382 | 0.339 | 0.668 | 0.525 | 0.53 |
| 100.00** | 0.436 | 0.395 | 0.399 | 0.371 | 0.236 | 0.218 | 0.790 | 0.712 | 0.769 | 0.351 | 0.308 | 0.621 | 0.513 | 0.52 |
| PGV (cm/sec) | 0.415 | 0.340 | 0.382 | 0.355 | 0.236 | 0.217 | 0.694 | 0.599 | 0.676 | 0.306 | 0.265 | 0.443 | 0.384 | 0.69 |

*5% damped pseudo absolute response spectra

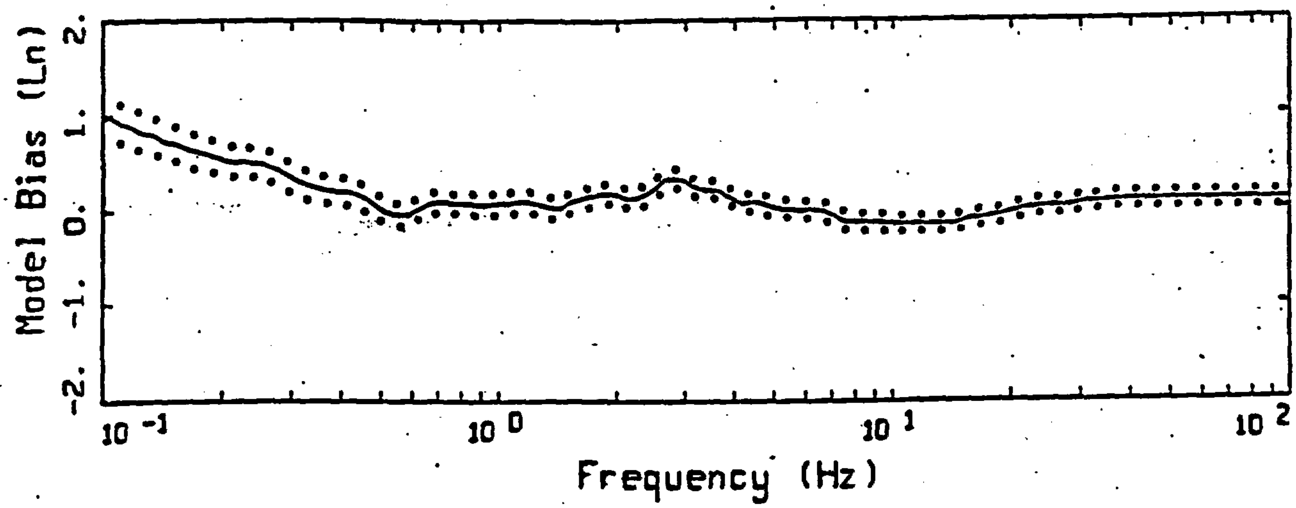
**Equivalent to PGA

***Total Modeling Sigma: Computed over 15 earthquakes of M 5.8 to 7.4 at 487 sites and a fault distance range of about 1 to 500 km

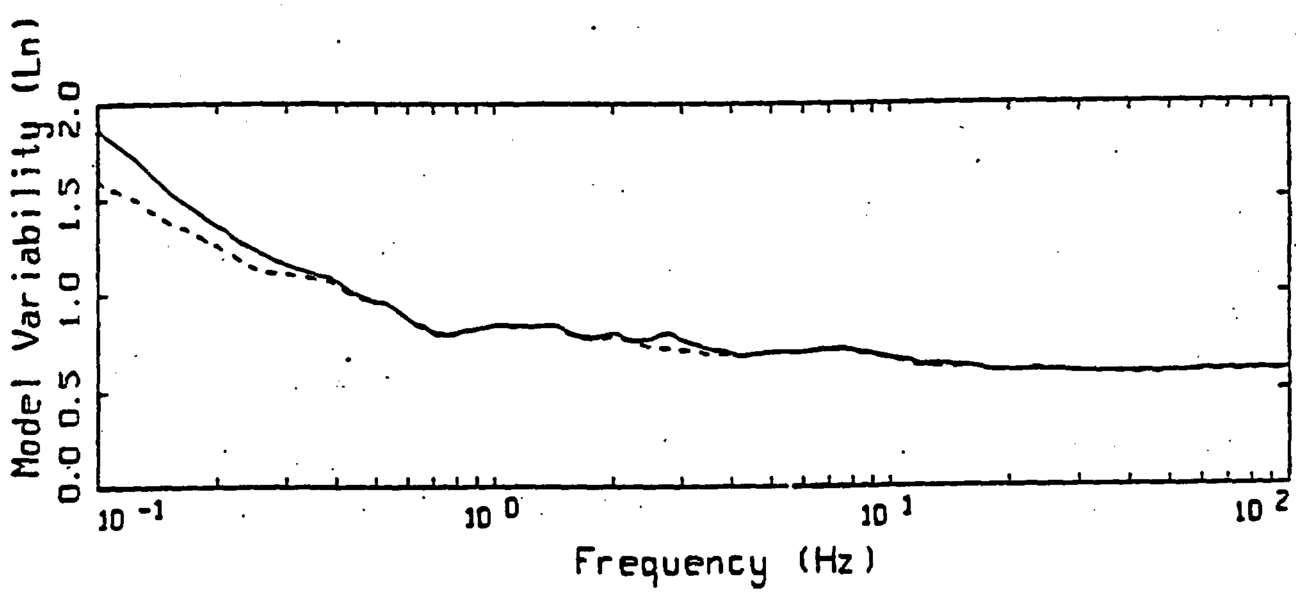
## Section 3.3.2

## Modeling Uncertainty for Silva Finite Fault Simulations

(see Section 13 for additional discussion)



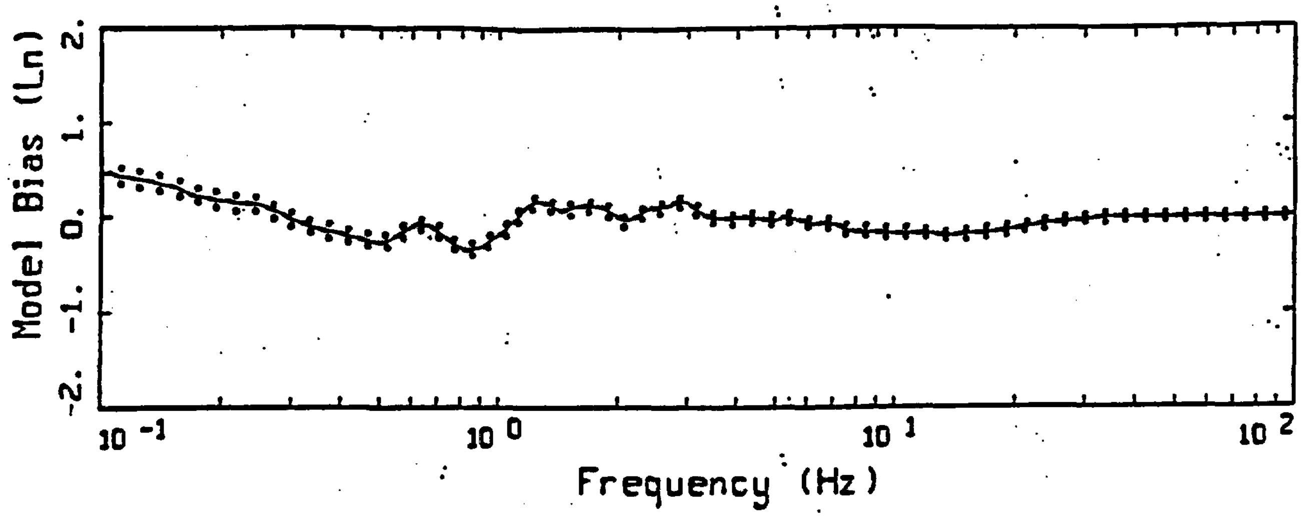

LEGEND
———— MODELING BIAS
• • • • • • 90% CONFIDENCE INTERVAL OF MODELING BIAS
• • • • • • 90% CONFIDENCE INTERVAL OF MODELING BIAS



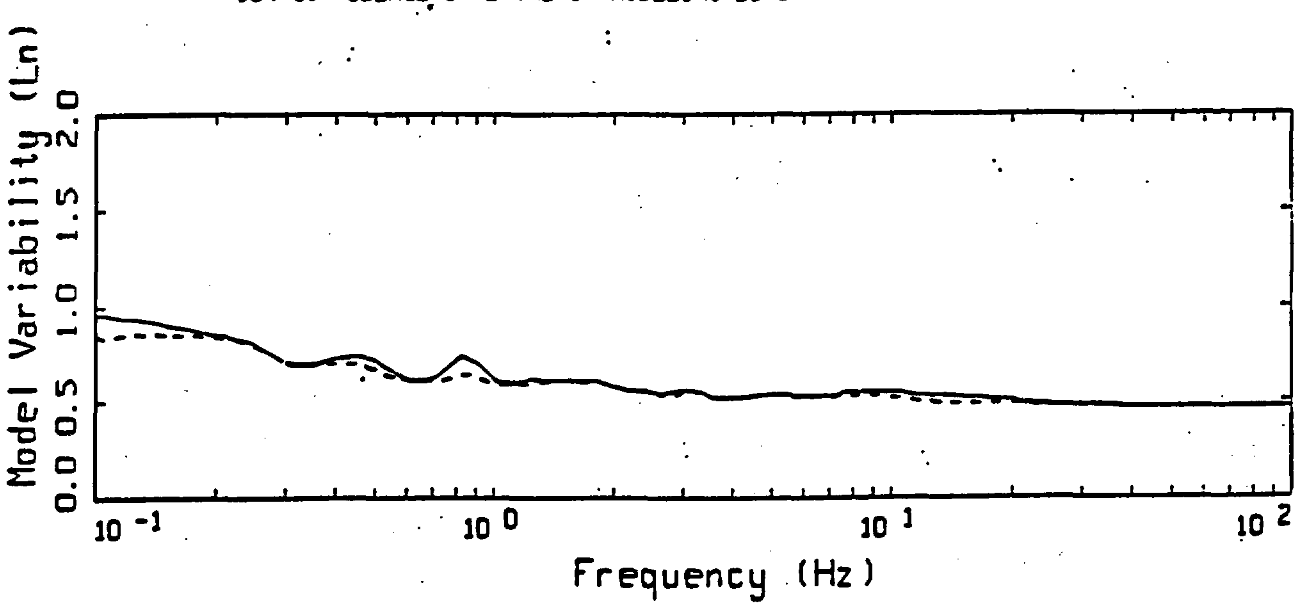

LEGEND
———— MEAN=0.0
------ BIAS CORRECTED

15 EARTHQUAKES FINITE-SOURCE
NONLINEAR, ALL 159 ROCK SITES

Figure 5.157




LEGEND
MODELING BIAS
90% CONFIDENCE INTERVAL OF MODELING BIAS
90% CONFIDENCE INTERVAL OF MODELING BIAS

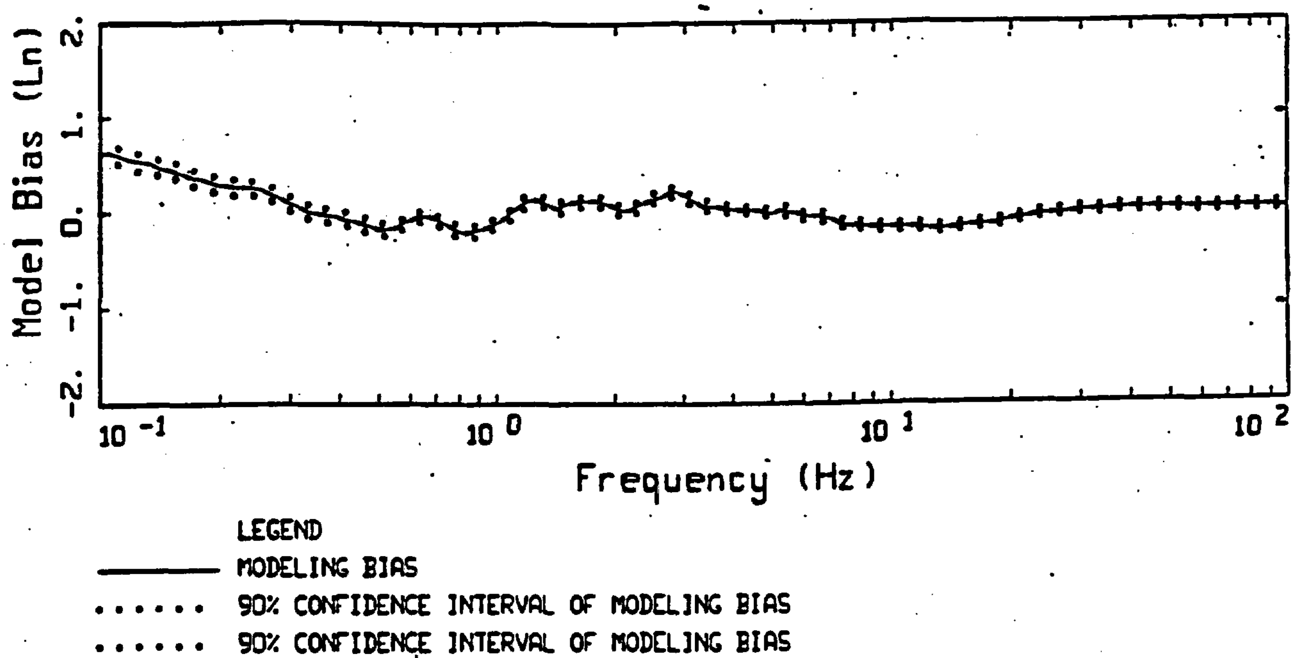


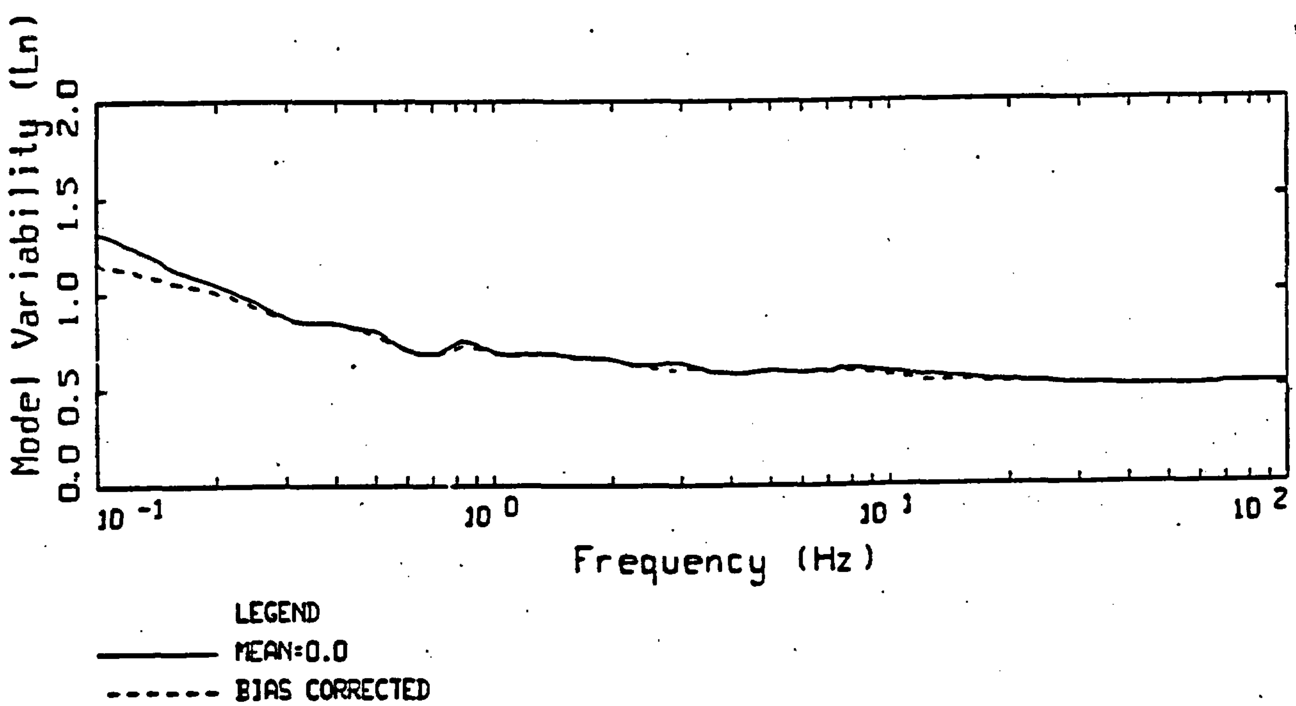

LEGEND
MEAN=0.0
BIAS CORRECTED

15 EARTHQUAKES FINITE-SOURCE
NONLINEAR, ALL 328 SOIL SITES

Figure 5.156

3.3.2-2




15 EARTHQUAKES FINITE-SOURCE
NONLINEAR, ALL 487 SITES

Figure 5.155

## Section 3.4

## Anderson and Zeng Simulations

March 10, 1997

# Revised Synthetics for Yucca Mountain Earthquake Scenarios

Yuehua Zeng and John G. Anderson

Seismological Laboratory /174, University of Nevada, Reno Nevada 89557.

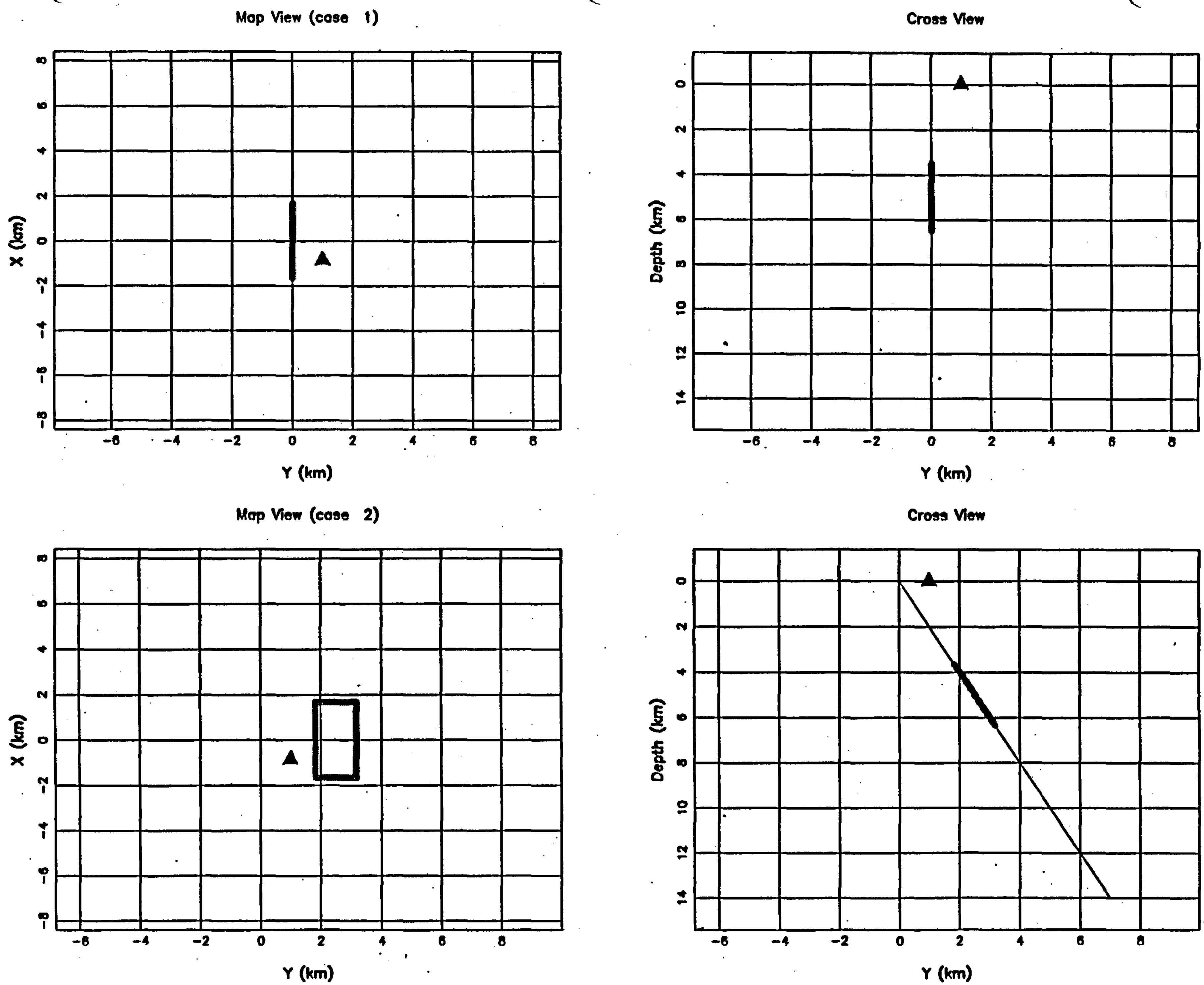
Contents

1. List of 16 Cases

| Case | M | Depth | Fault Type | $R_h$ | $R_{rup}$ | $R_{JB}$ |
|---|---|---|---|---|---|---|
| 1 | 5.0 | shallow | Strike-Slip | 1.0 | 3.64 | 1.0 |
| 2 | 5.0 | shallow | Normal (HW) | 1.0 | 3.76 | 0.84 |
| 3 | 5.0 | deep | Strike-Slip | 5.0 | 11.63 | 5.0 |
| 4 | 5.0 | deep | Normal (HW) | 5.0 | 10.66 | 0.34 |
| 5 | 5.8 | deep | Strike-Slip | 10.0 | 12.21 | 10.0 |
| 6 | 5.8 | deep | Normal (HW) | 20.0 | 17.89 | 12.99 |
| 7 | 6.5 | shallow | Strike-Slip | 1.0 | 1.0 | 1.0 |
| 8 | 6.5 | shallow | Normal (HW) | 1.0 | 0.89 | 0.0 |
| 9 | 6.5 | shallow | Normal (FW) | 1.0 | 1.0 | 1.0 |
| 10 | 6.5 | shallow | Normal (HW) | 5.0 | 4.47 | 0.0 |
| 11 | 6.5 | shallow | Normal (FW) | 5.0 | 5.0 | 5.0 |
| 12 | 6.5 | shallow | Strike-Slip | 50.0 | 50.0 | 50.0 |
| 13 | 6.5 | shallow | Normal (HW) | 50.0 | 45.97 | 44.76 |
| 14 | 7.0 | shallow | Strike-Slip | 10.0 | 10.0 | 10.0 |
| 15 | 7.5 | shallow | Strike-Slip | 50.0 | 50.0 | 50.0 |
| 16 | 7.5 | shallow | Normal (HW) | 50.0 | 45.21 | 42.99 |

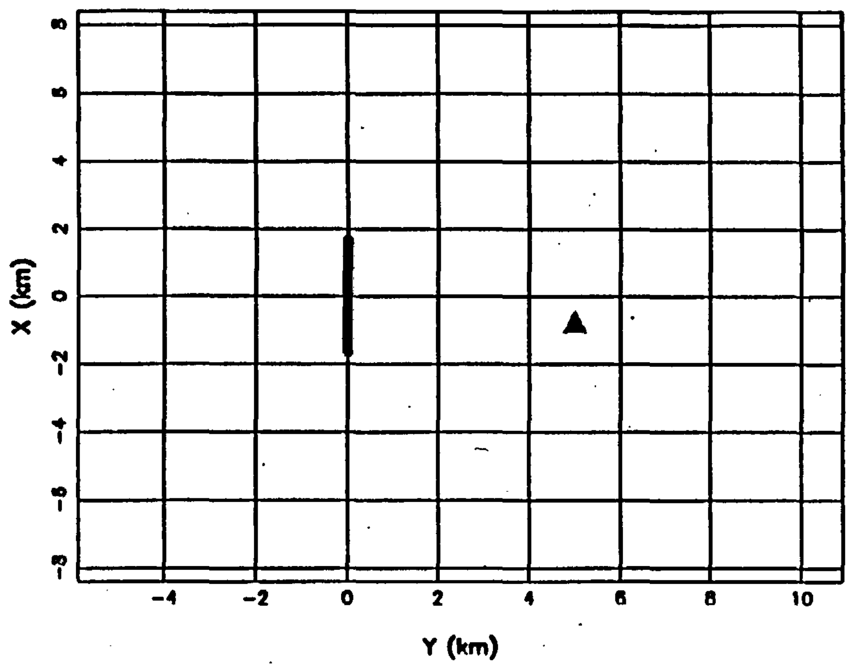
$R_h$: horizontal distance (km) from surface trace of "fault"
$R_{rup}$: closest distance to the rupture plane
$R_{JB}$: closest distance to the surface projection of rupture plane

## 2. Plots of the Source-receiver Geometry

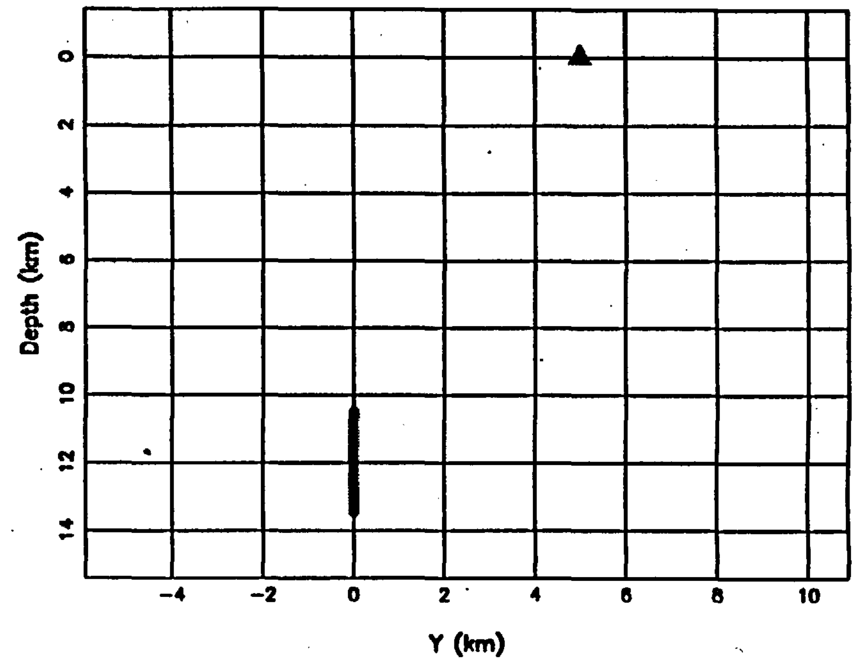


Map View (case 1)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)
Map View (case 2)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)

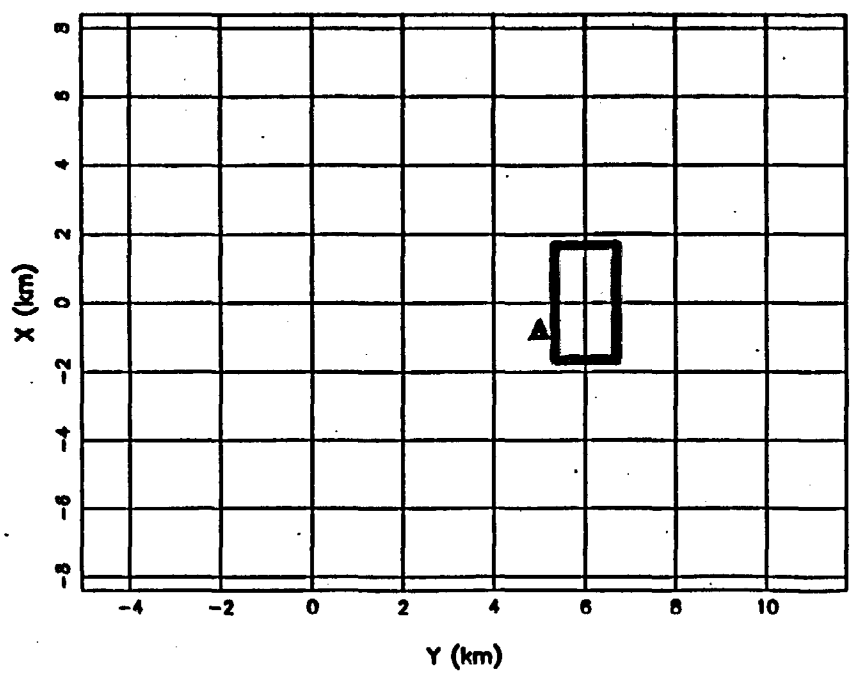
Map View (case 3)



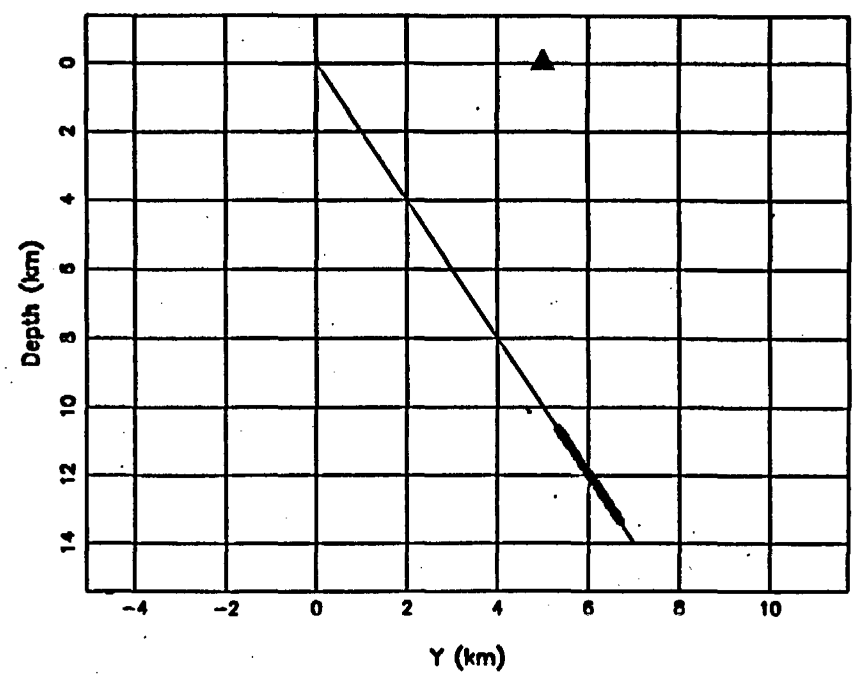

Cross View

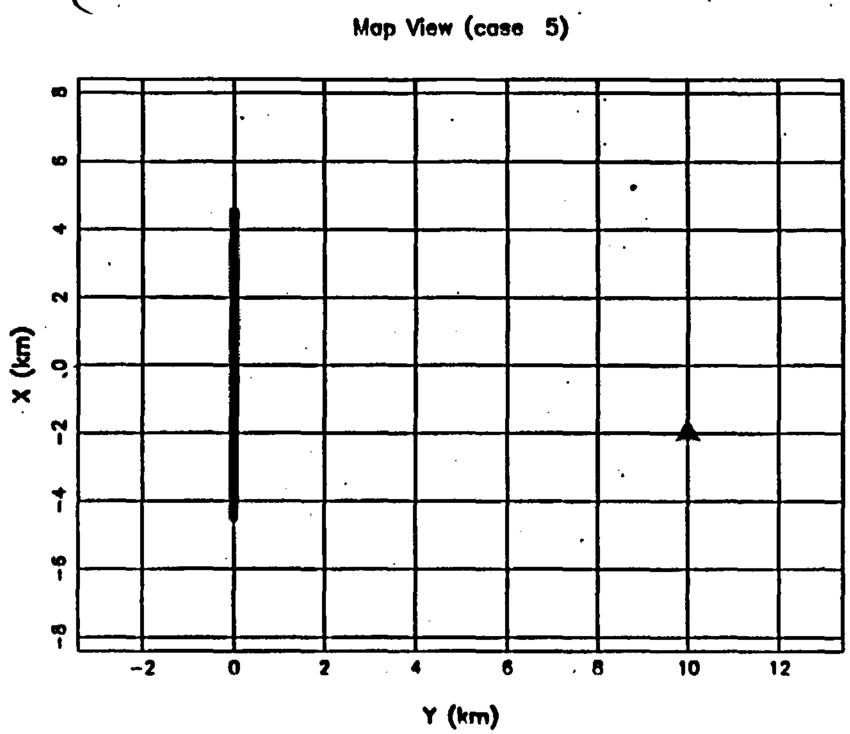


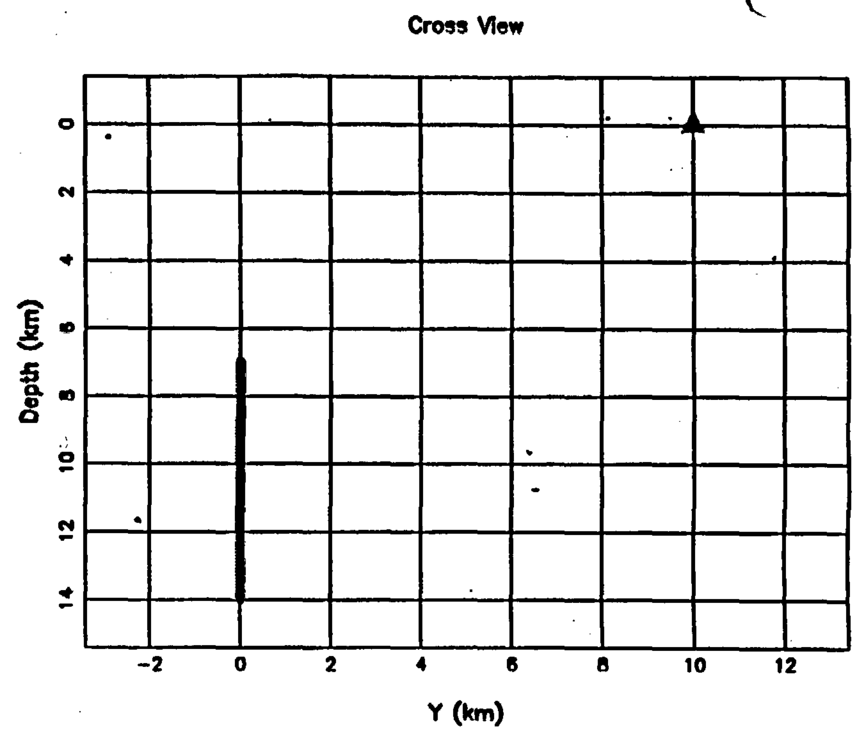

Map View (case 4)

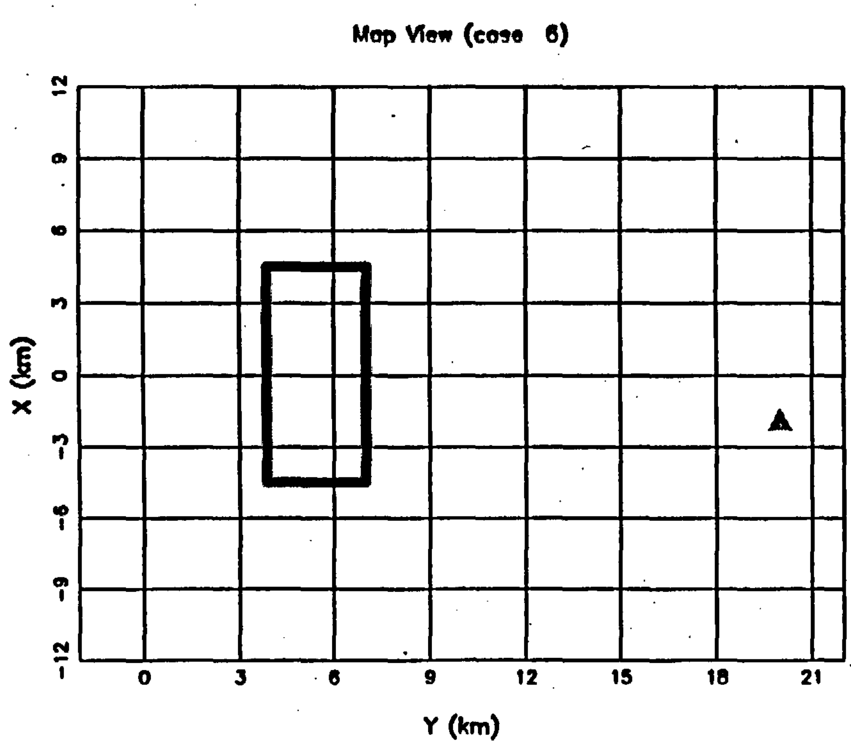


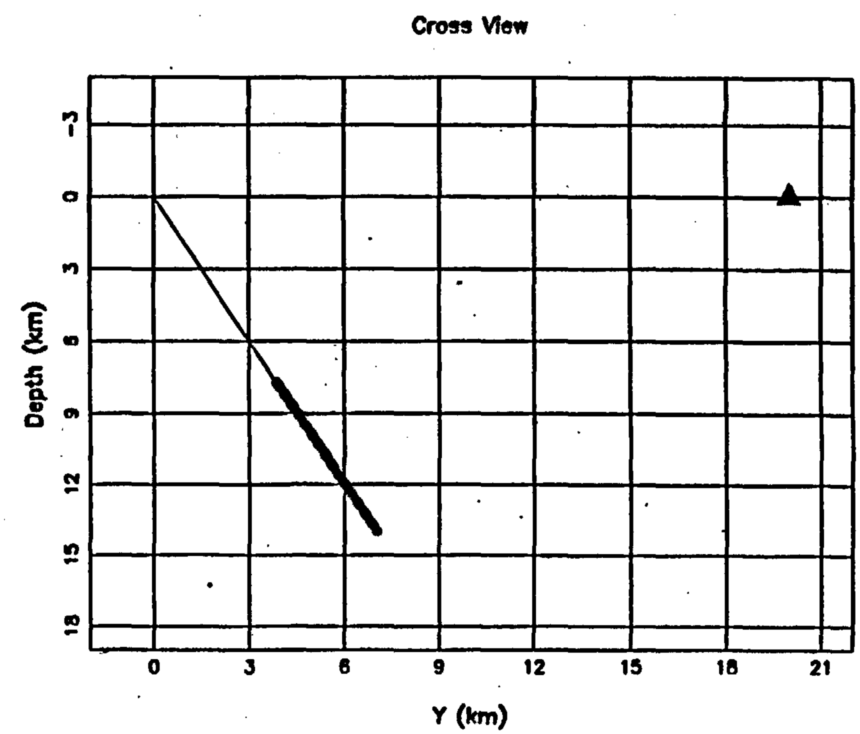

Cross View

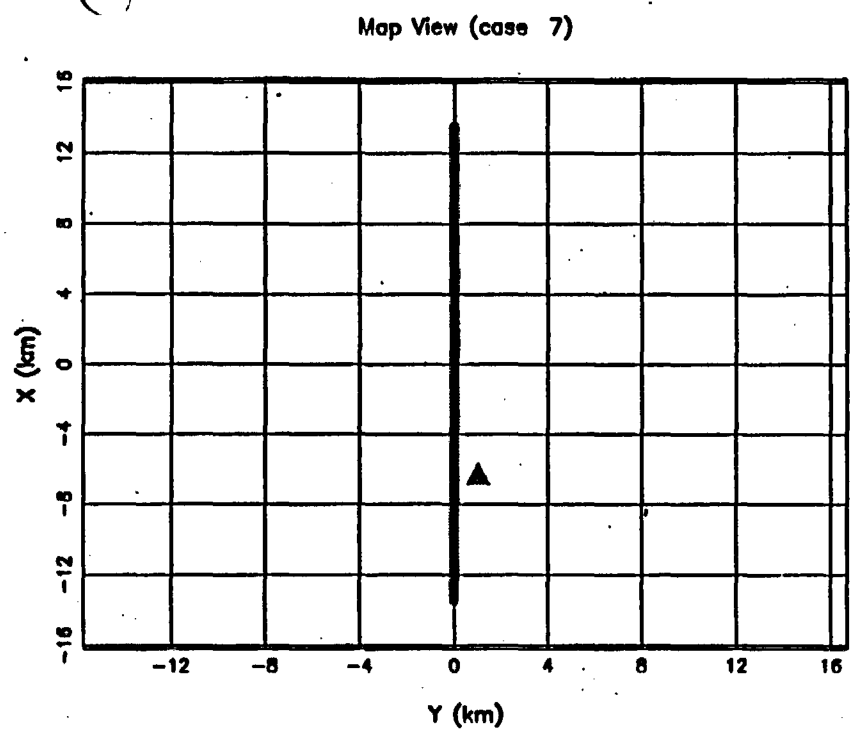



Map View (case 5)
X (km)
Y (km)

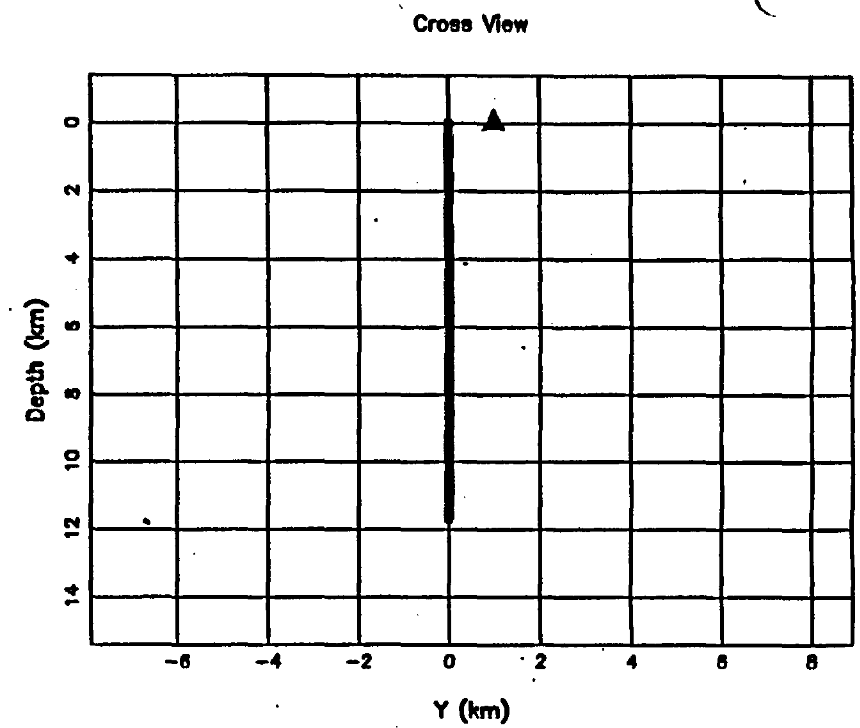

Cross View
Depth (km)
Y (km)


Map View (case 6)
X (km)
Y (km)

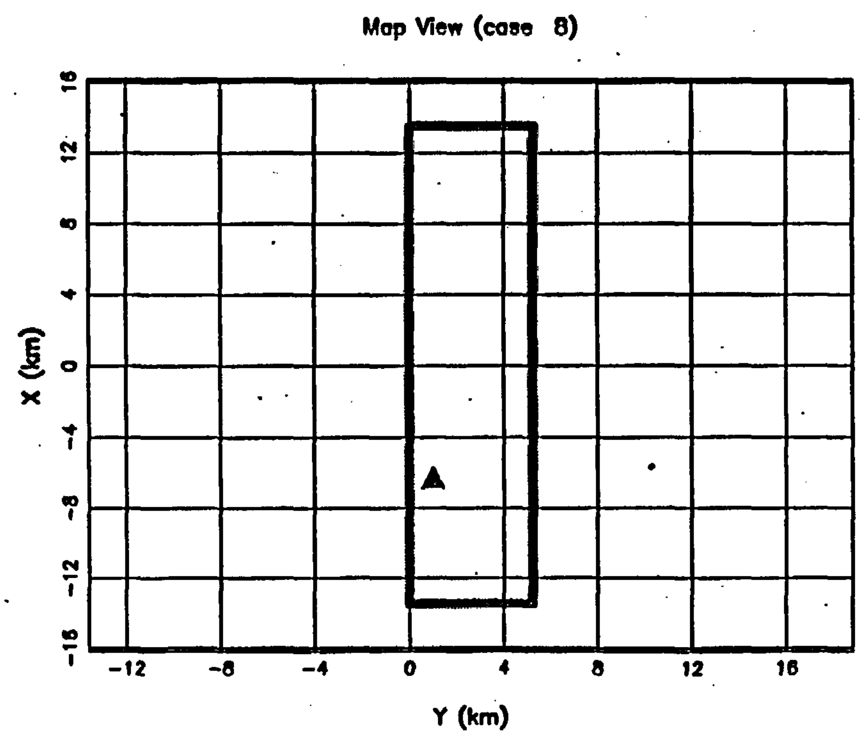

Cross View
Depth (km)
Y (km)



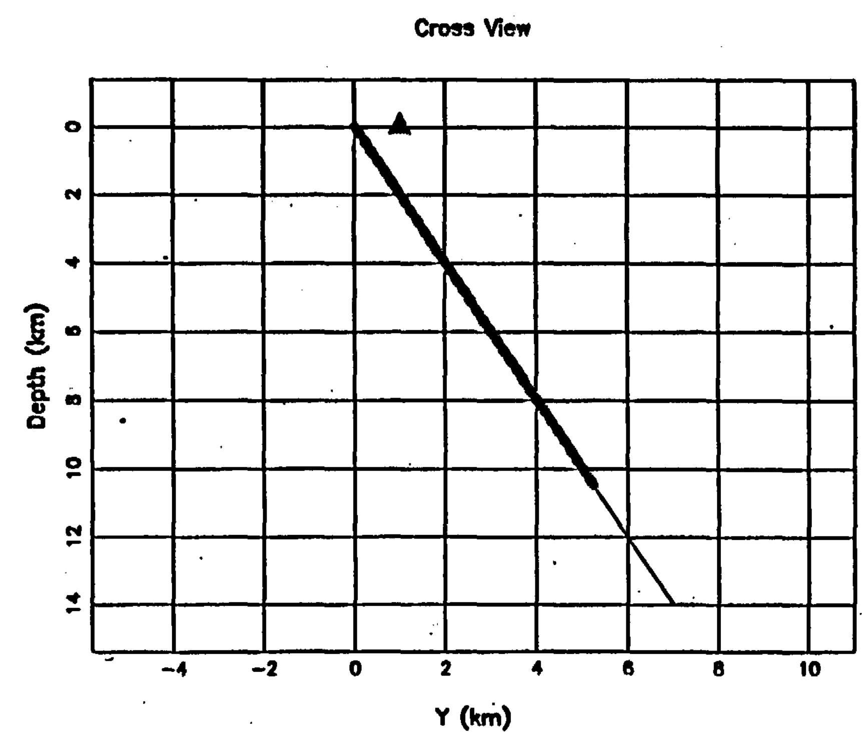
Map View (case 7)
X (km)
Y (km)

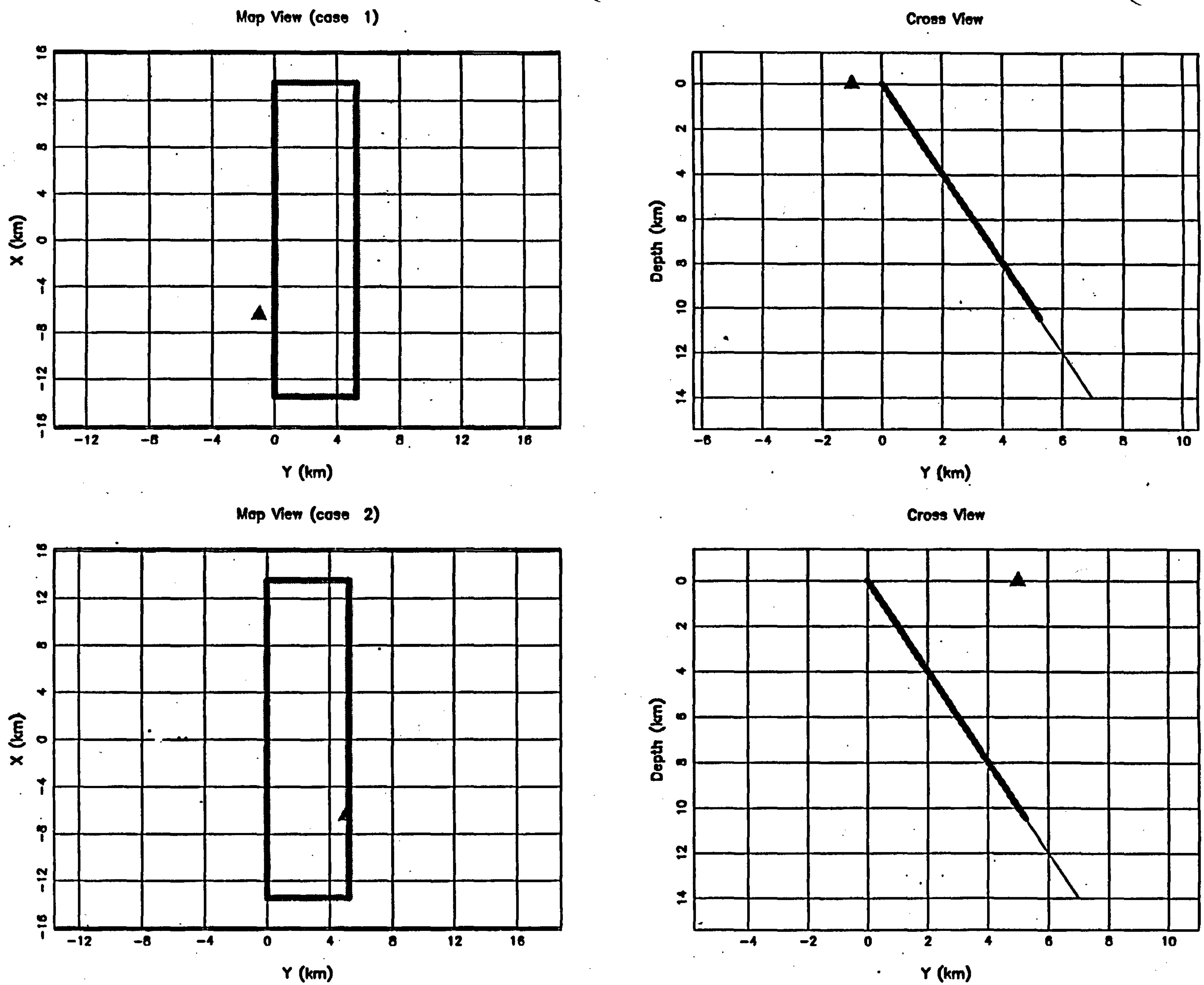
Cross View
Depth (km)
Y (km)

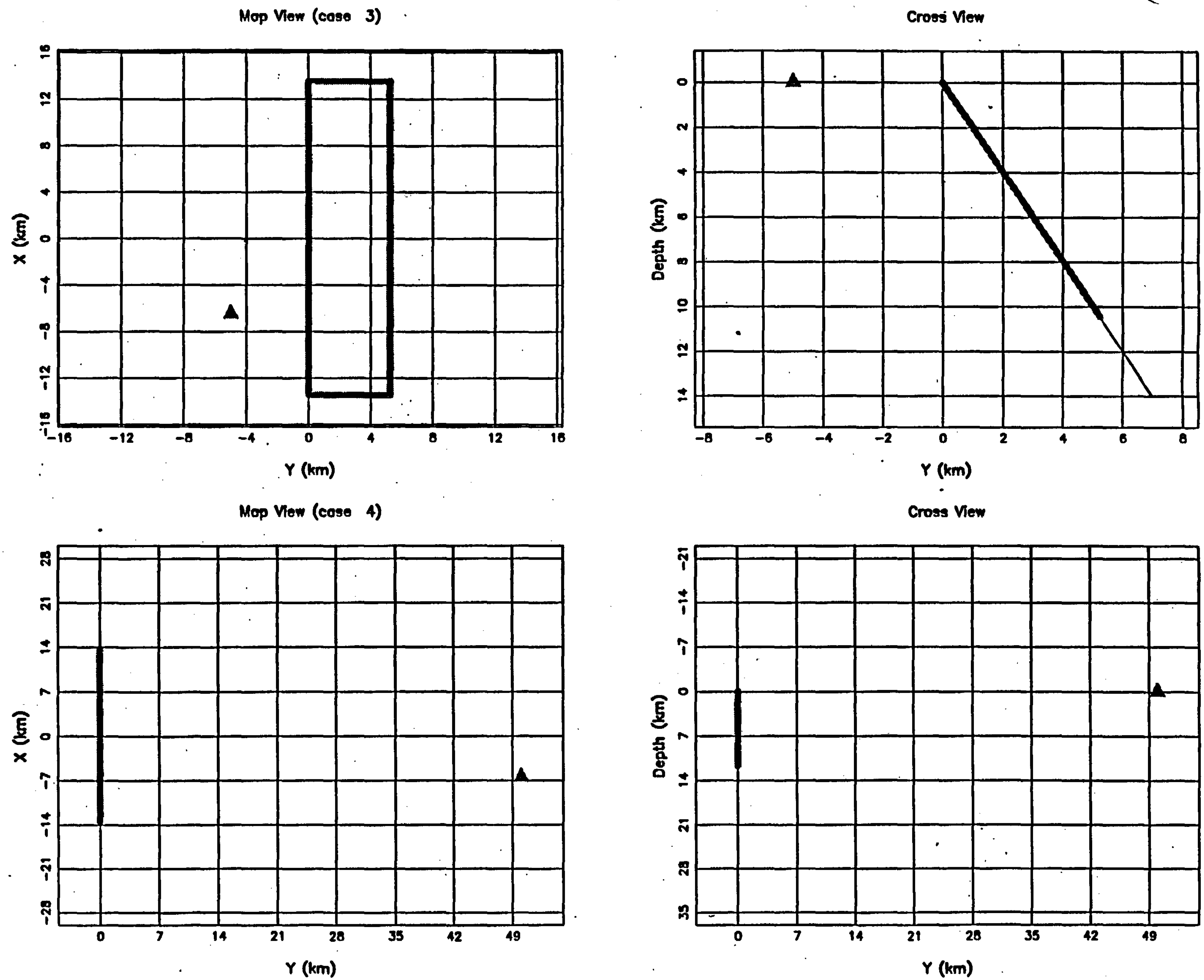



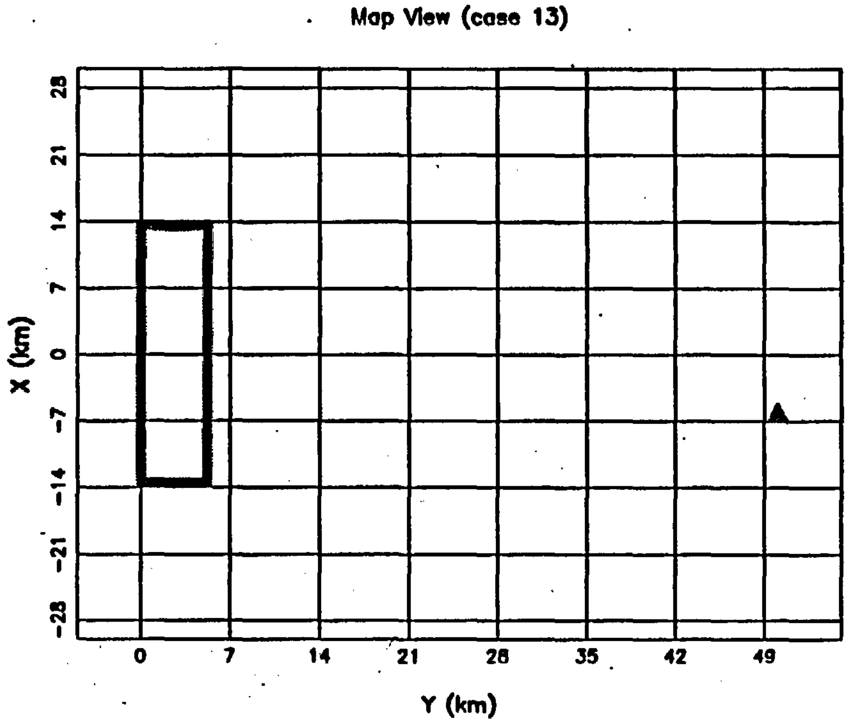
Map View (case 8)
X (km)
Y (km)

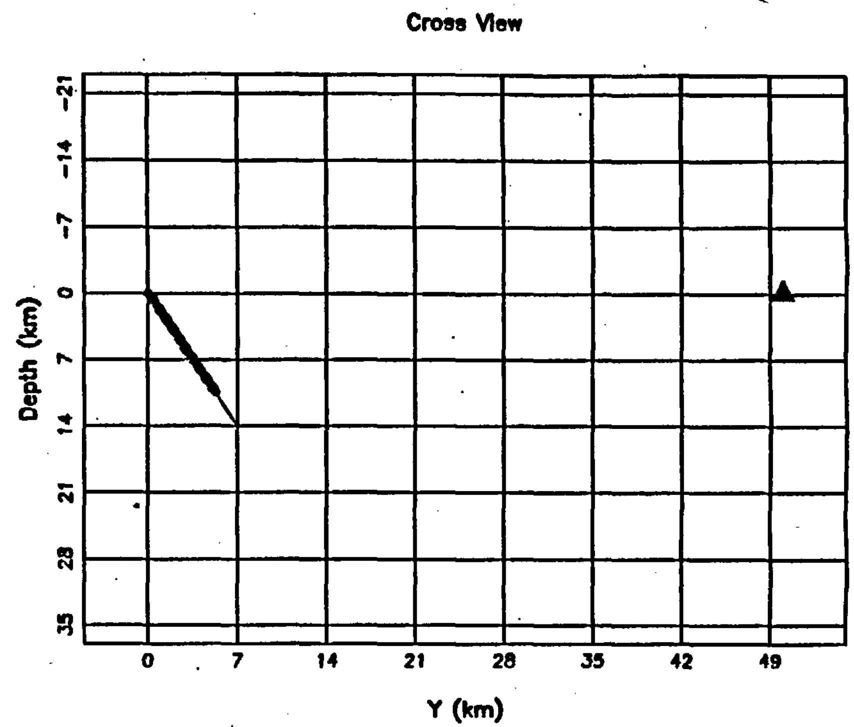



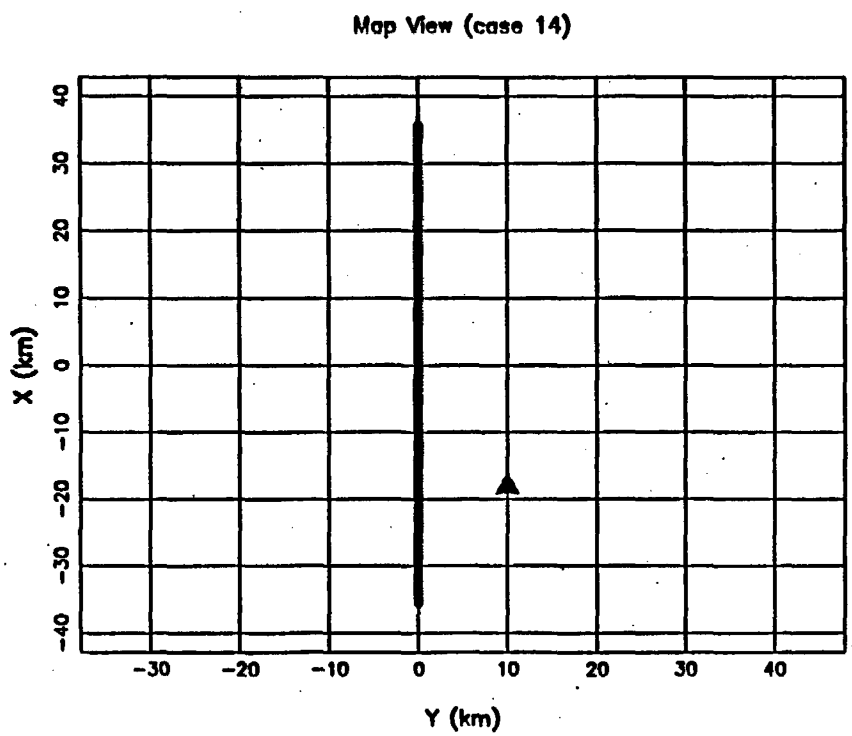
Cross View
Depth (km)
Y (km)

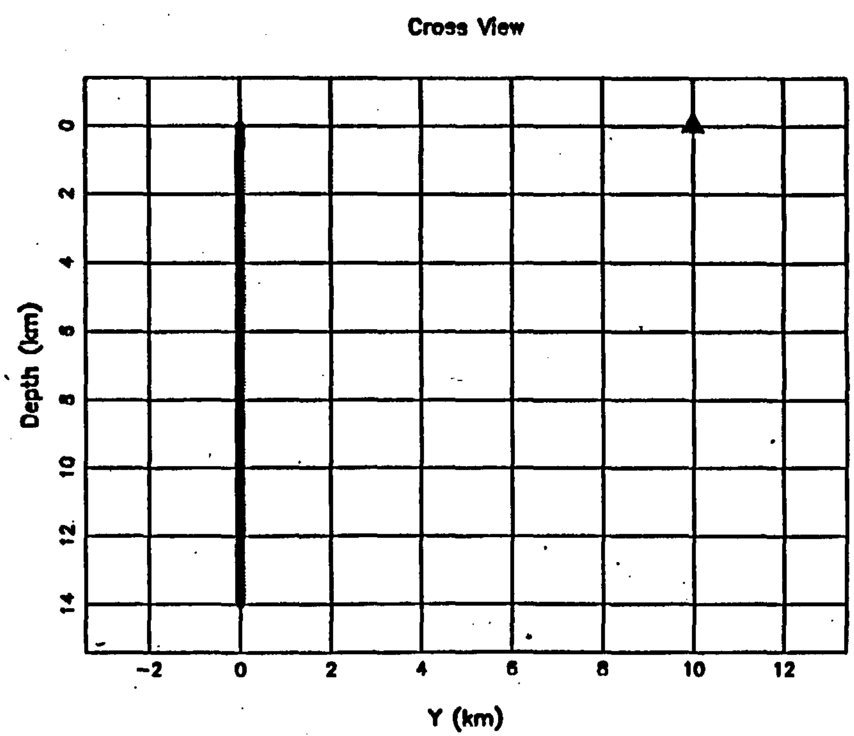

Map View (case 1)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)
Map View (case 2)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)


Map View (case 3)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)
Map View (case 4)
X (km)
Y (km)
Cross View
Depth (km)
Y (km)

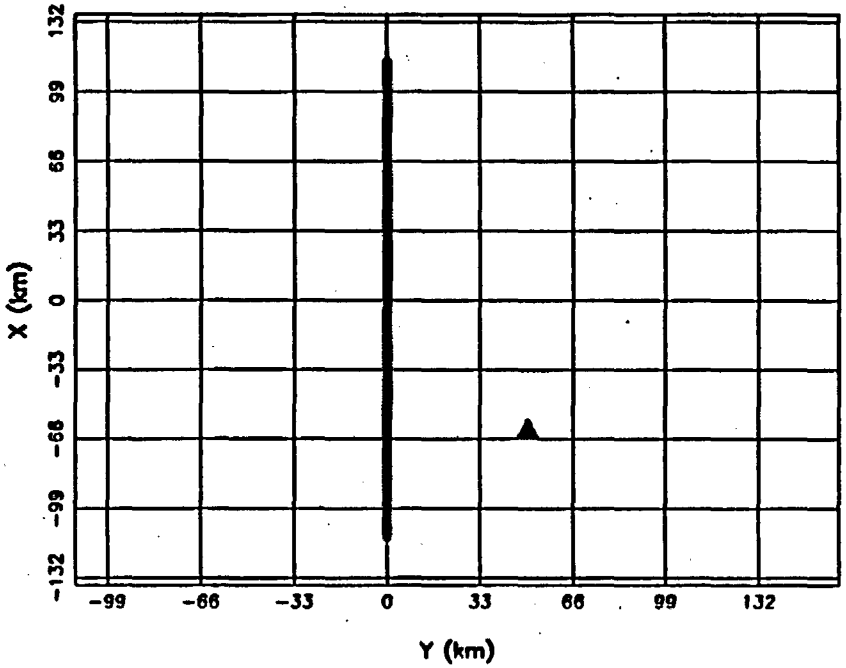

Map View (case 13)
X (km)
Y (km)
0
7
14
21
28
35
42
49
28
21
14
7
0
-7
-14
-21
-28


Cross View
Depth (km)
Y (km)
0
7
14
21
28
35
42
49
-21
-14
-7
0
7
14
21
28
35

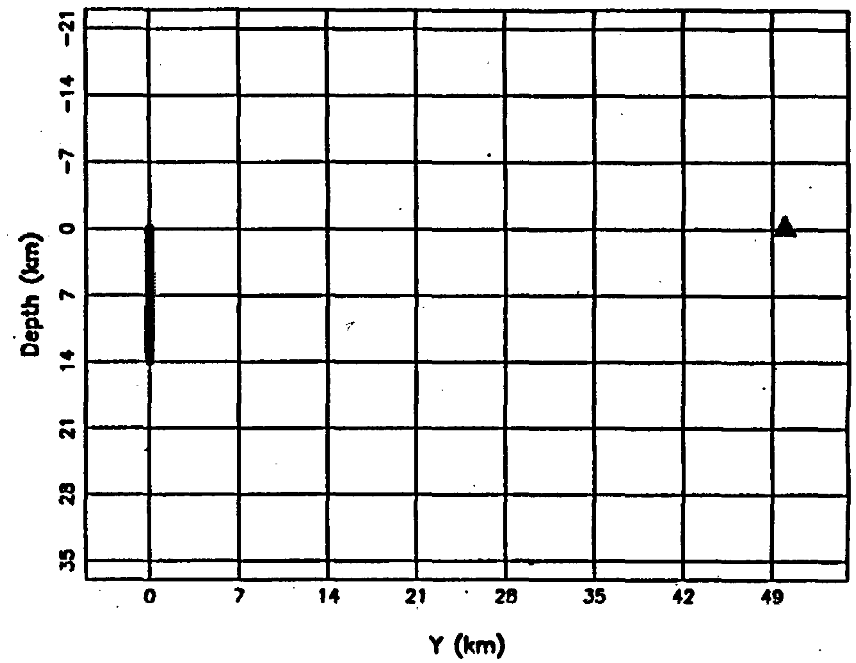

Map View (case 14)
X (km)
Y (km)
-30
-20
-10
0
10
20
30
40
40
30
20
10
0
-10
-20
-30
-40


Cross View
Depth (km)
Y (km)
-2
0
2
4
6
8
10
12
0
2
4
6
8
10
12
14

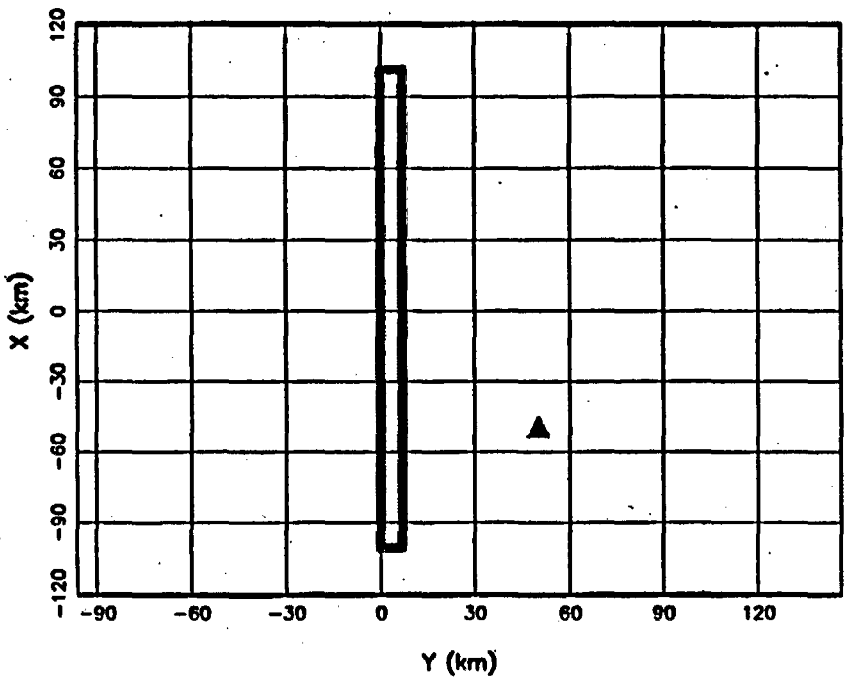
Map View (case 15)



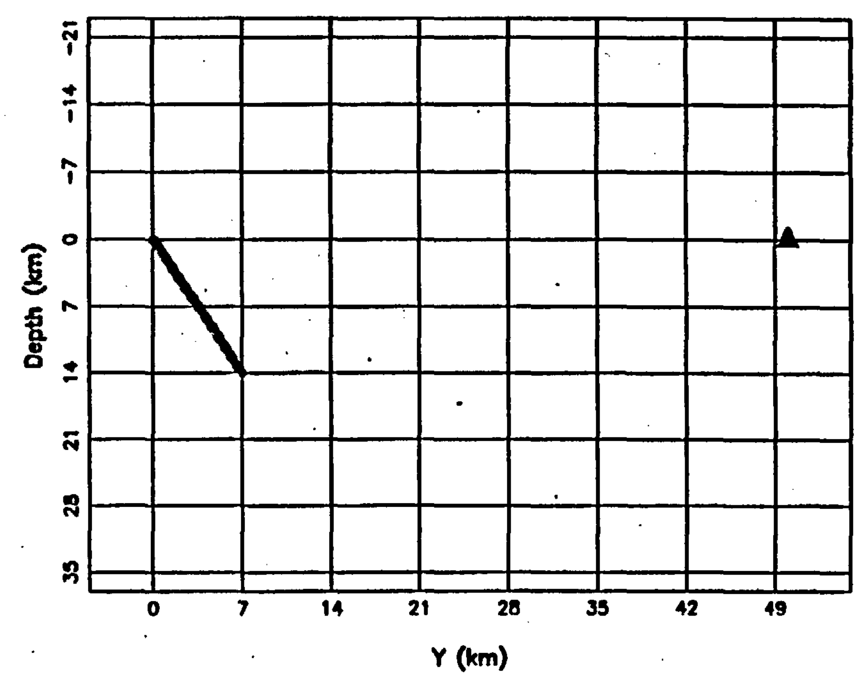

Cross View




Map View (case 16)




Cross View



## 3. Description of Model Parameters

### 3.1 Layered Velocity Model

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Layer thickness | 0.70 | 0.60 | 1.50 | 2.20 | 10.70 | 16.00 | 1000.0 |
| P-wave velocity | 3.2 | 3.6 | 5.0 | 5.8 | 6.2 | 6.5 | 7.8 |
| P-wave Q | 150.0 | 200.0 | 300.0 | 800.0 | 800.0 | 800.0 | 800.0 |
| S-wave velocity | 1.9 | 2.1 | 2.9 | 3.4 | 3.5 | 3.8 | 4.6 |
| S-wave Q | 70.0 | 100.0 | 150.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| Density | 2.4 | 2.4 | 2.5 | 2.7 | 2.75 | 2.9 | 3.3 |

No additional kappa added to the synthetics except that giving by the above Q model. The velocity randomization in the upper 1 km only affect the phase term of the Green's function. Any effect on seismic energy due to the randomization has been compensated.

3.2 Coda wave scattering mean free path = 100 km
intrinsic attenuation = $240*f^{0.5}$

### 3.3 Source Parameters

- D (fractal dimension) = 2.0
- Dynamic (subevent) stress drop range from 40 - 60 bars
- Rupture velocity = 2.8 km/sec
- Maximum subevents radius

| | | | | | |
|---|---|---|---|---|---|
| Magnitude | 5.0 | 5.8 | 6.5 | 7.0 | 7.5 |
| $R_{max}$ (km) | 1.0 | 2.5 | 4.0 | 5.0 | 6.0 |

- Number of source realization for each case is 30

- Subevent stress drops are linearly tapered to zero from 5 km depth to the free surface to simulate the effect of nonseismogenic zone in the upper 2 km of the crust.

- The rupture area $A = 10^{M-4}$

- The seismic moment $M_0 = 10^{1.5*Mw+16}$

4.1 Table of PGA, PGV and Their Standard Errors for the horizontal component

| CASE | PGA (mg) | Error | PGV (cm/s) | Error |
|---|---|---|---|---|
| 1 | 158.09 | 0.34 | 5.12 | 0.32 |
| 2 | 478.64 | 0.31 | 18.45 | 0.30 |
| 3 | 56.62 | 0.30 | 1.55 | 0.27 |
| 4 | 164.12 | 0.35 | 6.18 | 0.27 |
| 5 | 150.59 | 0.30 | 5.80 | 0.21 |
| 6 | 139.34 | 0.28 | 6.21 | 0.23 |
| 7 | 882.68 | 0.27 | 47.52 | 0.25 |
| 8 | 1689.99 | 0.26 | 80.02 | 0.32 |
| 9 | 1175.74 | 0.27 | 57.56 | 0.31 |
| 10 | 560.59 | 0.23 | 31.61 | 0.24 |
| 11 | 406.84 | 0.27 | 20.76 | 0.23 |
| 12 | 44.77 | 0.23 | 3.57 | 0.16 |
| 13 | 43.37 | 0.21 | 3.20 | 0.20 |
| 14 | 404.84 | 0.15 | 30.86 | 0.19 |
| 15 | 89.03 | 0.14 | 10.92 | 0.18 |
| 16 | 98.35 | 0.14 | 12.28 | 0.15 |

Note: error is the standard error of ln(PGA or PGV).

4.2 Table of PGA, PGV and Their Standard Errors for the vertical component

| CASE | PGA (mg) | Error | PGV (cm/s) | Error |
|---|---|---|---|---|
| 1 | 69.43 | 0.33 | 2.09 | 0.28 |
| 2 | 181.33 | 0.32 | 4.86 | 0.29 |
| 3 | 28.47 | 0.27 | 0.67 | 0.30 |
| 4 | 50.61 | 0.34 | 1.45 | 0.27 |
| 5 | 70.26 | 0.32 | 2.71 | 0.30 |
| 6 | 170.97 | 0.27 | 7.30 | 0.23 |
| 7 | 325.95 | 0.27 | 14.89 | 0.26 |
| 8 | 600.93 | 0.28 | 30.13 | 0.28 |
| 9 | 679.65 | 0.26 | 27.23 | 0.28 |
| 10 | 495.11 | 0.23 | 32.96 | 0.23 |
| 11 | 342.58 | 0.25 | 17.38 | 0.26 |
| 12 | 33.83 | 0.22 | 1.57 | 0.22 |
| 13 | 41.46 | 0.22 | 4.98 | 0.25 |
| 14 | 217.55 | 0.16 | 14.34 | 0.22 |
| 15 | 63.49 | 0.17 | 6.11 | 0.14 |
| 16 | 97.77 | 0.13 | 16.81 | 0.19 |

Note: error is the standard error of ln(PGA or PGV).

5. Table of SA and Their Standard Errors

CASE 1

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 2.57 | 6.93 | 31.25 | 75.55 | 232.41 | 360.32 | 267.76 |
| Error | 0.32 | 0.32 | 0.35 | 0.43 | 0.40 | 0.42 | 0.32 |
| SA (v) | 1.21 | 3.87 | 10.89 | 24.94 | 91.57 | 157.68 | 162.39 |
| Error | 0.24 | 0.25 | 0.30 | 0.36 | 0.28 | 0.40 | 0.37 |

CASE 2

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 8.28 | 25.96 | 111.69 | 266.11 | 686.82 | 1195.44 | 699.72 |
| Error | 0.24 | 0.24 | 0.30 | 0.30 | 0.42 | 0.32 | 0.29 |
| SA (v) | 3.86 | 9.80 | 23.39 | 59.65 | 160.62 | 389.07 | 338.61 |
| Error | 0.12 | 0.16 | 0.38 | 0.32 | 0.38 | 0.43 | 0.33 |

CASE 3

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 0.81 | 2.26 | 8.77 | 24.58 | 66.48 | 110.65 | 127.60 |
| Error | 0.21 | 0.14 | 0.25 | 0.33 | 0.28 | 0.34 | 0.36 |
| SA (v) | 0.36 | 0.97 | 3.56 | 9.51 | 55.10 | 71.41 | 54.70 |
| Error | 0.16 | 0.22 | 0.33 | 0.38 | 0.41 | 0.36 | 0.31 |

CASE 4

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 3.75 | 9.67 | 36.24 | 90.61 | 243.26 | 428.73 | 239.40 |
| Error | 0.22 | 0.16 | 0.28 | 0.32 | 0.29 | 0.39 | 0.33 |
| SA (v) | 1.46 | 2.12 | 7.33 | 18.80 | 64.31 | 124.29 | 106.56 |
| Error | 0.09 | 0.19 | 0.24 | 0.31 | 0.38 | 0.40 | 0.31 |

CASE 5

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 7.60 | 13.92 | 43.26 | 90.96 | 249.71 | 327.79 | 311.15 |
| Error | 0.20 | 0.27 | 0.26 | 0.27 | 0.37 | 0.31 | 0.35 |
| SA (v) | 3.53 | 5.25 | 18.07 | 47.85 | 119.55 | 177.13 | 134.47 |
| Error | 0.26 | 0.33 | 0.30 | 0.30 | 0.34 | 0.35 | 0.28 |

CASE 6

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 5.75 | 15.01 | 60.00 | 131.11 | 260.08 | 315.79 | 252.82 |
| Error | 0.18 | 0.30 | 0.25 | 0.35 | 0.29 | 0.28 | 0.27 |
| SA (v) | 8.48 | 13.57 | 49.18 | 195.71 | 335.92 | 415.16 | 299.82 |
| Error | 0.21 | 0.39 | 0.30 | 0.34 | 0.33 | 0.34 | 0.27 |

CASE 7

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 63.80 | 130.51 | 310.81 | 727.10 | 1483.31 | 2141.37 | 1377.80 |
| Error | 0.17 | 0.25 | 0.31 | 0.26 | 0.28 | 0.30 | 0.28 |
| SA (v) | 24.29 | 53.34 | 101.97 | 295.34 | 680.44 | 713.69 | 671.99 |
| Error | 0.44 | 0.41 | 0.37 | 0.35 | 0.31 | 0.27 | 0.27 |

CASE 8

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 78.55 | 196.70 | 553.21 | 1278.57 | 2904.31 | 4290.61 | 2280.01 |
| Error | 0.21 | 0.37 | 0.31 | 0.31 | 0.36 | 0.32 | 0.28 |
| SA (v) | 61.26 | 101.07 | 150.40 | 416.09 | 753.22 | 1287.65 | 1113.47 |
| Error | 0.33 | 0.34 | 0.35 | 0.32 | 0.31 | 0.33 | 0.34 |

CASE 9

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 58.11 | 146.56 | 407.33 | 961.44 | 2129.31 | 2864.99 | 1718.32 |
| Error | 0.23 | 0.34 | 0.29 | 0.30 | 0.36 | 0.28 | 0.28 |
| SA (v) | 48.05 | 89.10 | 149.70 | 411.89 | 878.86 | 1414.09 | 1264.28 |
| Error | 0.29 | 0.30 | 0.35 | 0.33 | 0.29 | 0.32 | 0.29 |

CASE 10

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 66.49 | 130.66 | 263.10 | 463.25 | 929.47 | 1226.92 | 1073.39 |
| Error | 0.30 | 0.31 | 0.26 | 0.20 | 0.32 | 0.26 | 0.27 |
| SA (v) | 100.24 | 146.27 | 221.30 | 369.25 | 791.30 | 1148.37 | 954.40 |
| Error | 0.34 | 0.37 | 0.34 | 0.26 | 0.29 | 0.27 | 0.31 |

CASE 11

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 41.29 | 84.69 | 138.98 | 307.96 | 726.16 | 978.74 | 688.39 |
| Error | 0.28 | 0.33 | 0.27 | 0.27 | 0.28 | 0.24 | 0.25 |
| SA (v) | 36.66 | 75.83 | 121.35 | 294.63 | 584.13 | 814.29 | 697.18 |
| Error | 0.26 | 0.30 | 0.28 | 0.31 | 0.25 | 0.23 | 0.27 |

CASE 12

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 11.51 | 17.82 | 36.77 | 62.53 | 100.11 | 100.46 | 66.74 |
| Error | 0.37 | 0.33 | 0.24 | 0.25 | 0.23 | 0.27 | 0.26 |
| SA (v) | 3.11 | 5.78 | 16.14 | 42.72 | 67.54 | 78.45 | 55.66 |
| Error | 0.42 | 0.34 | 0.34 | 0.25 | 0.23 | 0.27 | 0.25 |

CASE 13

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 7.05 | 15.88 | 41.04 | 82.04 | 80.82 | 83.82 | 68.35 |
| Error | 0.31 | 0.32 | 0.27 | 0.26 | 0.23 | 0.24 | 0.25 |
| SA (v) | 20.19 | 48.12 | 40.52 | 58.50 | 98.09 | 95.26 | 79.56 |
| Error | 0.44 | 0.33 | 0.26 | 0.25 | 0.30 | 0.29 | 0.30 |

CASE 14

| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 77.72 | 112.81 | 236.89 | 494.31 | 718.53 | 830.70 | 707.01 |
| Error | 0.31 | 0.31 | 0.20 | 0.22 | 0.19 | 0.16 | 0.19 |
| SA (v) | 34.65 | 57.05 | 122.76 | 326.56 | 417.94 | 451.55 | 406.93 |
| Error | 0.43 | 0.23 | 0.32 | 0.24 | 0.20 | 0.19 | 0.20 |

CASE 15

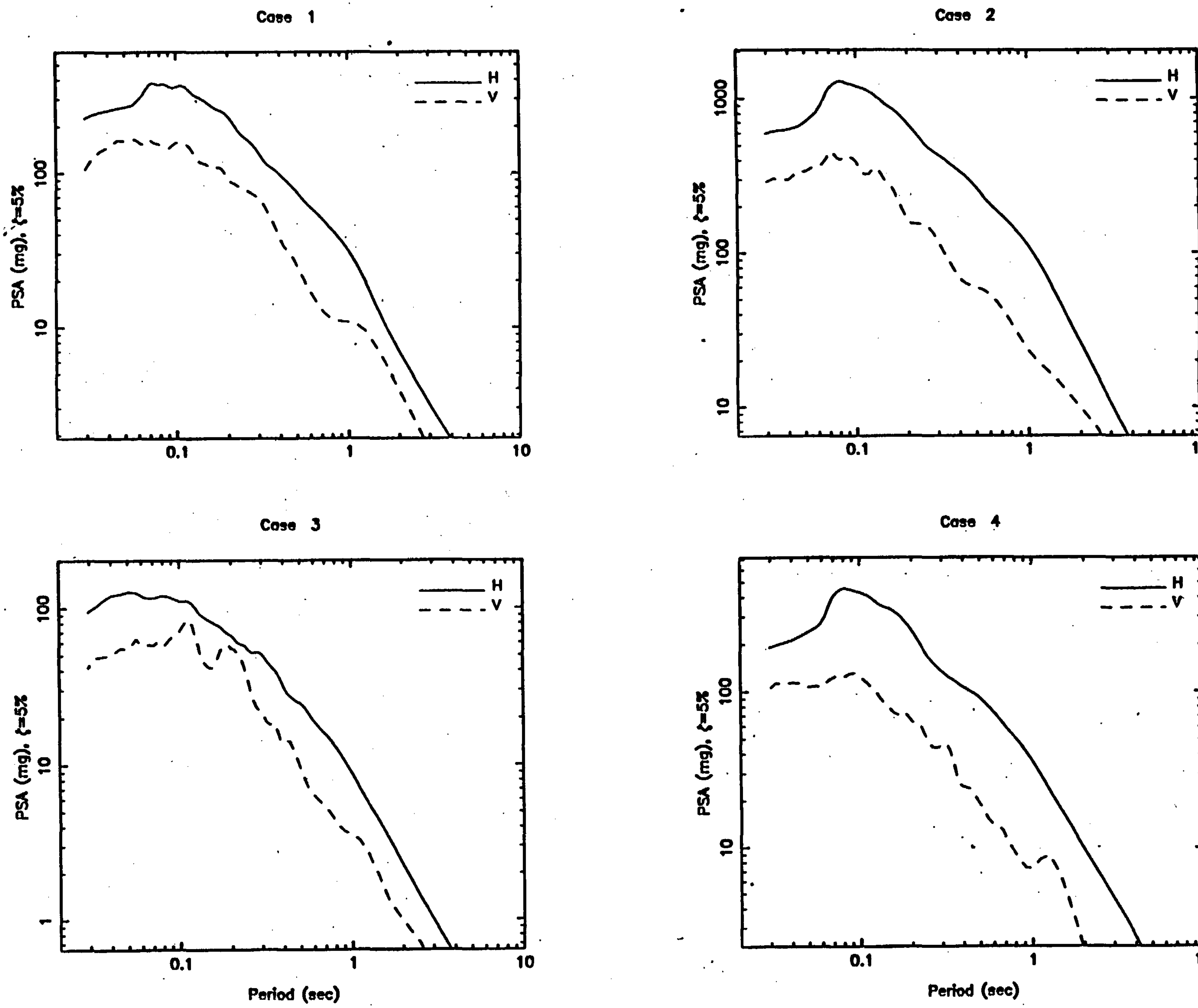
| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 47.60 | 66.24 | 100.61 | 191.20 | 196.97 | 170.09 | 123.90 |
| Error | 0.23 | 0.20 | 0.21 | 0.20 | 0.16 | 0.14 | 0.13 |
| SA (v) | 22.76 | 40.49 | 51.58 | 130.98 | 133.56 | 122.21 | 103.96 |
| Error | 0.33 | 0.31 | 0.19 | 0.23 | 0.15 | 0.18 | 0.12 |

CASE 16

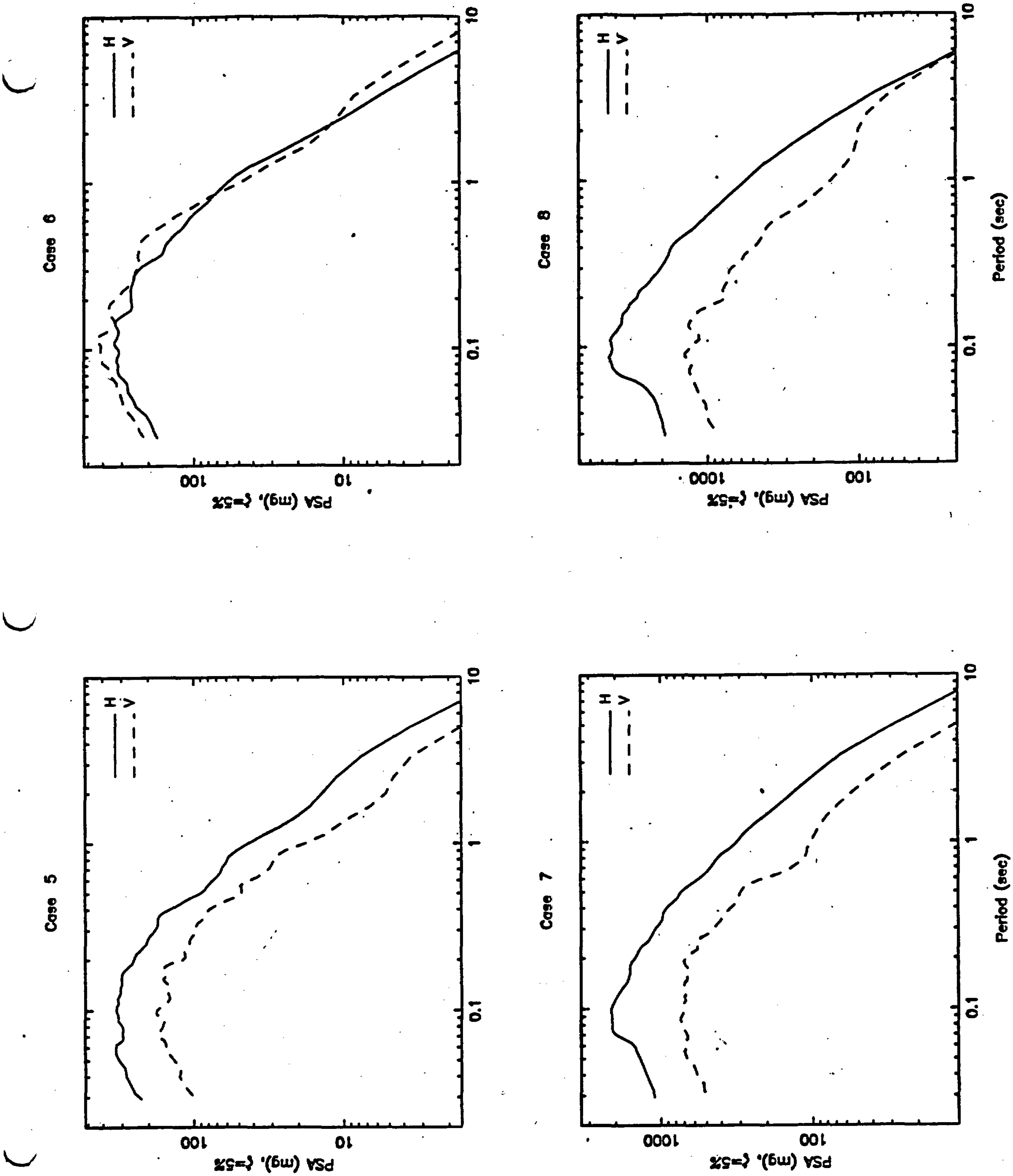
| Frequency | 0.30 | 0.50 | 1.00 | 2.00 | 5.00 | 10.00 | 20.00 |
|---|---|---|---|---|---|---|---|
| SA (h) | 41.35 | 81.95 | 131.64 | 237.08 | 208.39 | 175.85 | 133.63 |
| Error | 0.24 | 0.19 | 0.20 | 0.16 | 0.16 | 0.17 | 0.13 |
| SA (v) | 71.17 | 171.95 | 104.57 | 137.57 | 207.85 | 168.19 | 159.76 |
| Error | 0.23 | 0.25 | 0.23 | 0.16 | 0.19 | 0.12 | 0.15 |

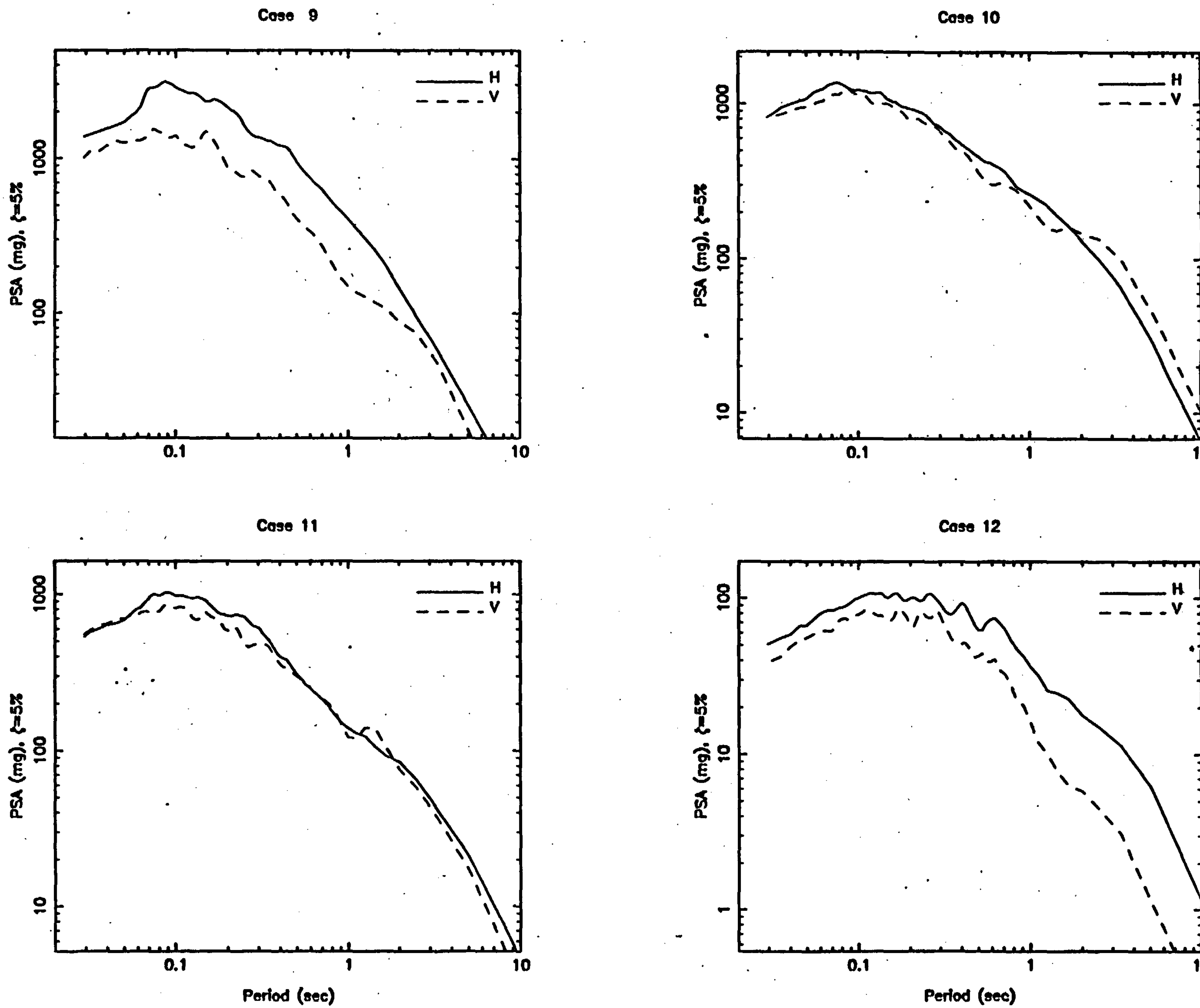
Note: Error is the error of ln(SA) relative to its mean
Frequency is in Hz
SA is in mg

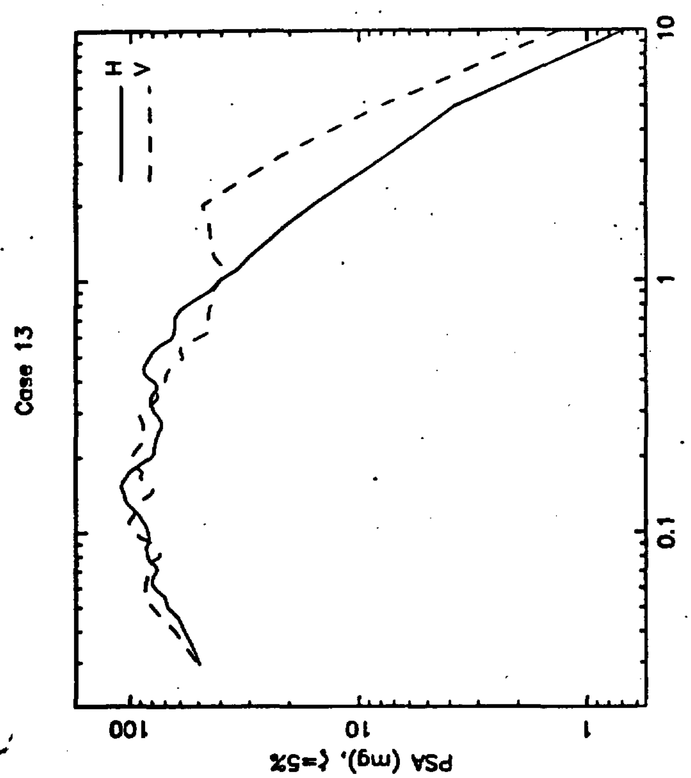
6. Plots of SA vs. Frequency

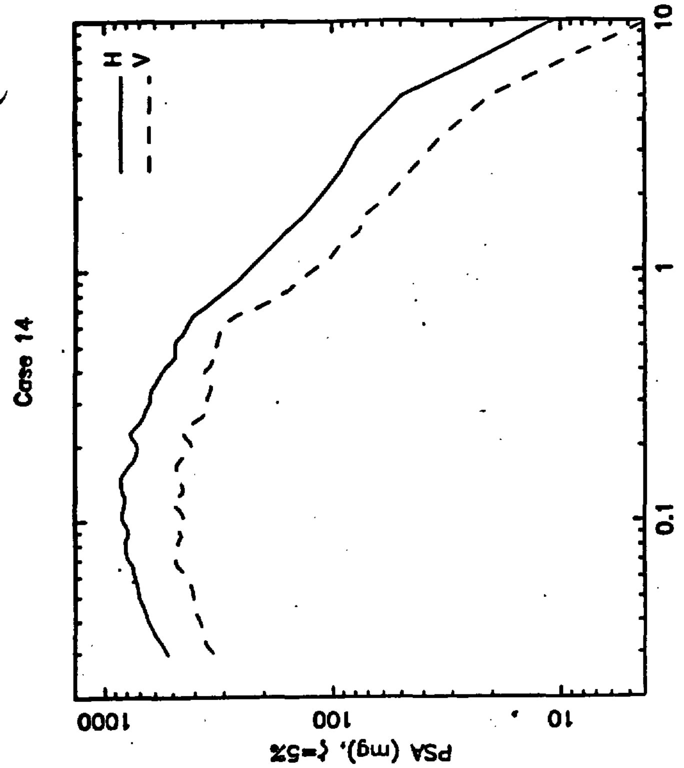


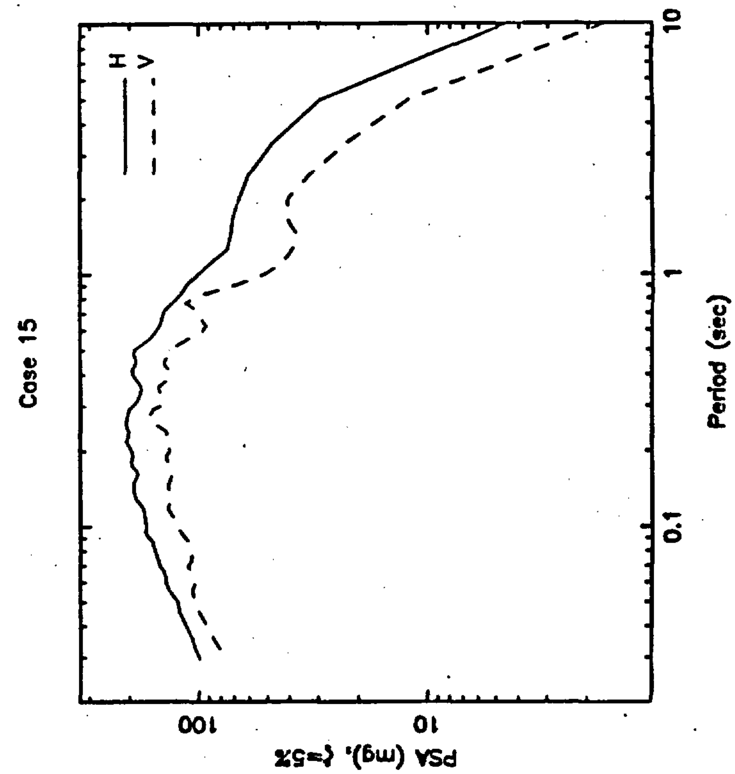
Case 1
Case 2
Case 3
Case 4
H
V
PSA (mg), ζ=5%
Period (sec)
0.1
1
10
100
1000

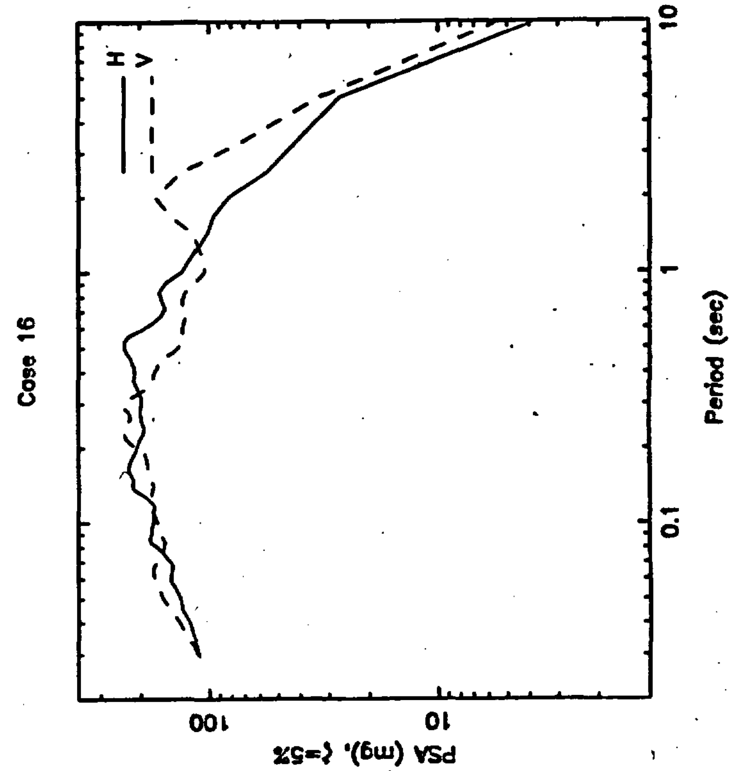

Case 5
Case 6
Case 7
Case 8
H
V
PSA (mg), ξ=5%
Period (sec)
0.1
1
10
100
1000


Case 9
Case 10
Case 11
Case 12
H
V
PSA (mg), ζ=5%
1000
100
10
1
0.1
1
10
Period (sec)

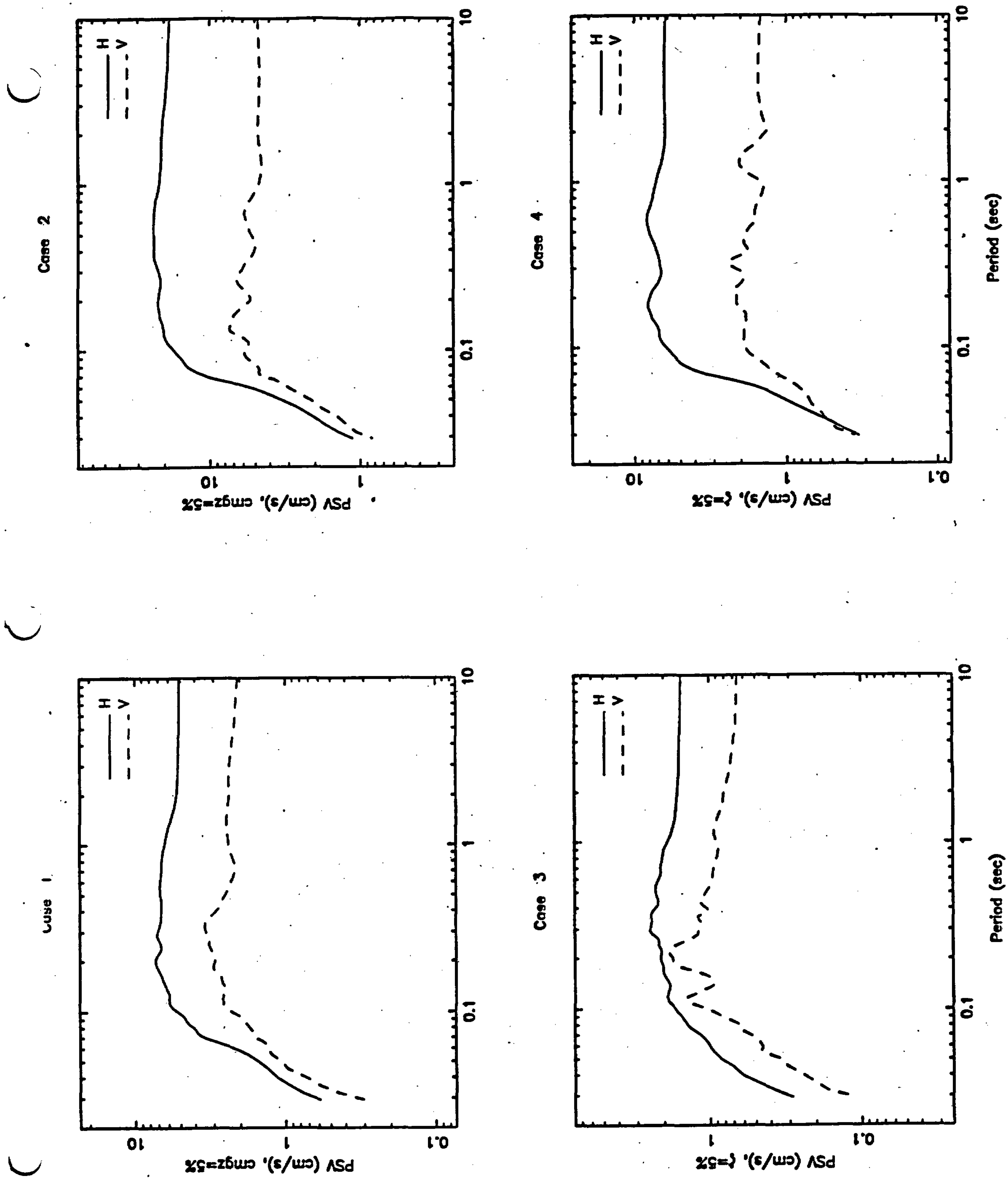

Case 13
PSA (mg), ξ=5%
Period (sec)
H
V


Case 14
PSA (mg), ξ=5%
H
V

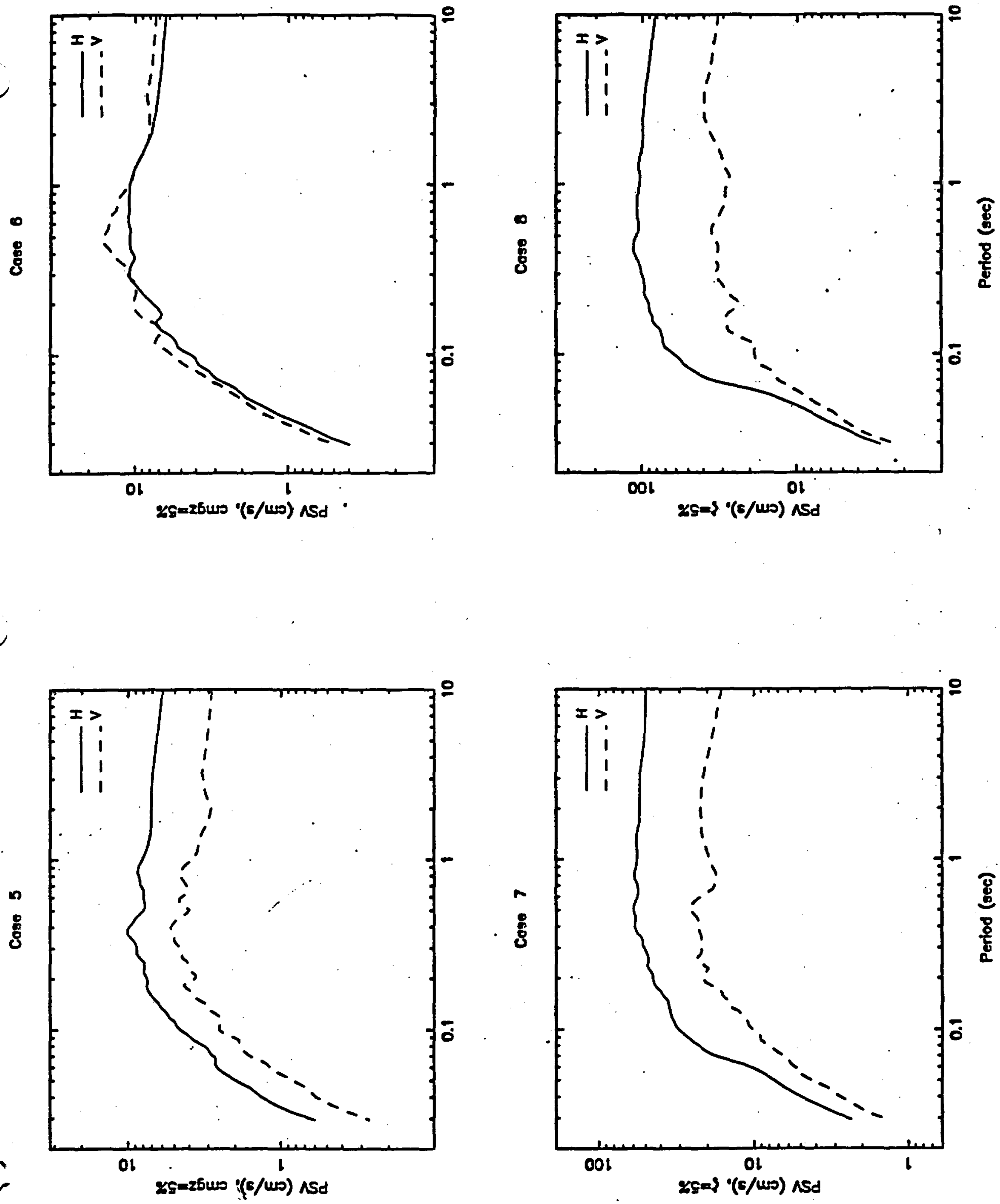

Case 15
PSA (mg), ξ=5%
Period (sec)
H
V

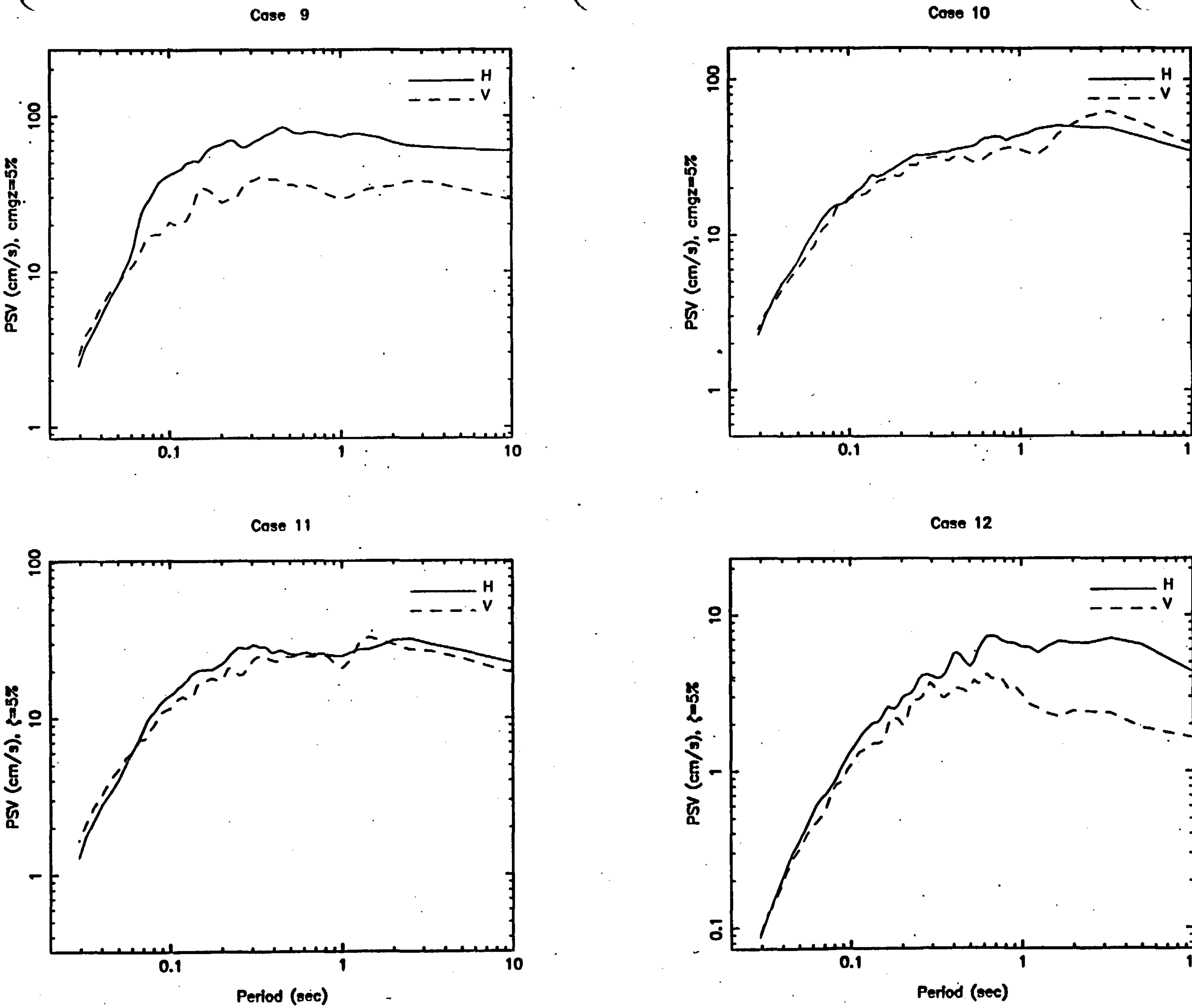

Case 16
PSA (mg), ξ=5%
Period (sec)
H
V

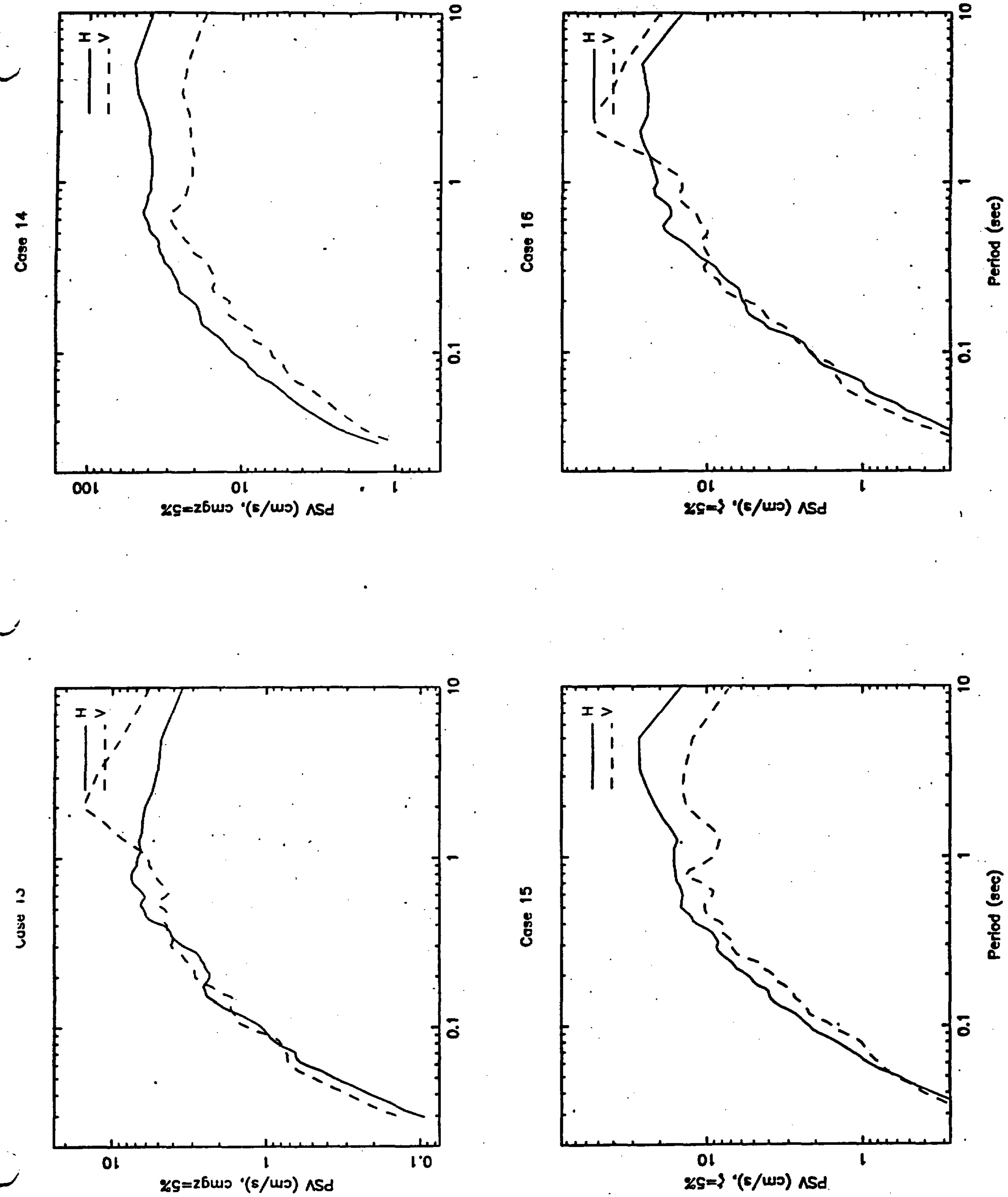
7. Plots of PSV vs. Frequency



Case 1
Case 2
Case 3
Case 4
H
V
PSV (cm/s), cmgz=5%
PSV (cm/s), ξ=5%
Period (sec)
0.1
1
10


Case 5
Case 6
Case 7
Case 8
H
V
PSV (cm/s), cmgz=5%
PSV (cm/s), ζ=5%
Period (sec)
0.1
1
10
100


Case 9
PSV (cm/s), cmgz=5%
H
V
100
10
1
0.1
1
10
Case 10
PSV (cm/s), cmgz=5%
H
V
100
10
1
0.1
1
10
Case 11
PSV (cm/s), ζ=5%
H
V
100
10
1
0.1
1
10
Period (sec)
Case 12
PSV (cm/s), ζ=5%
H
V
10
1
0.1
0.1
1
10
Period (sec)



Case 14
Case 16
Case 13
Case 15
H
V
PSV (cm/s), cmgz=5%
PSV (cm/s), ξ=5%
Period (sec)
100
10
1
0.1
0.1
1
10

3.4.2-1

UNR: Anderson Finite Fault

**Median Sa - Horizontal Component (g):**

| Frequency | $M_w$ 5.0 | | $M_w$ 5.0 Deep | | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | SS | HW | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| (Hz) | 1 km | 1 km | 5 km | 5 km | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.3 | 0.00257 | 0.00828 | 0.00081 | 0.00375 | 0.00760 | 0.00575 | 0.06380 | 0.07855 | 0.05811 | 0.06649 | 0.04129 | 0.01151 | 0.00705 | 0.07772 | 0.04760 | 0.04135 |
| 0.5 | 0.00693 | 0.02596 | 0.00226 | 0.00967 | 0.01392 | 0.01501 | 0.13051 | 0.19670 | 0.14656 | 0.13066 | 0.08469 | 0.01782 | 0.01588 | 0.11281 | 0.06624 | 0.08195 |
| 1. | 0.03125 | 0.11169 | 0.00877 | 0.03624 | 0.04326 | 0.06000 | 0.31081 | 0.55321 | 0.40733 | 0.26310 | 0.13898 | 0.03677 | 0.04104 | 0.23689 | 0.10061 | 0.13164 |
| 2. | 0.07555 | 0.26611 | 0.02458 | 0.09061 | 0.09096 | 0.13111 | 0.72710 | 1.27857 | 0.96144 | 0.46325 | 0.30796 | 0.06253 | 0.08204 | 0.49431 | 0.19120 | 0.23708 |
| 5. | 0.23241 | 0.68682 | 0.06648 | 0.24326 | 0.24971 | 0.26008 | 1.48331 | 2.90431 | 2.12931 | 0.92947 | 0.72616 | 0.10011 | 0.08082 | 0.71853 | 0.19697 | 0.20839 |
| 10. | 0.36032 | 1.19544 | 0.11065 | 0.42873 | 0.32779 | 0.31579 | 2.14137 | 4.29061 | 2.86499 | 1.22692 | 0.97874 | 0.10046 | 0.08382 | 0.83070 | 0.17009 | 0.17585 |
| 20. | 0.26776 | 0.69972 | 0.12760 | 0.23940 | 0.31115 | 0.25282 | 1.37780 | 2.28001 | 1.71832 | 1.07339 | 0.68839 | 0.06674 | 0.06835 | 0.70701 | 0.12390 | 0.13363 |
| pga | 0.15809 | 0.47864 | 0.05662 | 0.16412 | 0.15059 | 0.13934 | 0.88268 | 1.68999 | 1.17574 | 0.56059 | 0.40684 | 0.04477 | 0.04337 | 0.40484 | 0.08903 | 0.09835 |
| pgv cm/sec | 5.12 | 18.45 | 1.55 | 6.18 | 5.80 | 6.21 | 47.52 | 80.02 | 57.56 | 31.61 | 20.76 | 3.57 | 3.20 | 30.86 | 10.92 | 12.28 |

**Aleatory Variability about Median Sa - Horizontal Component:**

| Frequency | $M_w$ 5.0 | | $M_w$ 5.0 Deep | | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | SS | HW | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| (Hz) | 1 km | 1 km | 5 km | 5 km | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.3 | 0.32 | 0.24 | 0.21 | 0.22 | 0.20 | 0.18 | 0.17 | 0.21 | 0.23 | 0.30 | 0.28 | 0.37 | 0.31 | 0.31 | 0.23 | 0.24 |
| 0.5 | 0.32 | 0.24 | 0.14 | 0.16 | 0.27 | 0.30 | 0.25 | 0.37 | 0.34 | 0.31 | 0.33 | 0.33 | 0.32 | 0.31 | 0.20 | 0.19 |
| 1. | 0.35 | 0.30 | 0.25 | 0.28 | 0.26 | 0.25 | 0.31 | 0.31 | 0.29 | 0.26 | 0.27 | 0.24 | 0.27 | 0.20 | 0.21 | 0.20 |
| 2. | 0.43 | 0.30 | 0.33 | 0.32 | 0.27 | 0.35 | 0.26 | 0.31 | 0.30 | 0.20 | 0.27 | 0.25 | 0.26 | 0.22 | 0.20 | 0.16 |
| 5. | 0.40 | 0.42 | 0.28 | 0.29 | 0.37 | 0.29 | 0.28 | 0.36 | 0.36 | 0.32 | 0.28 | 0.23 | 0.23 | 0.19 | 0.16 | 0.16 |
| 10. | 0.42 | 0.32 | 0.34 | 0.39 | 0.31 | 0.28 | 0.30 | 0.32 | 0.28 | 0.26 | 0.24 | 0.27 | 0.24 | 0.16 | 0.14 | 0.17 |
| 20. | 0.32 | 0.29 | 0.36 | 0.33 | 0.35 | 0.27 | 0.28 | 0.28 | 0.28 | 0.27 | 0.25 | 0.26 | 0.25 | 0.19 | 0.13 | 0.13 |
| pga | 0.34 | 0.31 | 0.30 | 0.35 | 0.30 | 0.28 | 0.27 | 0.26 | 0.27 | 0.23 | 0.27 | 0.23 | 0.21 | 0.15 | 0.14 | 0.14 |
| pgv cm/sec | 0.32 | 0.30 | 0.27 | 0.27 | 0.21 | 0.23 | 0.25 | 0.32 | 0.31 | 0.24 | 0.23 | 0.16 | 0.20 | 0.19 | 0.18 | 0.15 |

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UNR: Anderson Finite Fault

**Median Sa - Vertical Component (g):**

| Frequency | $M_w$ 5.0 | | $M_w$ 5.0 Deep | | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | SS | HW | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| (Hz) | 1 km | 1 km | 5 km | 5 km | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.3 | 0.0012 | 0.00386 | 0.00036 | 0.00146 | 0.00353 | 0.00848 | 0.02429 | 0.06126 | 0.04805 | 0.10024 | 0.03666 | 0.00311 | 0.02019 | 0.03465 | 0.02276 | 0.07117 |
| 0.5 | 0.0039 | 0.00980 | 0.00097 | 0.00212 | 0.00525 | 0.01357 | 0.05334 | 0.10107 | 0.08910 | 0.14627 | 0.07583 | 0.00578 | 0.04812 | 0.05705 | 0.04049 | 0.17195 |
| 1. | 0.0109 | 0.02339 | 0.00356 | 0.00733 | 0.01807 | 0.04918 | 0.10197 | 0.15040 | 0.14970 | 0.22130 | 0.12135 | 0.01614 | 0.04052 | 0.12276 | 0.05158 | 0.10457 |
| 2. | 0.0249 | 0.05965 | 0.00951 | 0.01880 | 0.04785 | 0.19571 | 0.29534 | 0.41609 | 0.41189 | 0.36925 | 0.29463 | 0.04272 | 0.05850 | 0.32656 | 0.13098 | 0.13757 |
| 5. | 0.0916 | 0.16062 | 0.05510 | 0.06431 | 0.11955 | 0.33592 | 0.68044 | 0.75322 | 0.87886 | 0.79130 | 0.58413 | 0.06754 | 0.09809 | 0.41794 | 0.13356 | 0.20785 |
| 10. | 0.1577 | 0.38907 | 0.07141 | 0.12429 | 0.17713 | 0.41516 | 0.71369 | 1.28765 | 1.41409 | 1.14837 | 0.81429 | 0.07845 | 0.09526 | 0.45155 | 0.12221 | 0.16819 |
| 20. | 0.1624 | 0.33861 | 0.05470 | 0.10656 | 0.13447 | 0.29982 | 0.67199 | 1.11347 | 1.26428 | 0.95440 | 0.69718 | 0.05566 | 0.07956 | 0.40693 | 0.10396 | 0.15976 |
| pga | 0.06943 | 0.18133 | 0.02847 | 0.05061 | 0.07026 | 0.17097 | 0.32595 | 0.60093 | 0.67965 | 0.49511 | 0.34258 | 0.03383 | 0.04146 | 0.21755 | 0.06349 | 0.09777 |
| pgv cm/sec | 2.09 | 4.86 | 0.67 | 1.45 | 2.71 | 7.30 | 14.89 | 30.13 | 27.23 | 32.96 | 17.38 | 1.57 | 4.98 | 14.34 | 6.11 | 16.81 |

3.4.3-1

**Aleatory Variability about Median Sa - Vertical Component:**

| Frequency | $M_w$ 5.0 | | $M_w$ 5.0 Deep | | $M_w$ 5.8 Deep | | $M_w$ 6.5 | | | | | | | $M_w$ 7.0 | $M_w$ 7.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SS | HW | SS | HW | SS | HW | SS | HW | FW | HW | FW | SS | HW | SS | SS | HW |
| (Hz) | 1 km | 1 km | 5 km | 5 km | 10 km | 20 km | 1 km | 1 km | 1 km | 5 km | 5 km | 50 km | 50 km | 10 km | 50 km | 50 km |
| 0.3 | 0.24 | 0.12 | 0.16 | 0.09 | 0.26 | 0.21 | 0.44 | 0.33 | 0.29 | 0.34 | 0.26 | 0.42 | 0.44 | 0.43 | 0.33 | 0.23 |
| 0.5 | 0.25 | 0.16 | 0.22 | 0.19 | 0.33 | 0.39 | 0.41 | 0.34 | 0.30 | 0.37 | 0.30 | 0.34 | 0.33 | 0.23 | 0.31 | 0.25 |
| 1. | 0.30 | 0.38 | 0.33 | 0.24 | 0.30 | 0.30 | 0.37 | 0.35 | 0.35 | 0.34 | 0.28 | 0.34 | 0.26 | 0.32 | 0.19 | 0.23 |
| 2. | 0.36 | 0.32 | 0.38 | 0.31 | 0.30 | 0.34 | 0.35 | 0.32 | 0.33 | 0.26 | 0.31 | 0.25 | 0.25 | 0.24 | 0.23 | 0.16 |
| 5. | 0.28 | 0.38 | 0.41 | 0.38 | 0.34 | 0.33 | 0.31 | 0.31 | 0.29 | 0.29 | 0.25 | 0.23 | 0.30 | 0.20 | 0.15 | 0.19 |
| 10. | 0.40 | 0.43 | 0.36 | 0.40 | 0.35 | 0.34 | 0.27 | 0.33 | 0.32 | 0.27 | 0.23 | 0.27 | 0.29 | 0.19 | 0.18 | 0.12 |
| 20. | 0.37 | 0.33 | 0.31 | 0.31 | 0.28 | 0.27 | 0.27 | 0.34 | 0.29 | 0.31 | 0.27 | 0.25 | 0.30 | 0.20 | 0.12 | 0.15 |
| pga | 0.33 | 0.32 | 0.27 | 0.34 | 0.32 | 0.27 | 0.27 | 0.28 | 0.26 | 0.23 | 0.25 | 0.22 | 0.22 | 0.16 | 0.17 | 0.13 |
| pgv cm/sec | 0.28 | 0.29 | 0.30 | 0.27 | 0.30 | 0.23 | 0.26 | 0.28 | 0.28 | 0.23 | 0.26 | 0.22 | 0.25 | 0.22 | 0.14 | 0.19 |

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The modeling uncertainty for the Zeng and Anderson simulation procedure was estimated for the Northridge and Landers earthquakes as part of the SCEC c-cubed study. The resulting modeling uncertainties are plotted here.

## Standard Error for Rock Sites

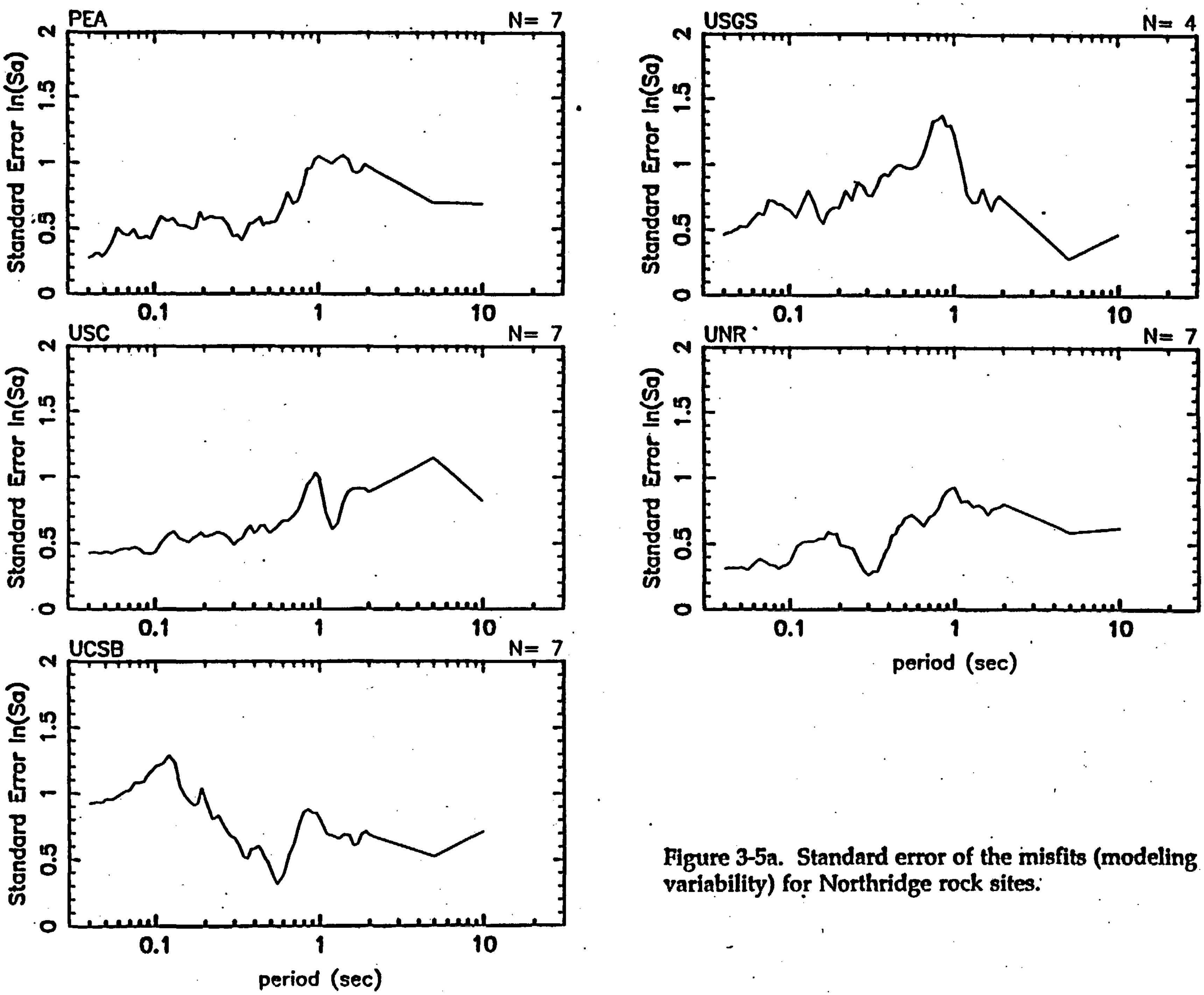



Figure 3-5a. Standard error of the misfits (modeling variability) for Northridge rock sites.

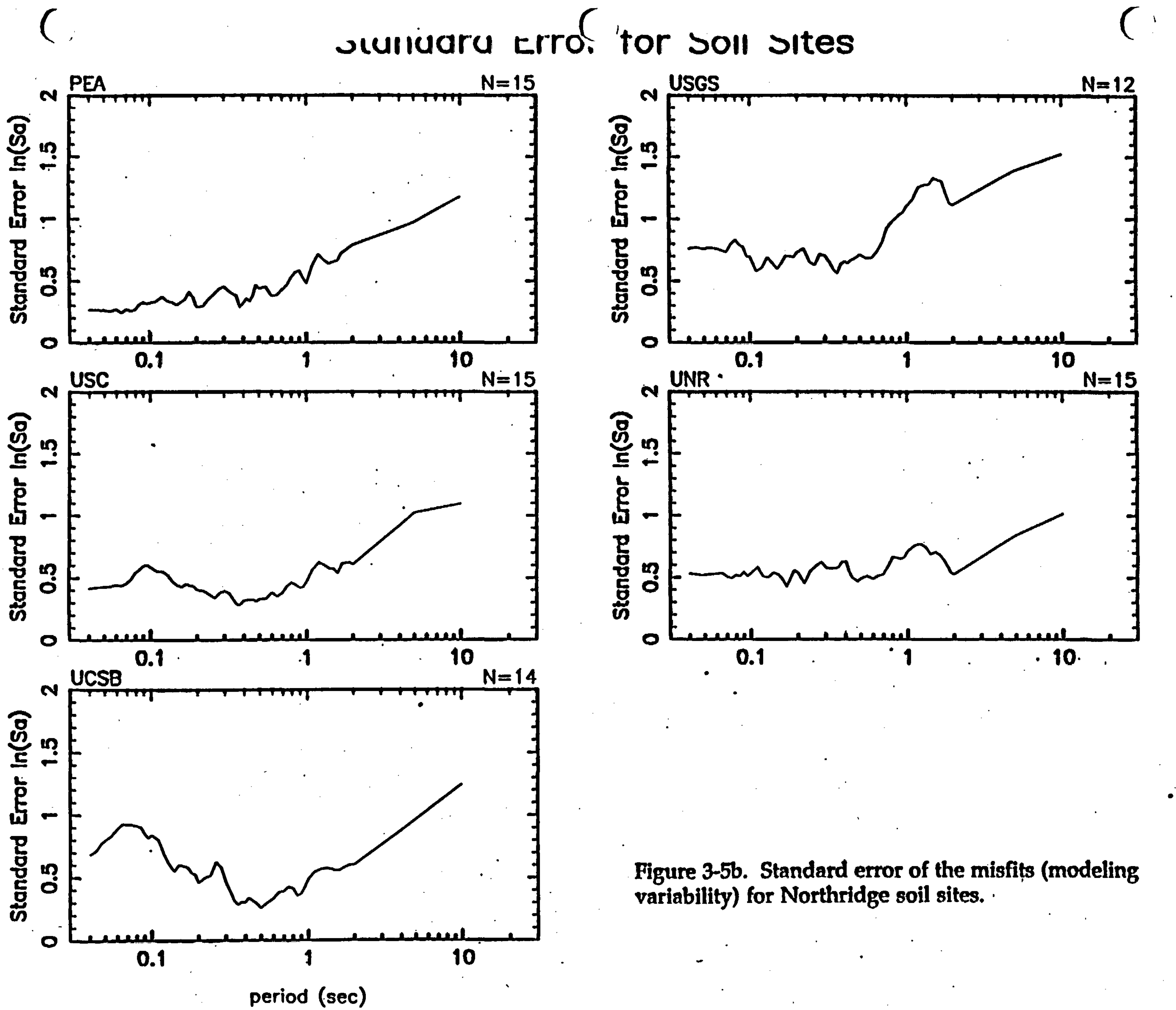



Figure 3-5b. Standard error of the misfits (modeling variability) for Northridge soil sites.

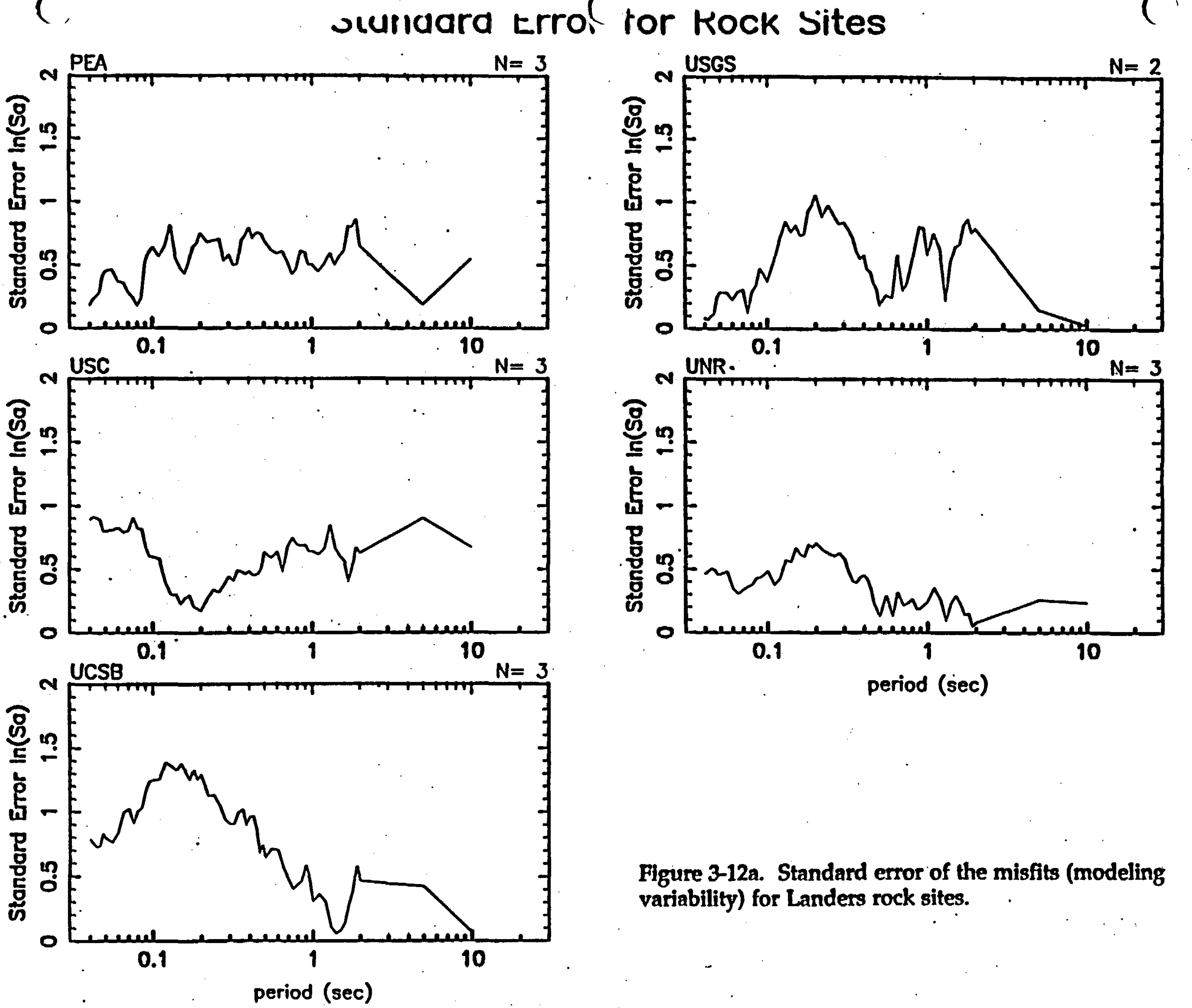



Figure 3-12a. Standard error of the misfits (modeling variability) for Landers rock sites.

# Section 4.0

# Empirical Models

## 4.1 Additional Documentation

### 4.1.1 Abrahamson & Silva update for normal faulting

Abrahamson used the 9 normal faulting events in the Spudich et al (1996) data base to compute style-of-faulting factors for normal faulting events for the Abrahamson & Silva (1997) attenuation model. These new style-of-faulting factors were estimated by holding the magnitude, distance, and site coefficients fixed to the values given in the previous model, and then applying the random effects model.

The resulting coefficients were then smoothed over period to produce the following model:

## Abrahamson and Silva (1997) - Modified for Normal faulting

The general functional form is given by:

$$\ln Sa(g) = f_1(m, R_{rup}) + F_1\, f_3(m) + F_3 a_{14} + HW\, f_4(m, R_{rup}) + S\, f_5(\widehat{pga}_{rock}) \quad (28)$$

where S is a dummy variable for the site class (0 for rock or shallow soil, 1 for deep soil) and F =fault type: 0 for strike-slip and normal, 0.5 for reverse/oblique, 1.0 for reverse, and F3=1 for normal and 0 otherwise.

The basic attenuation for strike-slip and normal events at rock sites is given by:

$$f_1(m,r) = \begin{cases} a_1 + a_2(m-m_1) + a_{12}(8.5-m)^n + [a_3 + a_{13}(m-m_1)]\ln(R) & \text{for } m \le m_1 \\ a_1 + a_4(m-m_1) + a_{12}(8.5-m)^n + [a_3 + a_{13}(m-m_1)]\ln(R) & \text{for } m > m_1 \end{cases} \quad (29)$$

where

$$R = \sqrt{R_{rup}^2 + c_4^2} \quad (30)$$

The style-of-faulting factor is allowed to be magnitude and period dependent:

$$f_3(m) = \begin{cases} a_5 & \text{for } m \le 5.8 \\ a_5 + \dfrac{(a_6 - a_5)}{m_1 - 5.8}(m - 5.8) & \text{for } 5.8 < m < m_1 \\ a_6 & \text{for } m \ge m_1 \end{cases} \quad (31)$$

The hanging wall effect for dipping faults is magnitude and distance dependence and is modeled as separable in magnitude and distance so that

$$f_4(m,r) = f_{HW}(m)\, f_{HW}(R_{rup}) \tag{32}$$

where

$$f_{hw}(m) = \begin{cases} 0 & \text{for } m \leq 5.5 \\ m-5.5 & \text{for } 5.5 < m < 6.5 \\ 1 & \text{for } m \geq 6.5 \end{cases} \tag{33}$$

and

$$f_{hw}(R_{rup}) = \begin{cases} 0 & R_{rup} < 4 \\ a_9(R_{rup}-4)/4 & 4 < R_{rup} < 8 \\ a_9 & 8 < R_{rup} < 18 \\ a_9(1-(R_{rup}-18)/7) & 18 < R_{rup} < 25 \\ 0 & 25 < R_{rup} \end{cases} \tag{34}$$

The non-linear soil response is modeled by

$$f_5(\widehat{PGA}_{rock}) = a_{10} + a_{11} \ln(\widehat{PGA}_{rock} + c_5) \tag{35}$$

where $\widehat{PGA}_{rock}$ is the expected peak acceleration on rock in g (as predicted by the attenuation relation with S=0).

The standard error is allowed to be magnitude dependent and is modeled as follows:

$$\sigma(m) = \begin{cases} b_1 & \text{for } m \leq 5.0 \\ b_1 - b_2(m-5) & \text{for } 5.0 < m < 7.0 \\ b_1 - 2b_2 & \text{for } m \geq 7.0 \end{cases} \tag{36}$$

*** Changes from previous version.

The change from the previous version is the addition of the $a_{14}$ term for normal faulting events.

# Smoothed Model Coefficients

## $a_{14}$

| Freq | Horiz | Vert |
|---|---|---|
| PGA | -0.16 | -0.25 |
| 20 | -0.16 | -0.25 |
| 10 | -0.16 | -0.13 |
| 5 | -0.12 | 0.00 |
| 2 | -0.07 | 0.07 |
| 1 | -0.20 | -0.08 |
| 2 | -0.40 | -0.30 |

### 4.1.2 Boore et al. 1993 Horizontal Component Variability

Most of the ground motion models are for the average horizontal component. For this project, we are interested in the random horizontal component. The variability between the two horizontal components has been estimated by Boore et al (1993) and by Spudich et al (1996).

The following table lists the variability between the two horizontal components (in natural log units) :

| Period | Spudich et al (1996) | Boore et al (1993) |
|---|---|---|
| 0.00 | 0.22 | .23 |
| 0.10 | 0.26 | .19 |
| 0.20 | 0.28 | .25 |
| 0.50 | 0.30 | .30 |
| 1.0 | 0.32 | .32 |
| 2.0 | 0.32 | .36 |

This additional source of aleatory uncertainty should be included in the total aleatory uncertainty.

The following attenuation relationship for peak horizontal acceleration at rock sites was developed:

$$Ln(a) = \alpha_o + exp(\alpha_1 + \alpha_2 M) - exp(\beta_1 + \beta_2 M) Ln(R+10) + F\phi - f(M,R)$$

in which $M$ is moment magnitude; $R$ is the closest distance to the rupture surface in km for $M > 6$ and the hypo-central distance for smaller magnitudes; $F = 0$ for strike slip, $F = 1$ for reverse and $F = ½$ for oblique sources. The parameters $\alpha_o$, $\alpha_1$, $\alpha_2$, $\beta_1$, $\beta_2$ and $\phi$ are given below:

for $M < 6$ $\alpha_o = 0.010$ $\alpha_1 = 1.175$ $\alpha_2 = 0.0105$;

$\beta_1 = 1.117$ $\beta_2 = -0.102$; $f(M,R) = 0$, and

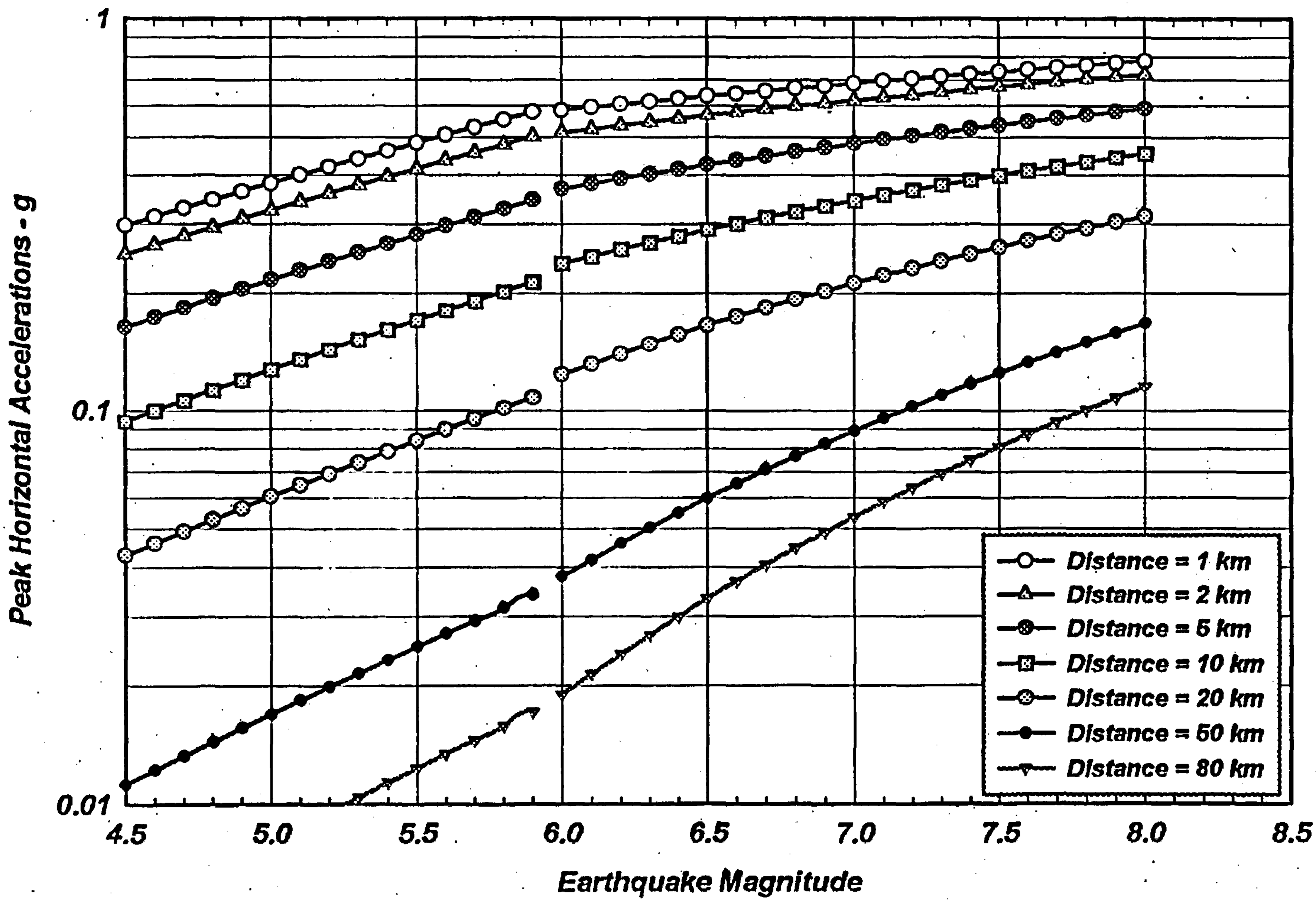
for $M \geq 6$ $\alpha_o = 0$ $\alpha_1 = 3.132$ $\alpha_2 = -0.309$;

$\beta_1 = 2.354$ $\beta_2 = -0.306$;

$$f(M,R) = (0.48 - 0.06M)(1 - 0.1R)(1 - tanh(R/20))$$

and $\phi = 0.28$ for all magnitudes and distances. The standard error term for peak horizontal accelerations is given by: $SE = 1.29 - 0.12M$, with $SE \geq 0.42$ (natural logarithm basis).

4.1.3-2



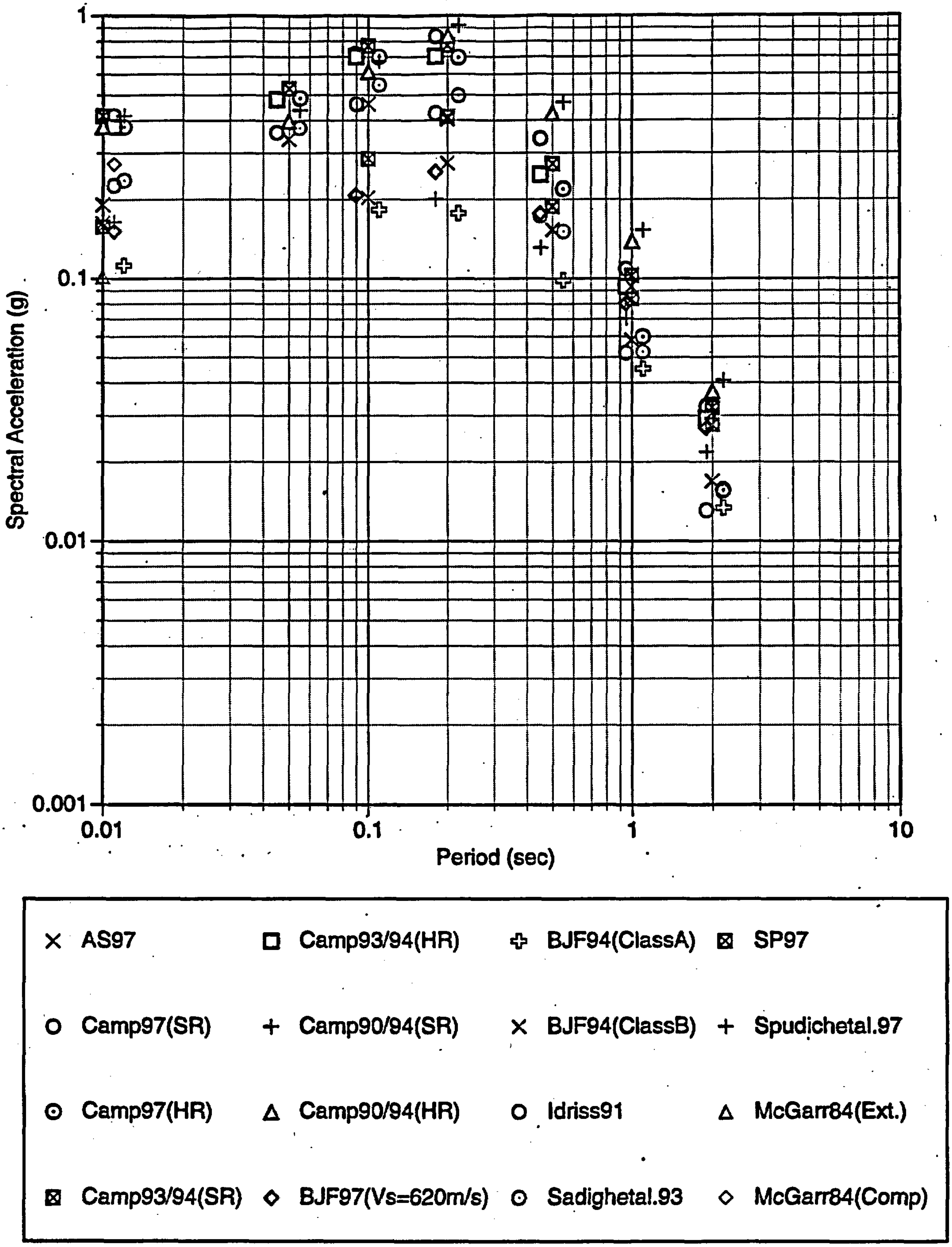
Peak Horizontal Accelerations - g
1
0.1
0.01
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Earthquake Magnitude
Distance = 1 km
Distance = 2 km
Distance = 5 km
Distance = 10 km
Distance = 20 km
Distance = 50 km
Distance = 80 km

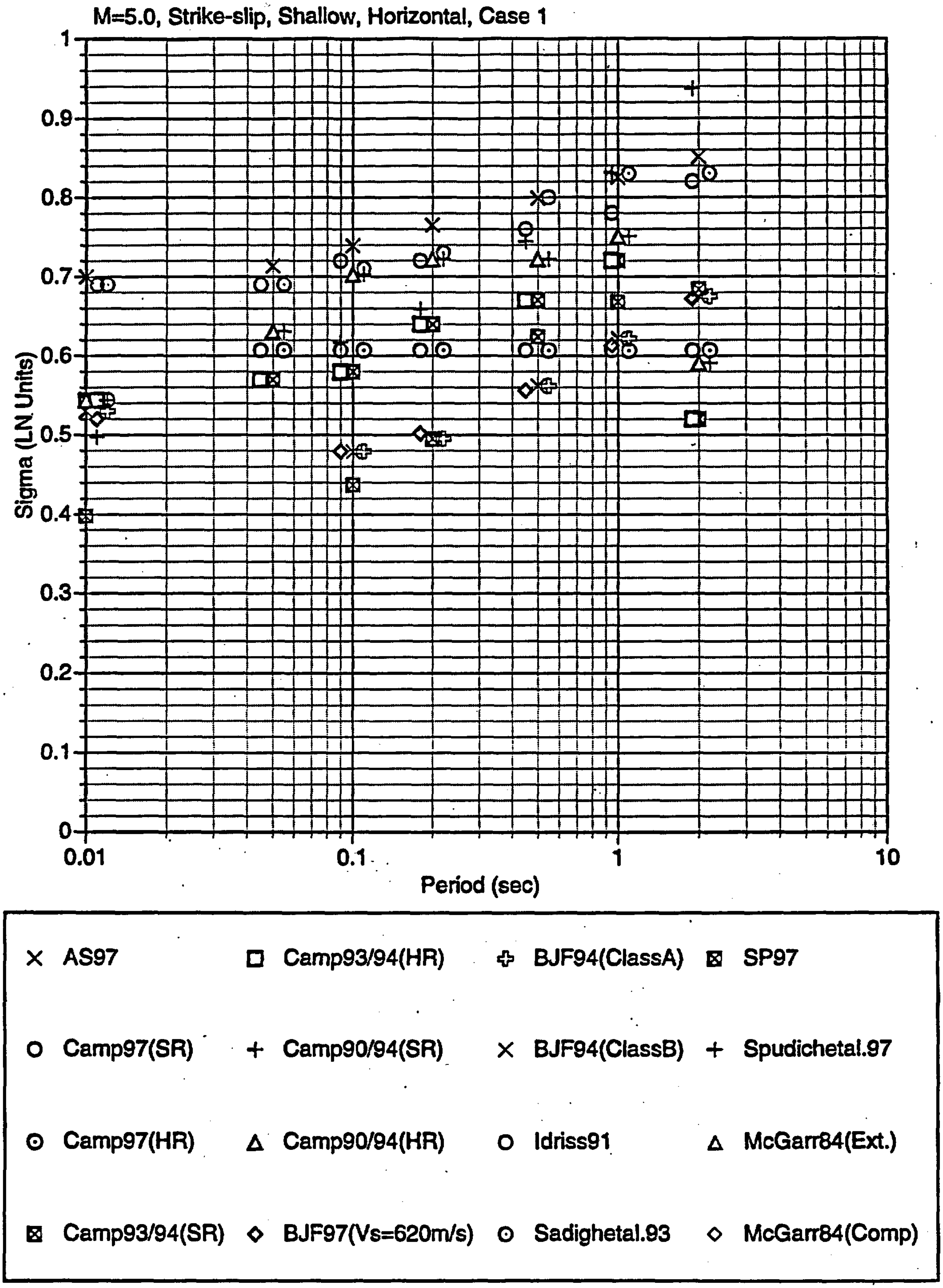
Section 4.1.4: McGarr (1984) Estimates

| Magnitude | Depth | x | Mech | PGV, cm/s |
|---|---|---|---|---|
| 5.0 | shallow | 1 | SS | 7.3 |
| 5.0 | shallow | 1 | HW | 7.1 |
| 5.0 | deep | 5 | SS | 5.6 |
| 5.0 | deep | 5 | HW | 5.9 |
| 5.8 | deep | 10 | SS | 12.1 |
| 5.8 | deep | 20 | HW | 10.9 |
| 6.5 | shallow | 1 | SS | 34.9 |
| 6.5 | shallow | 1 | HW | 33.3 |
| 6.5 | shallow | 1 | FW | 31.0 |
| 6.5 | shallow | 5 | HW | 36.0 |
| 6.5 | shallow | 5 | FW | 25.8 |
| 7.0 | shallow | 10 | SS | 48.4 |

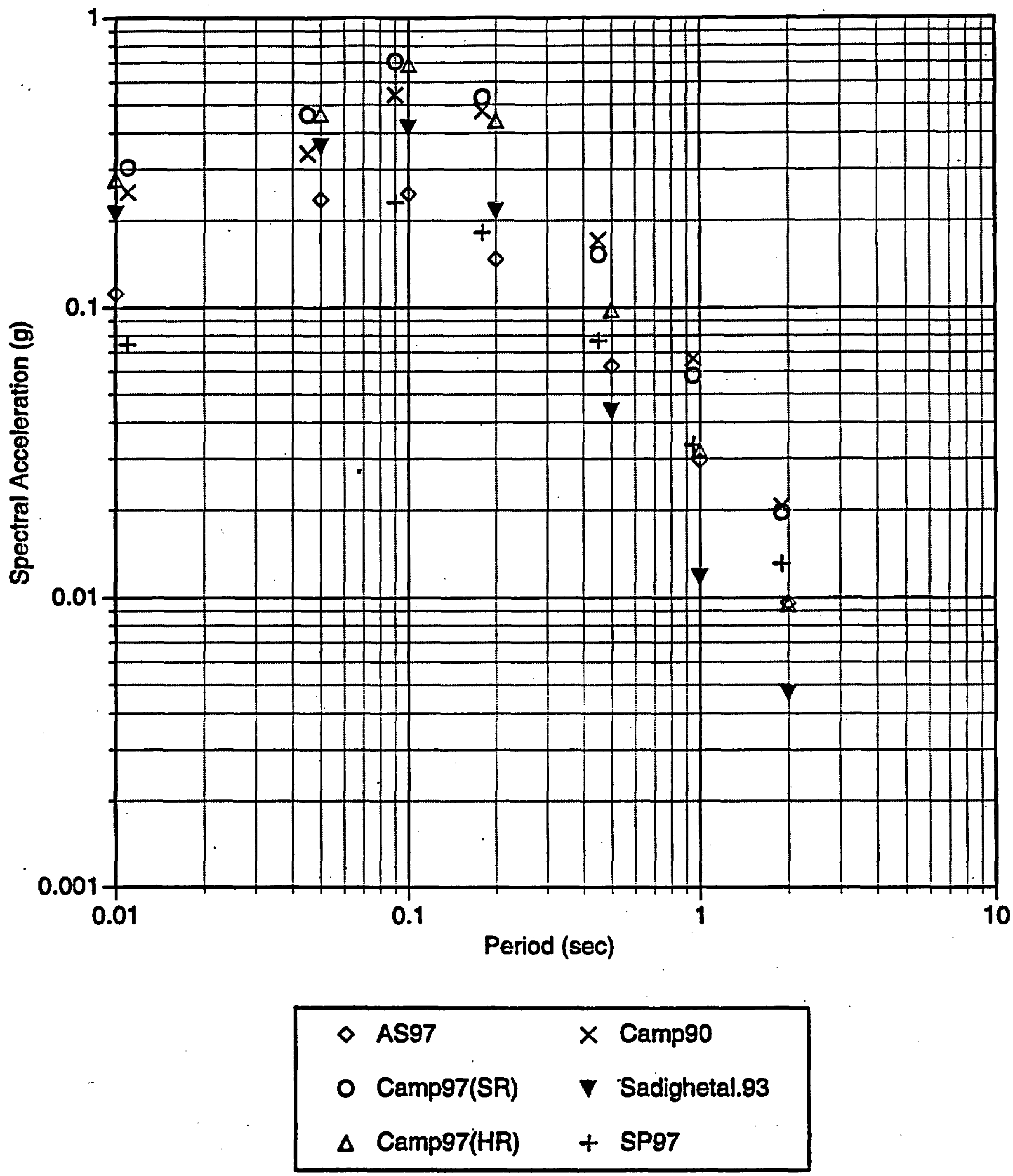
## 4.3 Plots for Empirical Models Without Adjustments

M=5.0, Strike-slip, Shallow, Horizontal, Case 1

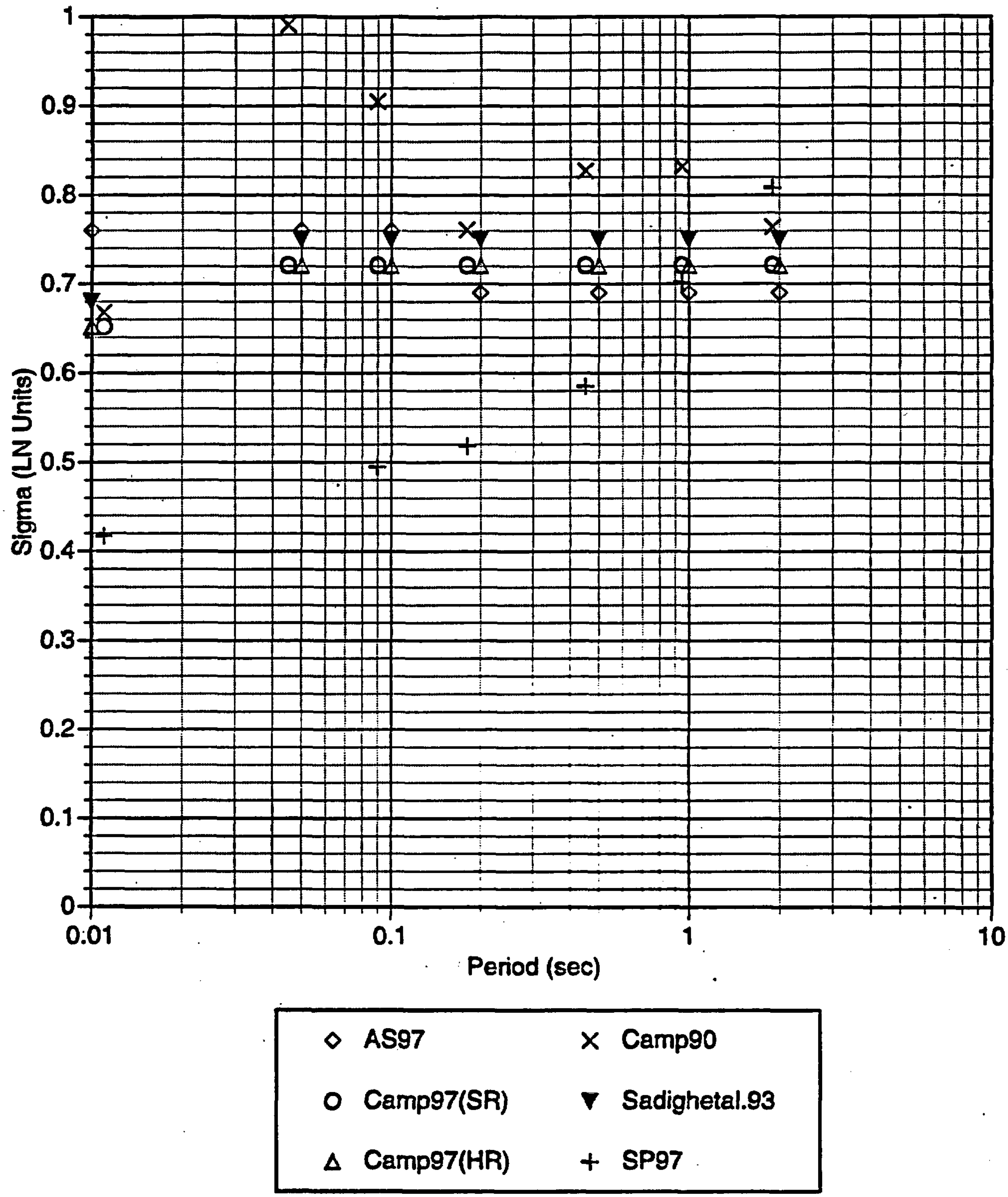



M=5.0, Strike-slip, Shallow, Horizontal, Case 1
Sigma (LN Units)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

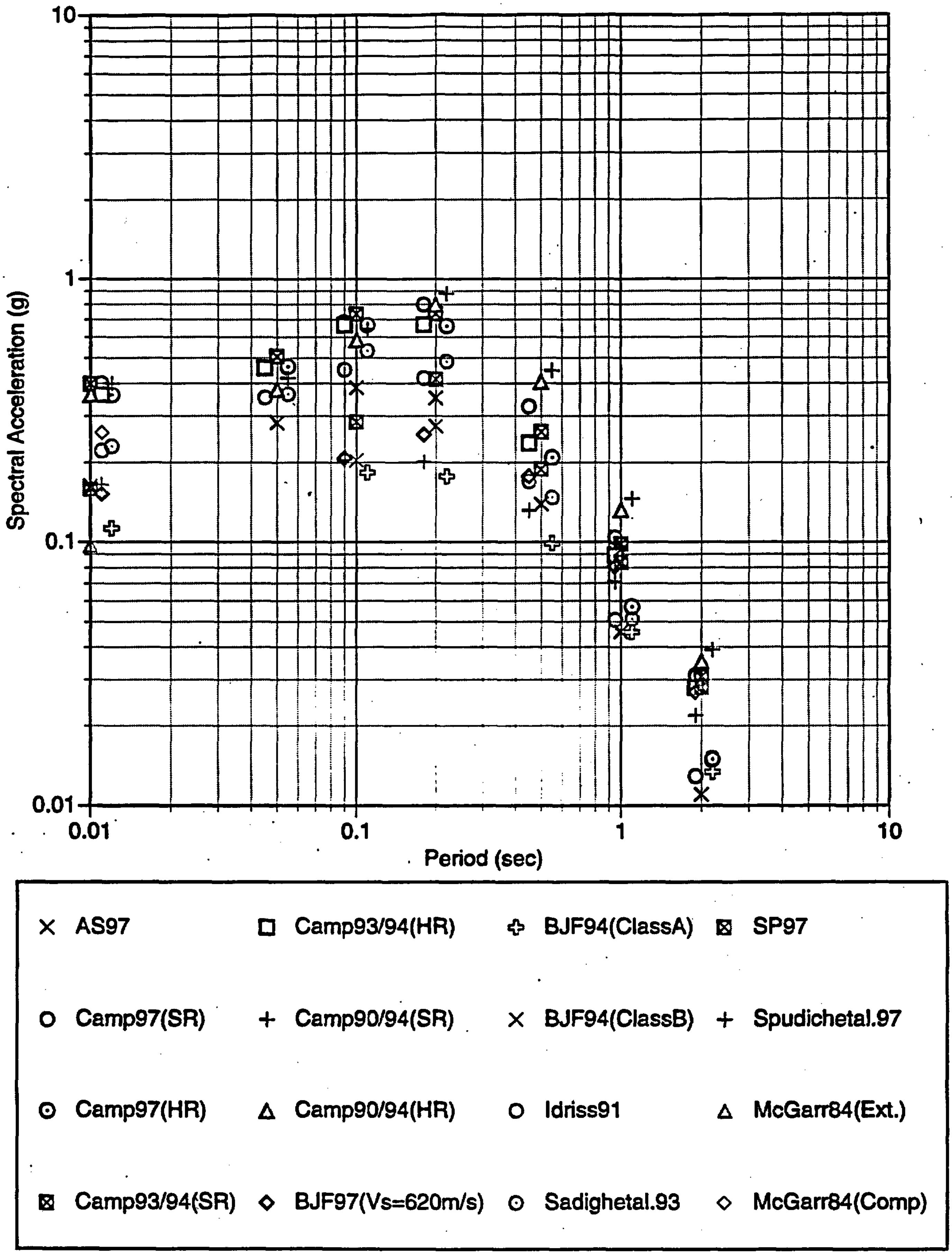
M=5.0, Strike-slip, Shallow, Vertical, Case 1

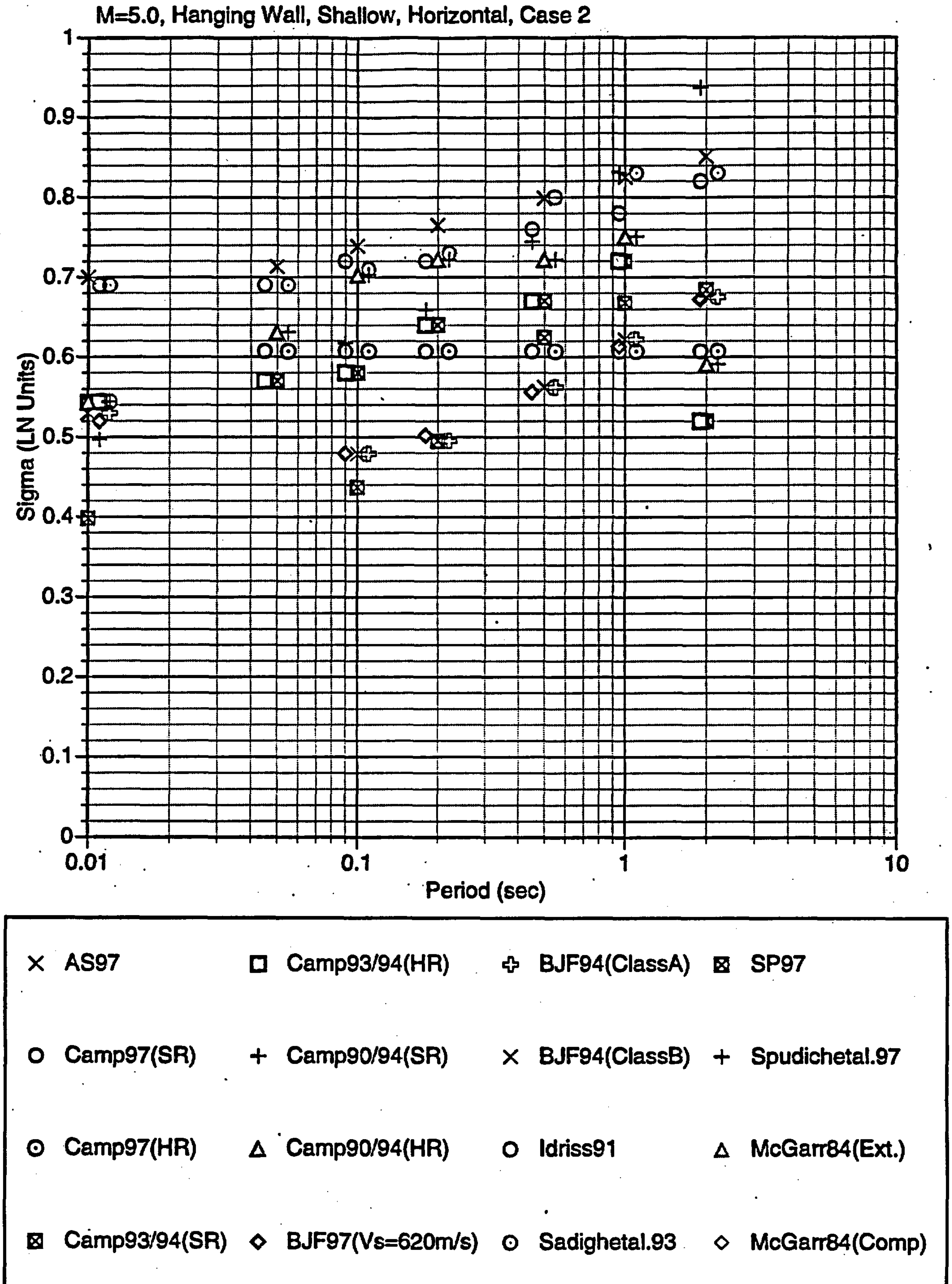


M=5.0, Strike-slip, Shallow, Vertical, Case 1

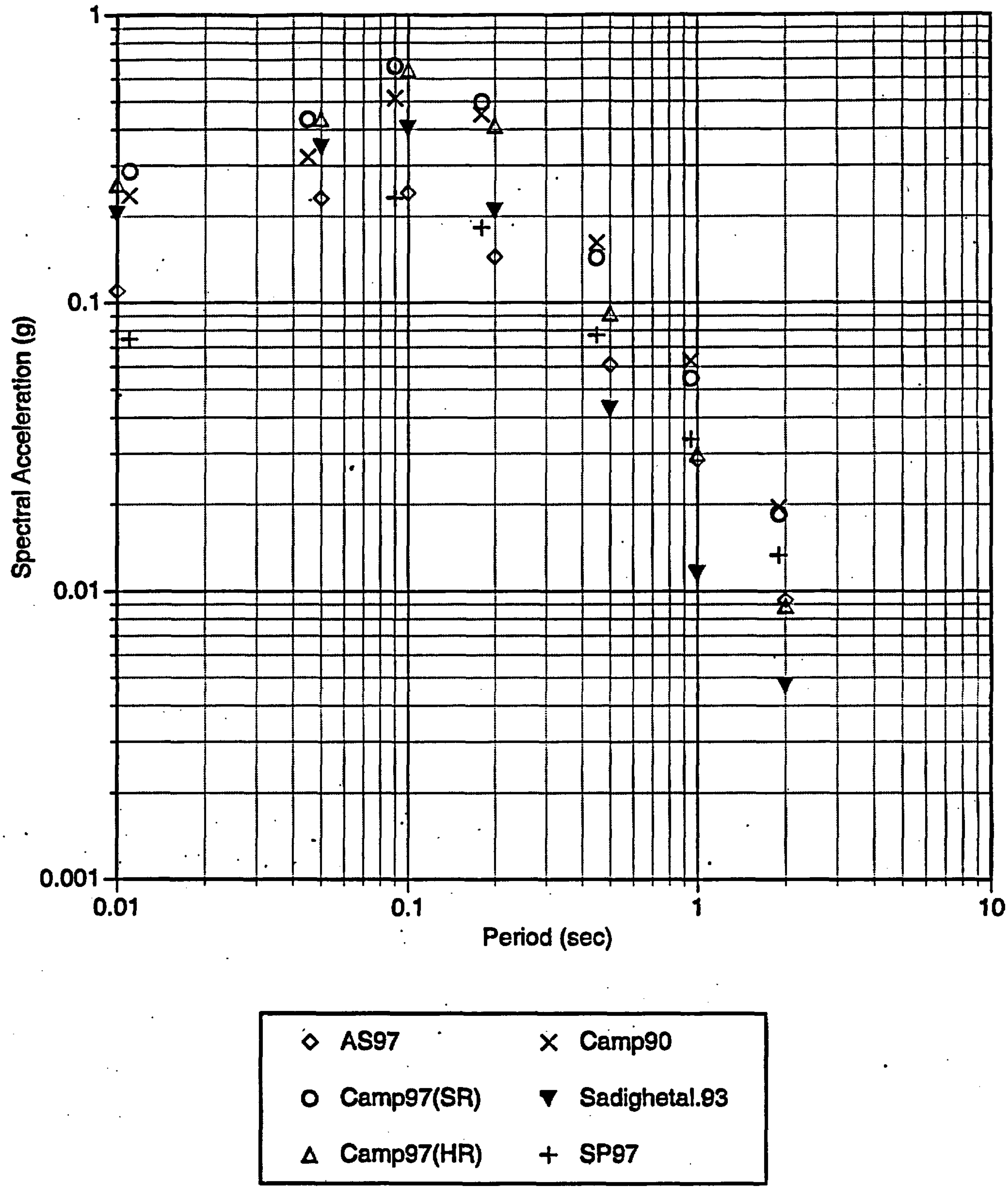


M=5.0, Hanging Wall, Shallow, Horizontal, Case 2

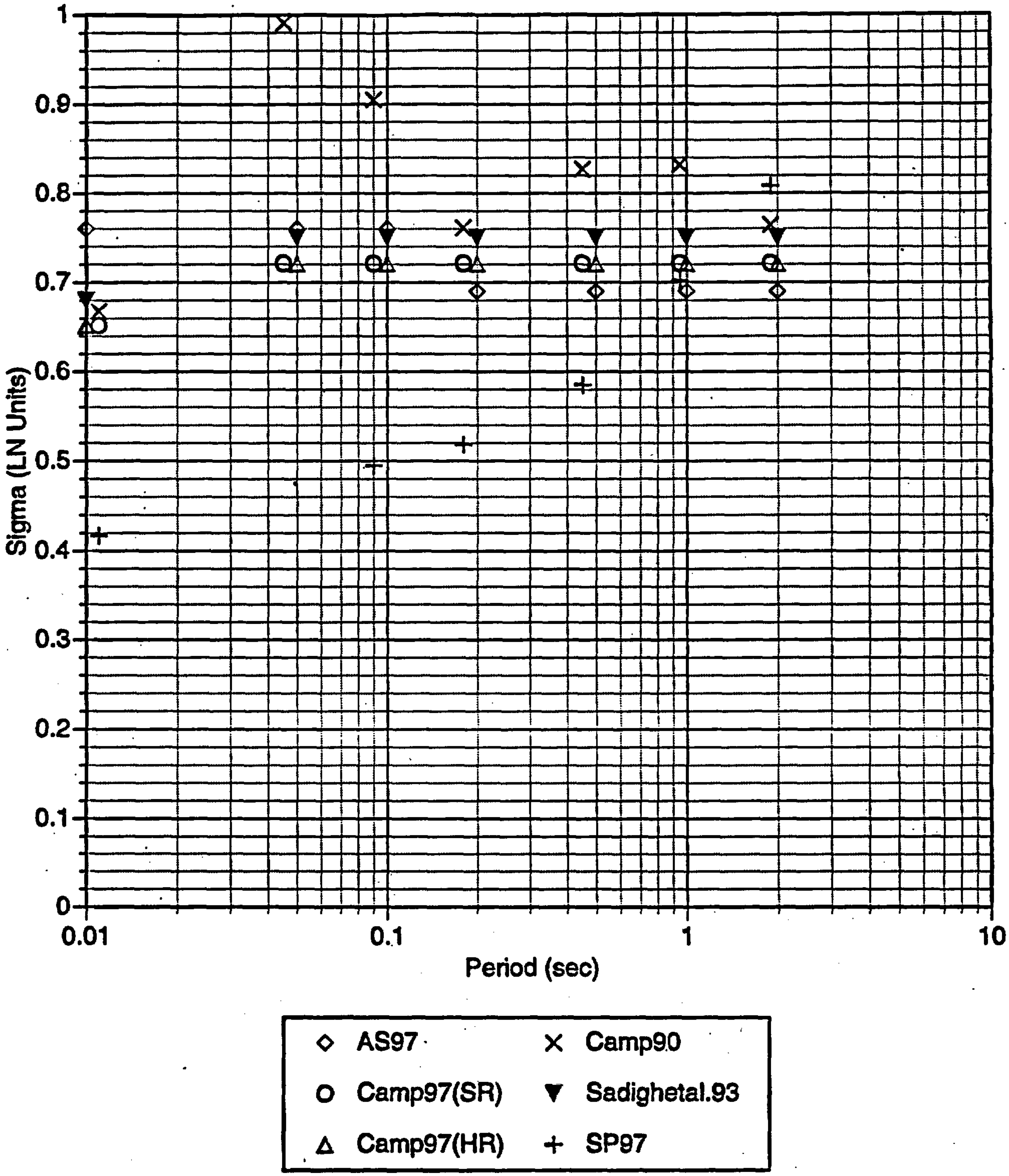


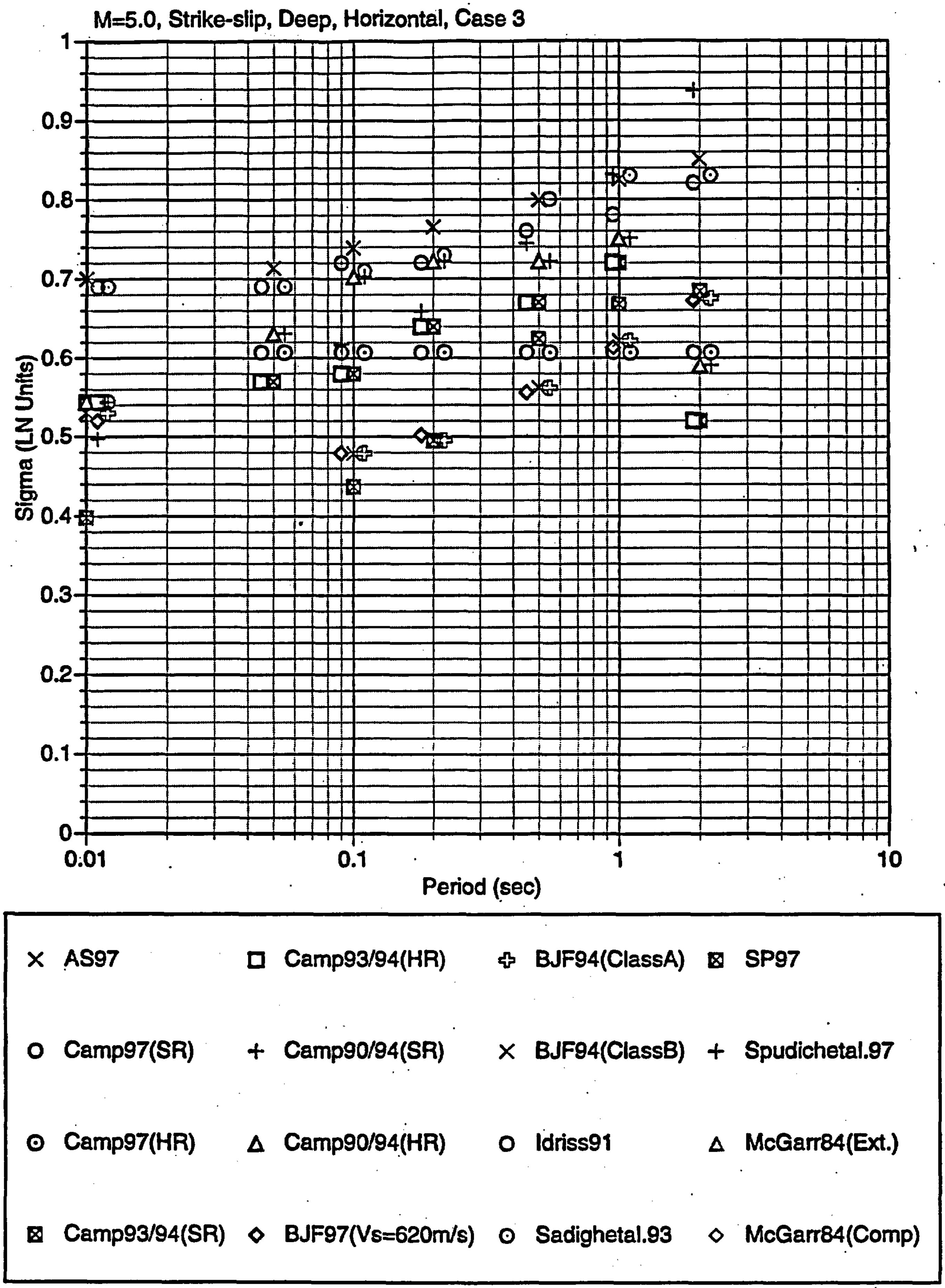

M=5.0, Hanging Wall, Shallow, Horizontal, Case 2
Sigma (LN Units)
Period (sec)
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=5.0, Hanging Wall, Shallow, Vertical, Case 2



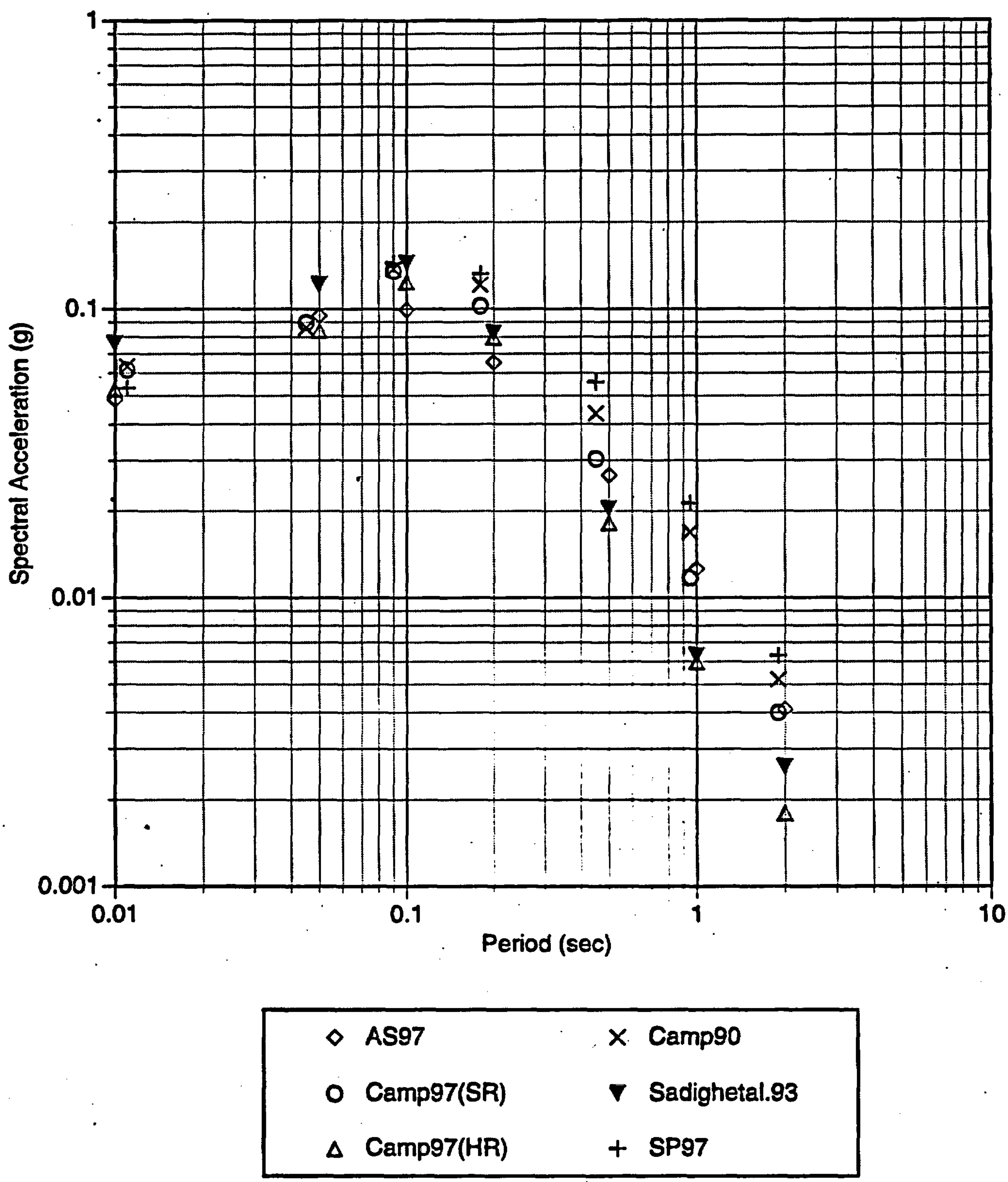
M=5.0, Hanging Wall, Shallow, Vertical, Case 2



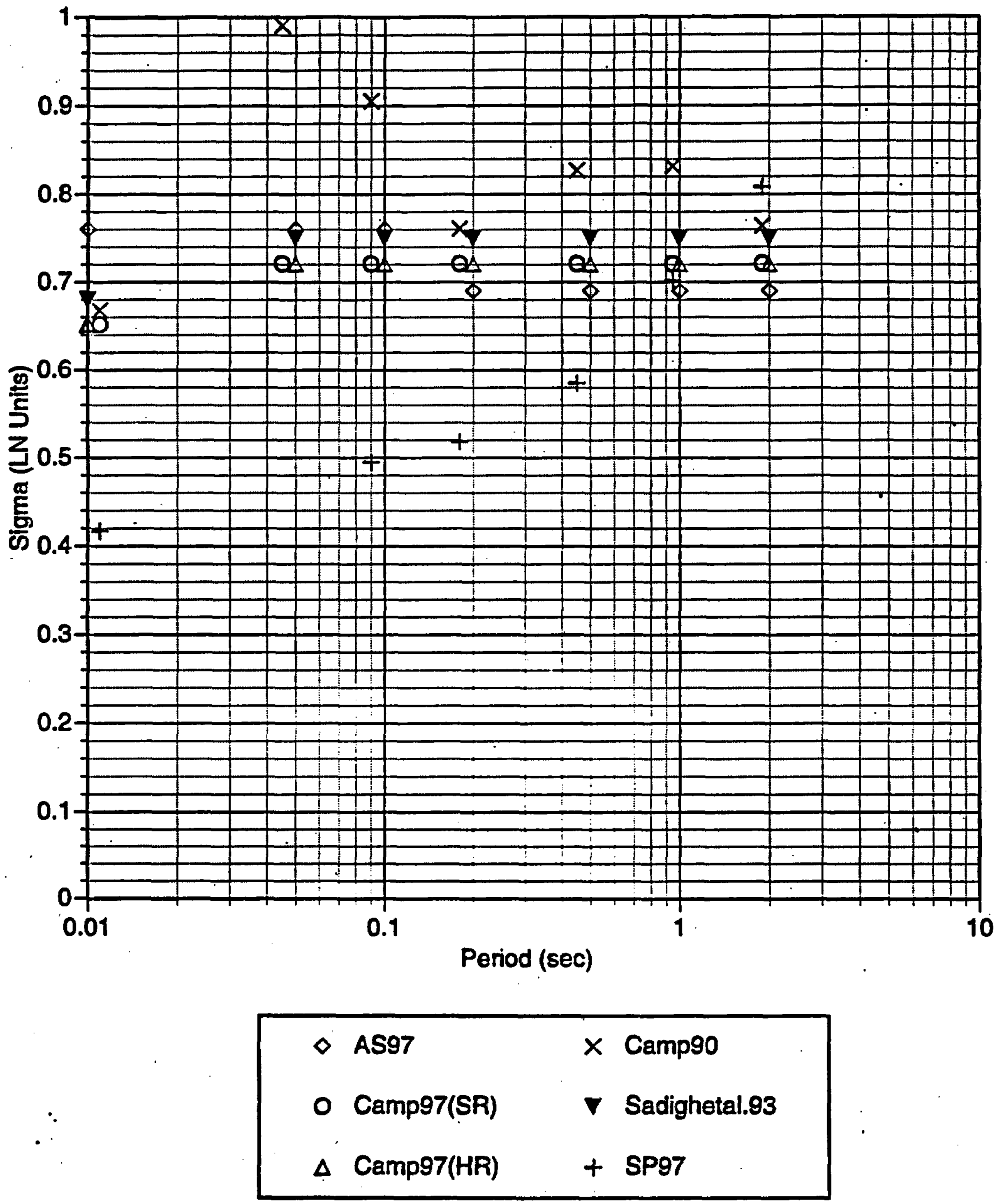


M=5.0, Strike-slip, Deep, Horizontal, Case 3
Sigma (LN Units)
Period (sec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

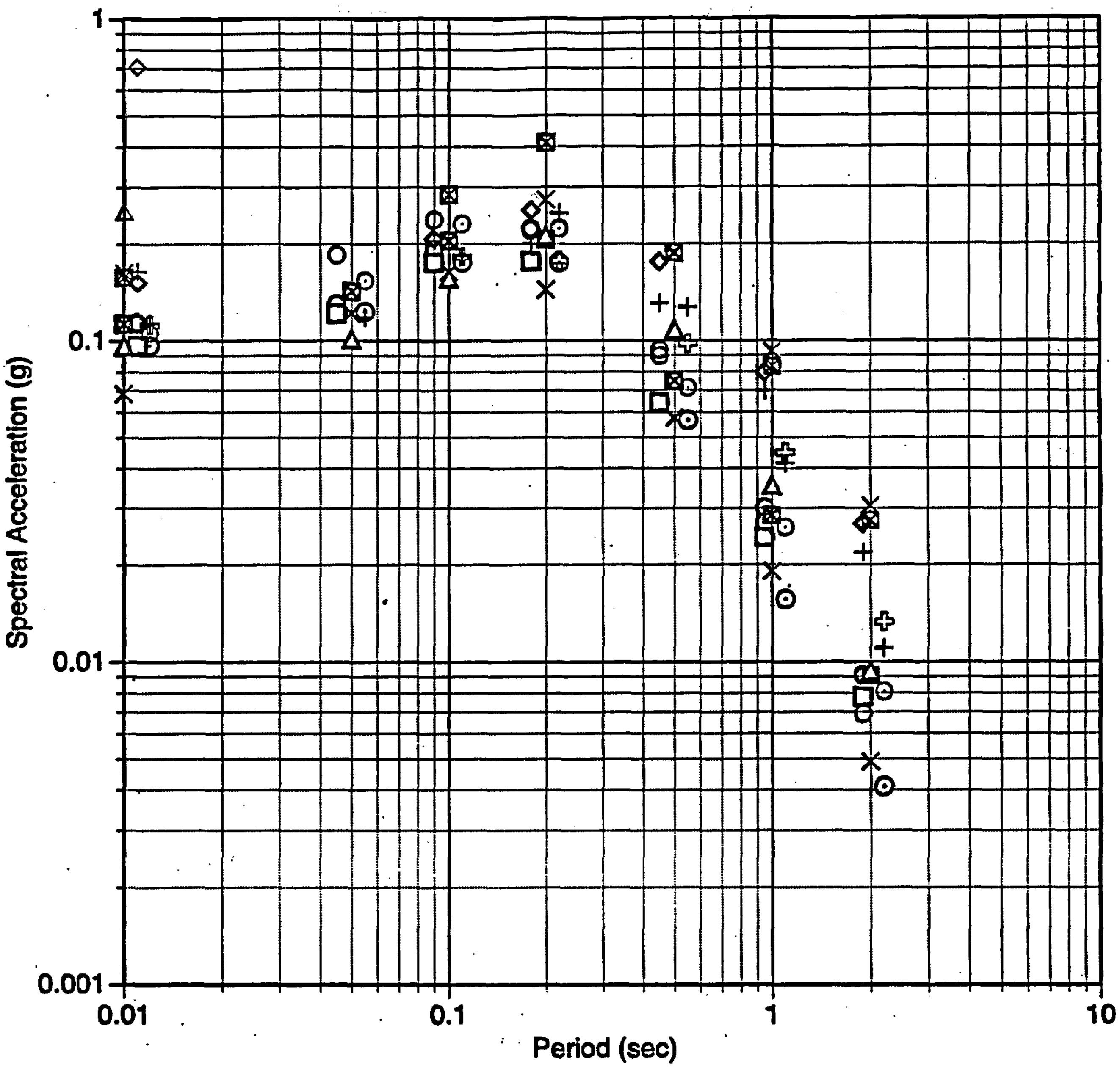
M=5.0, Strike-slip, Deep, Vertical, Case 3



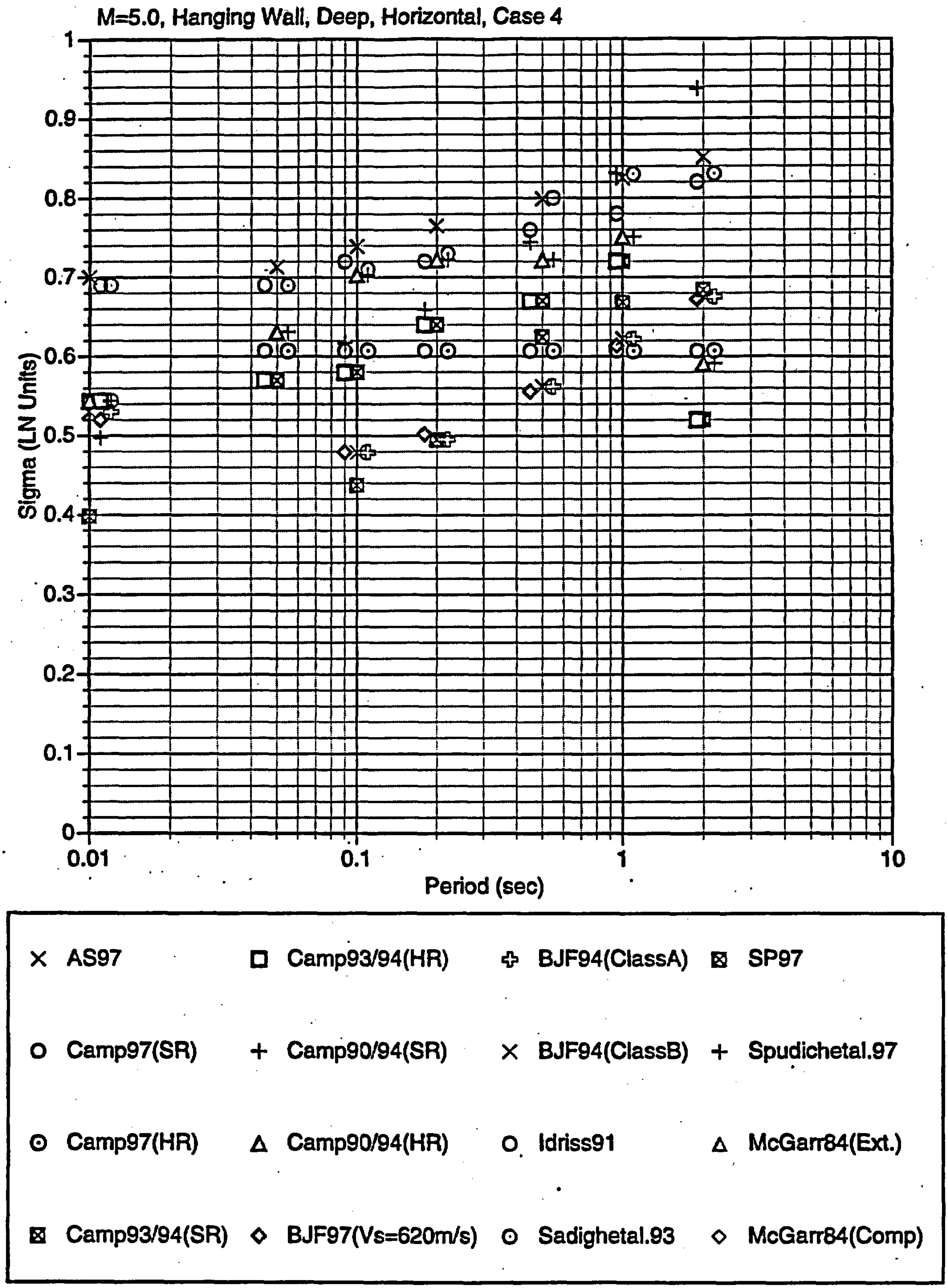
M=5.0, Strike-slip, Deep, Vertical, Case 3



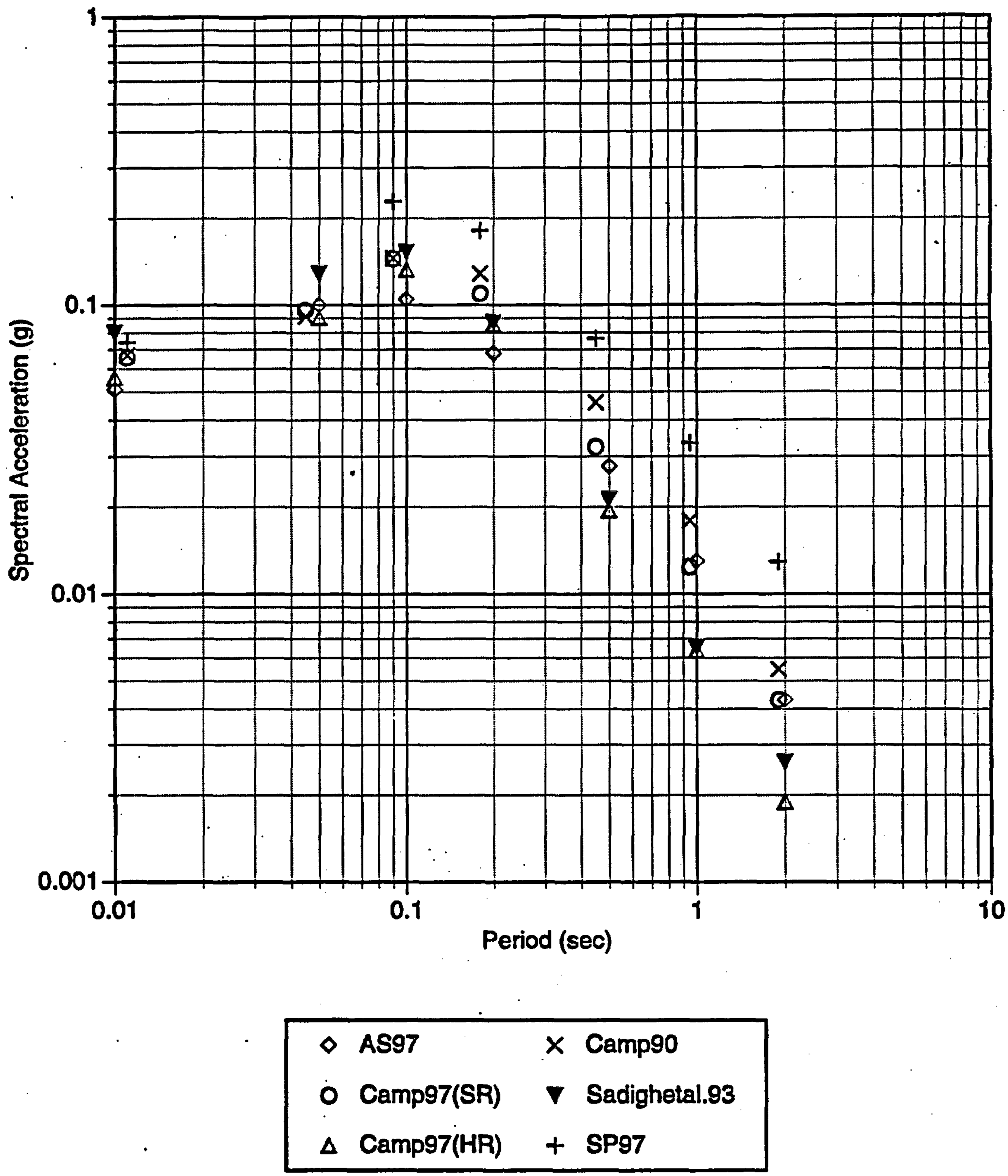
M=5.0, Hanging Wall, Deep, Horizontal, Case 4



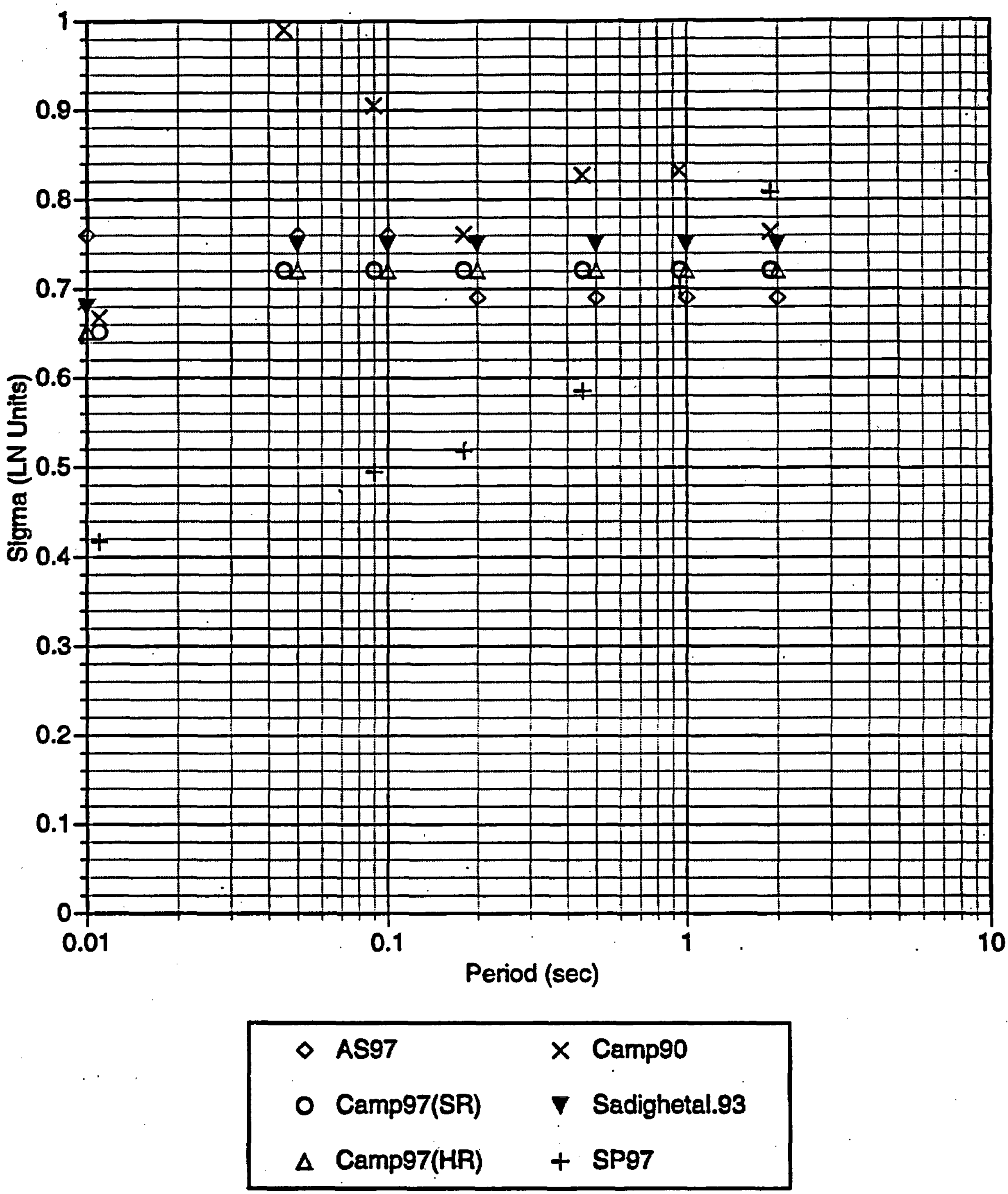

| | | | |
|---|---|---|---|
| × AS97 | □ Camp93/94(HR) | ✤ BJF94(ClassA) | ⊠ SP97 |
| ○ Camp97(SR) | + Camp90/94(SR) | × BJF94(ClassB) | + Spudichetal.97 |
| ⊙ Camp97(HR) | △ Camp90/94(HR) | ○ Idriss91 | △ McGarr84(Ext.) |
| ⊠ Camp93/94(SR) | ◇ BJF97(Vs=620m/s) | ⊙ Sadighetal.93 | ◇ McGarr84(Comp) |

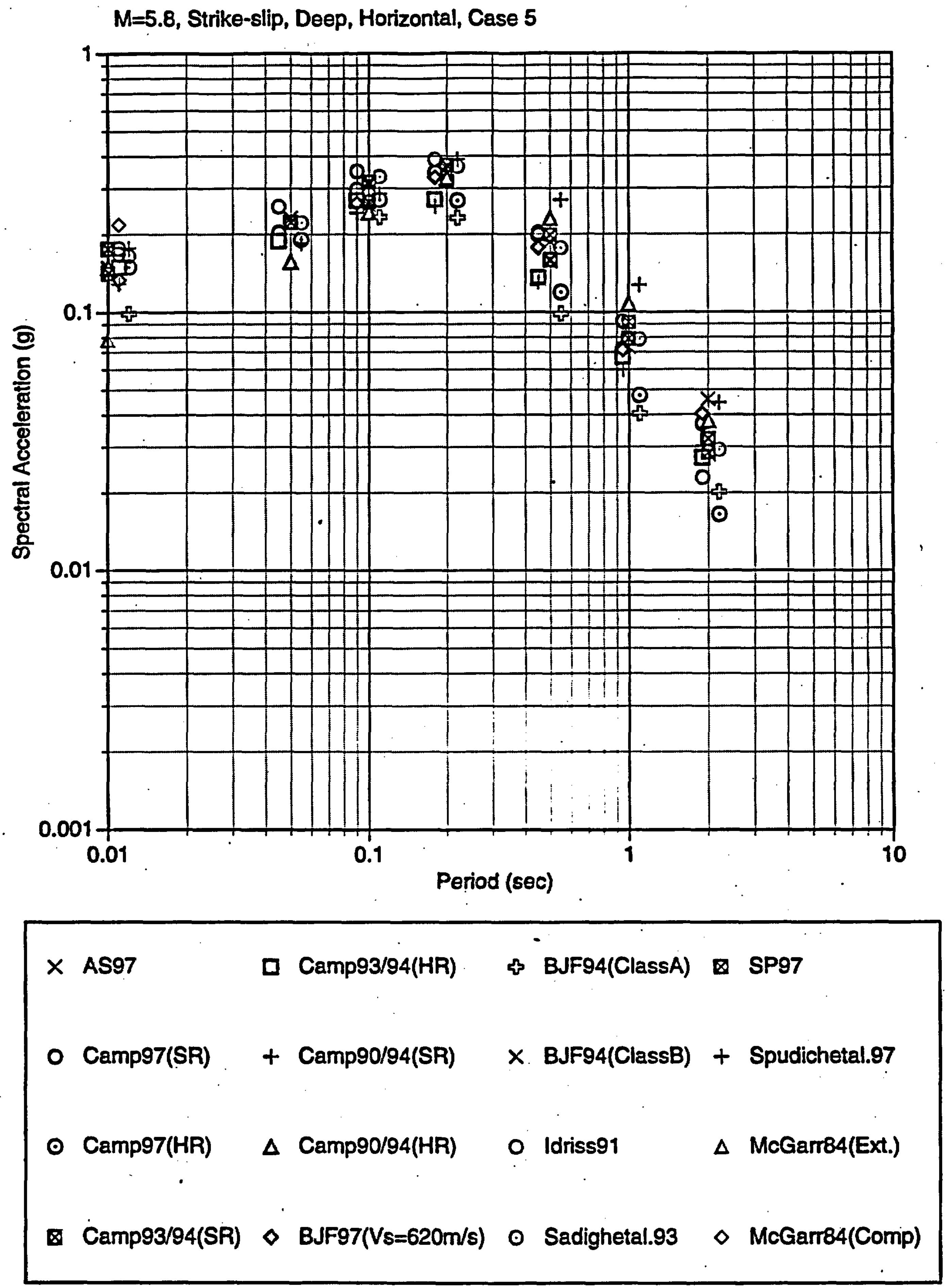

M=5.0, Hanging Wall, Deep, Horizontal, Case 4
Sigma (LN Units)
Period (sec)
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

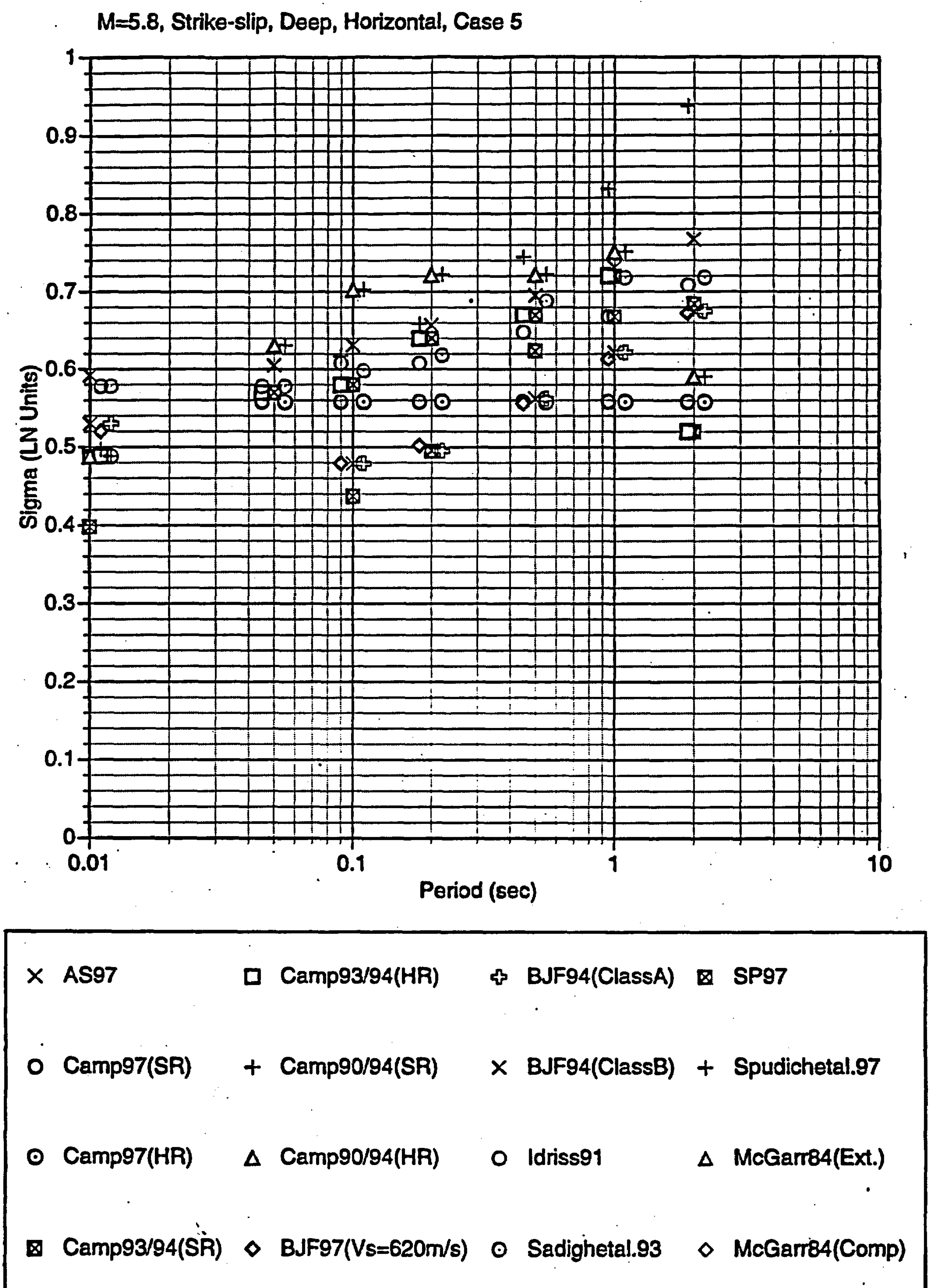
M=5.0, Hanging Wall, Deep, Vertical, Case 4



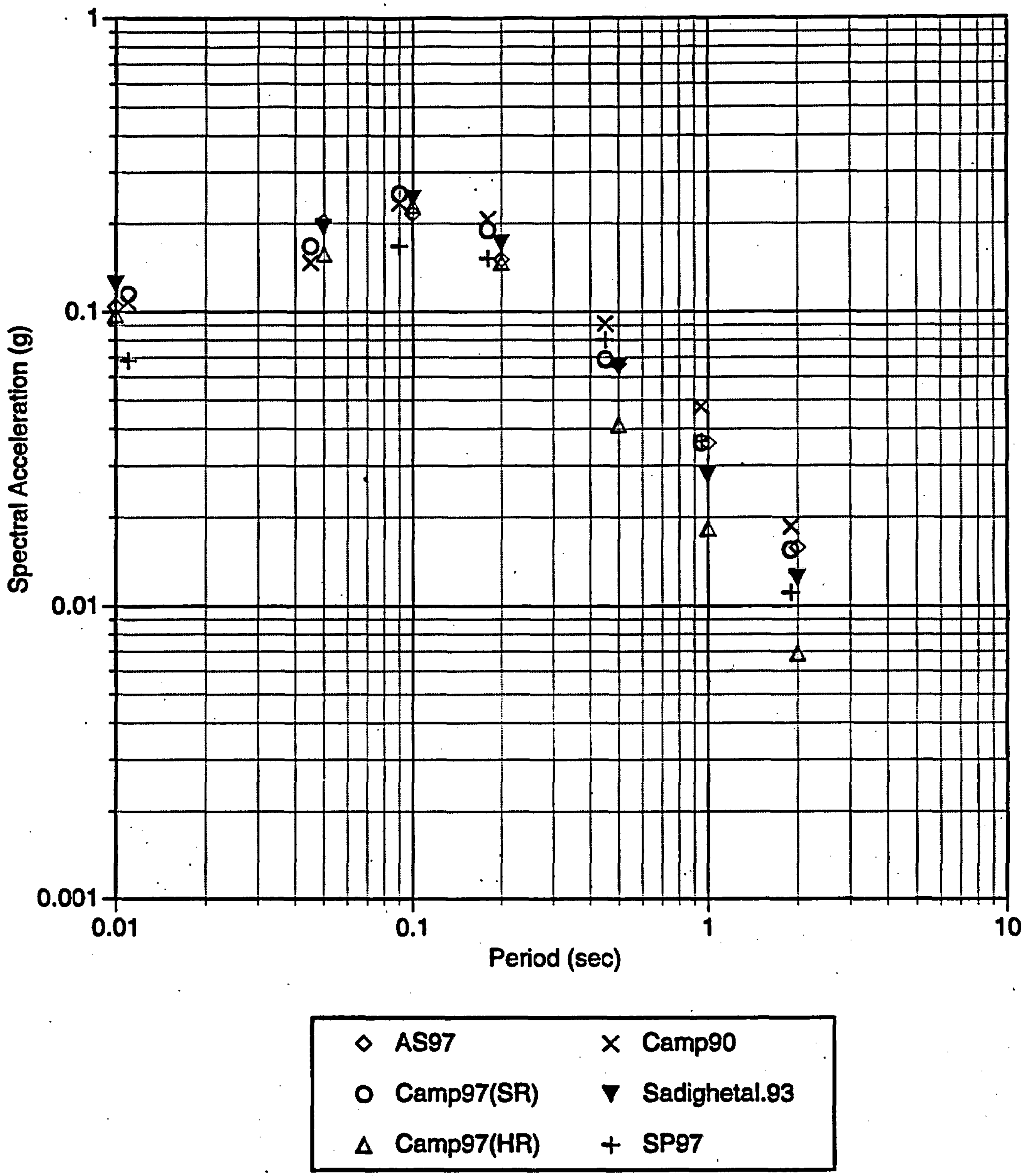
M=5.0, Hanging Wall, Deep, Vertical, Case 4



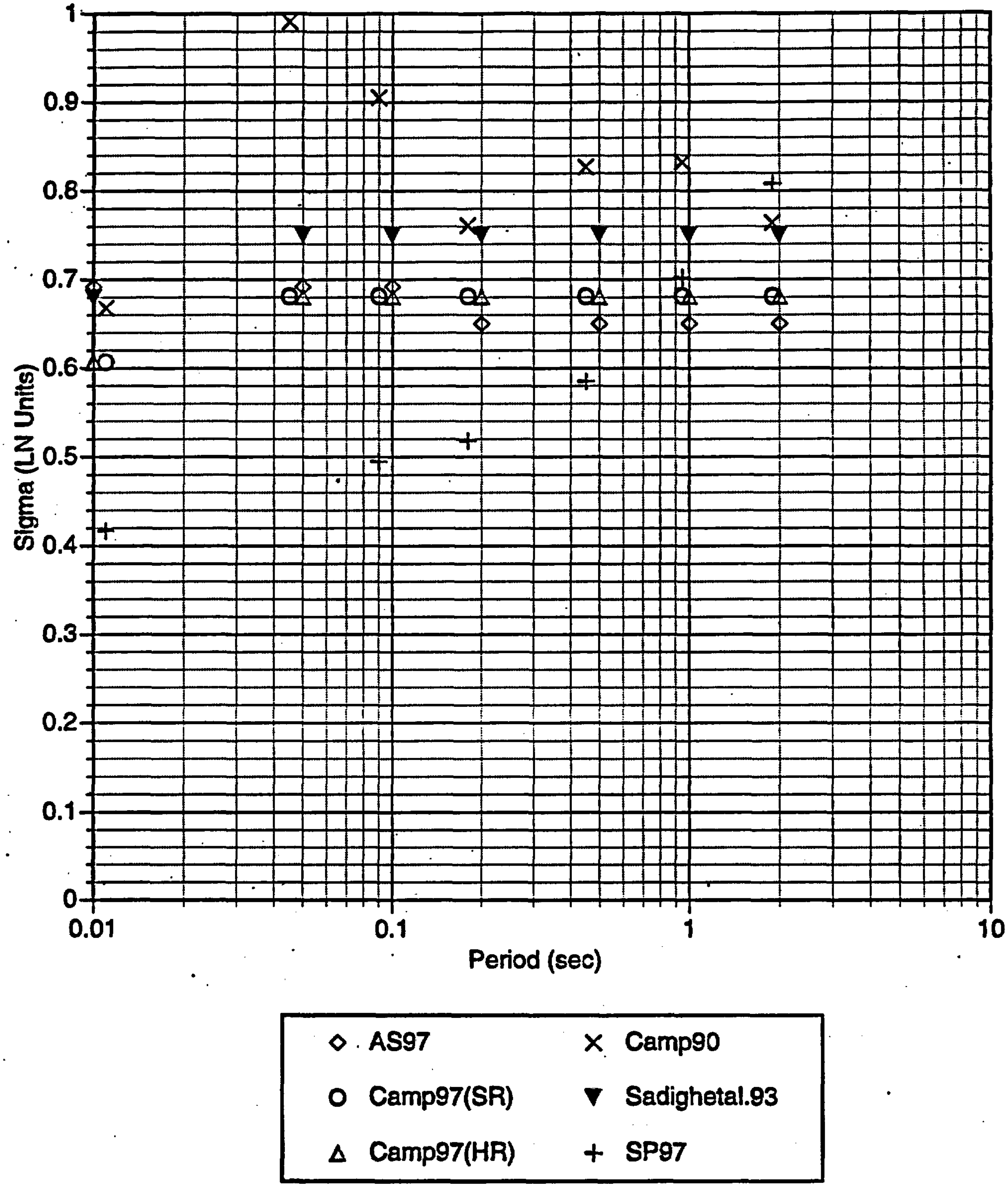

M=5.8, Strike-slip, Deep, Horizontal, Case 5
Spectral Acceleration (g)
1
0.1
0.01
0.001
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

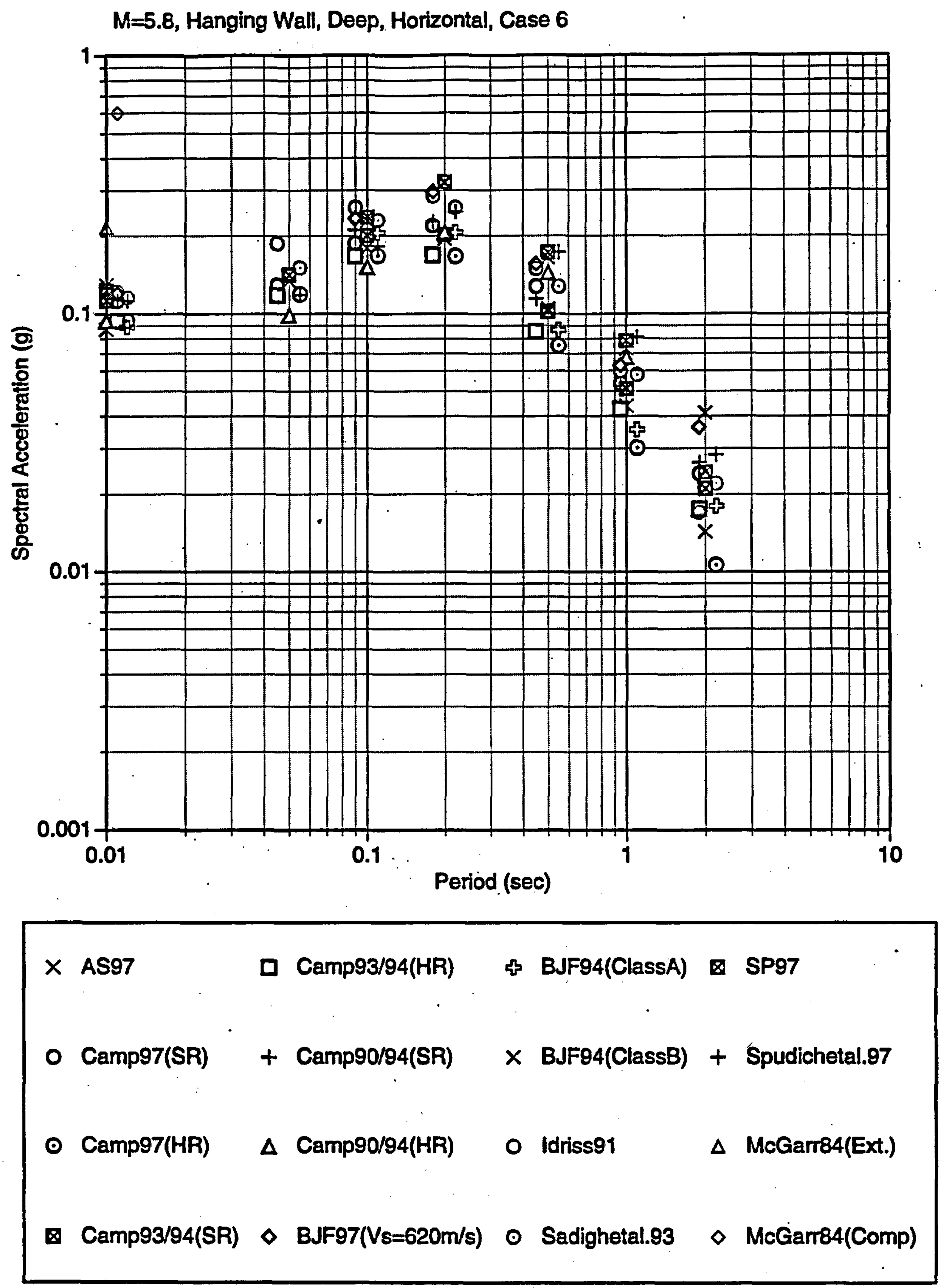

M=5.8, Strike-slip, Deep, Horizontal, Case 5
Sigma (LN Units)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=5.8, Strike-slip, Deep, Vertical, Case 5



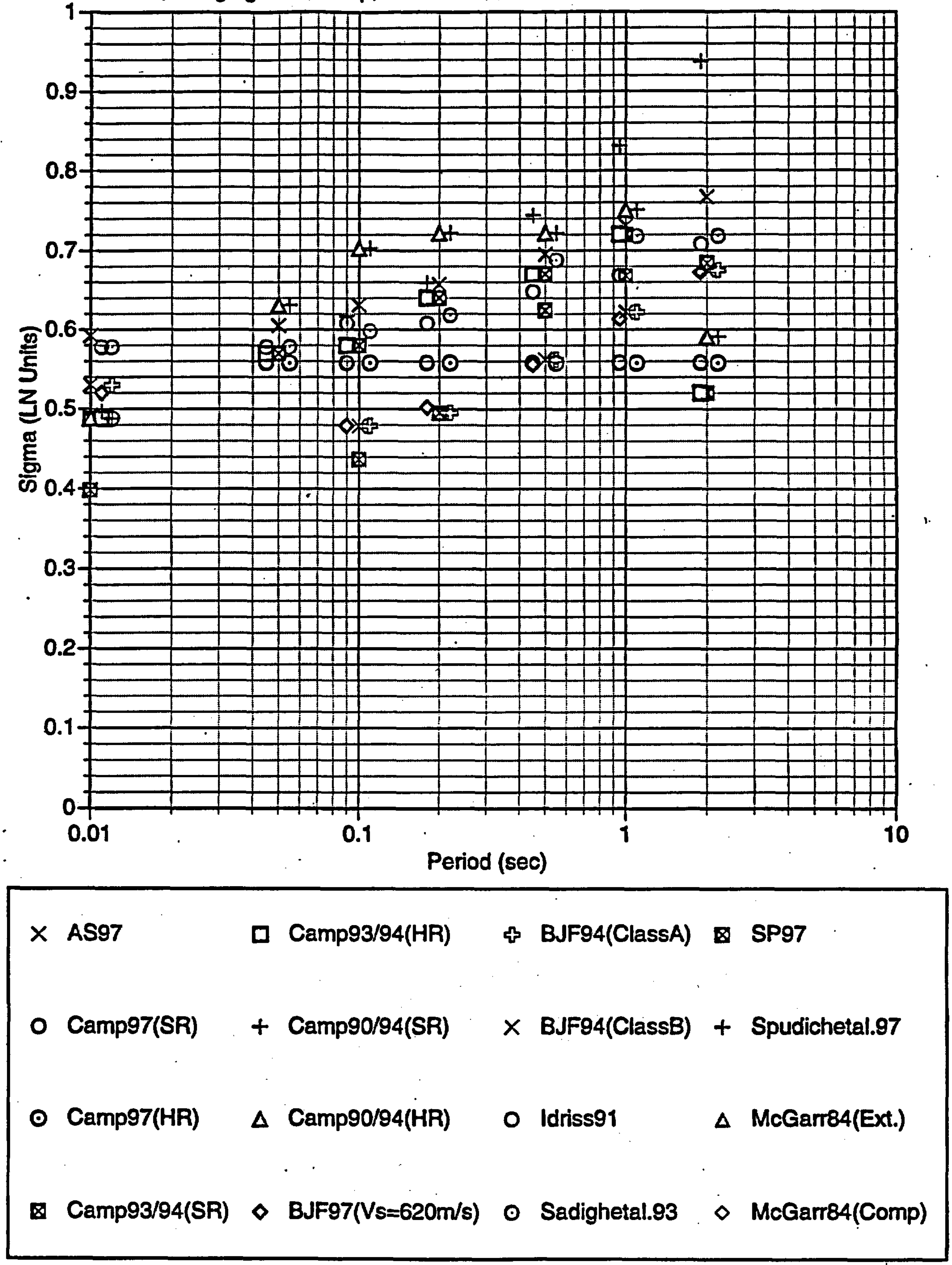
M=5.8, Strike-slip, Deep, Vertical, Case 5



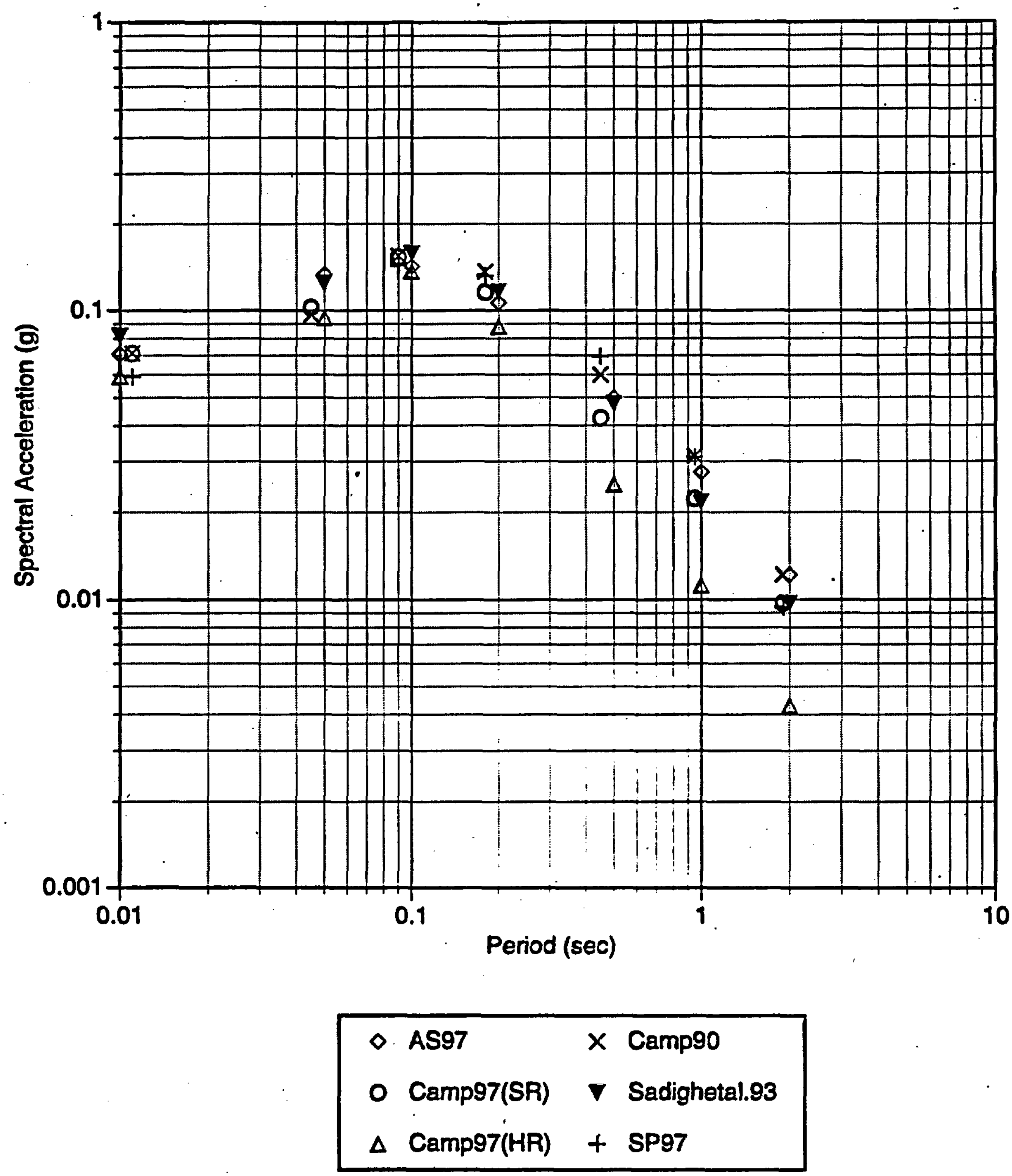


M=5.8, Hanging Wall, Deep, Horizontal, Case 6
Spectral Acceleration (g)
1
0.1
0.01
0.001
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

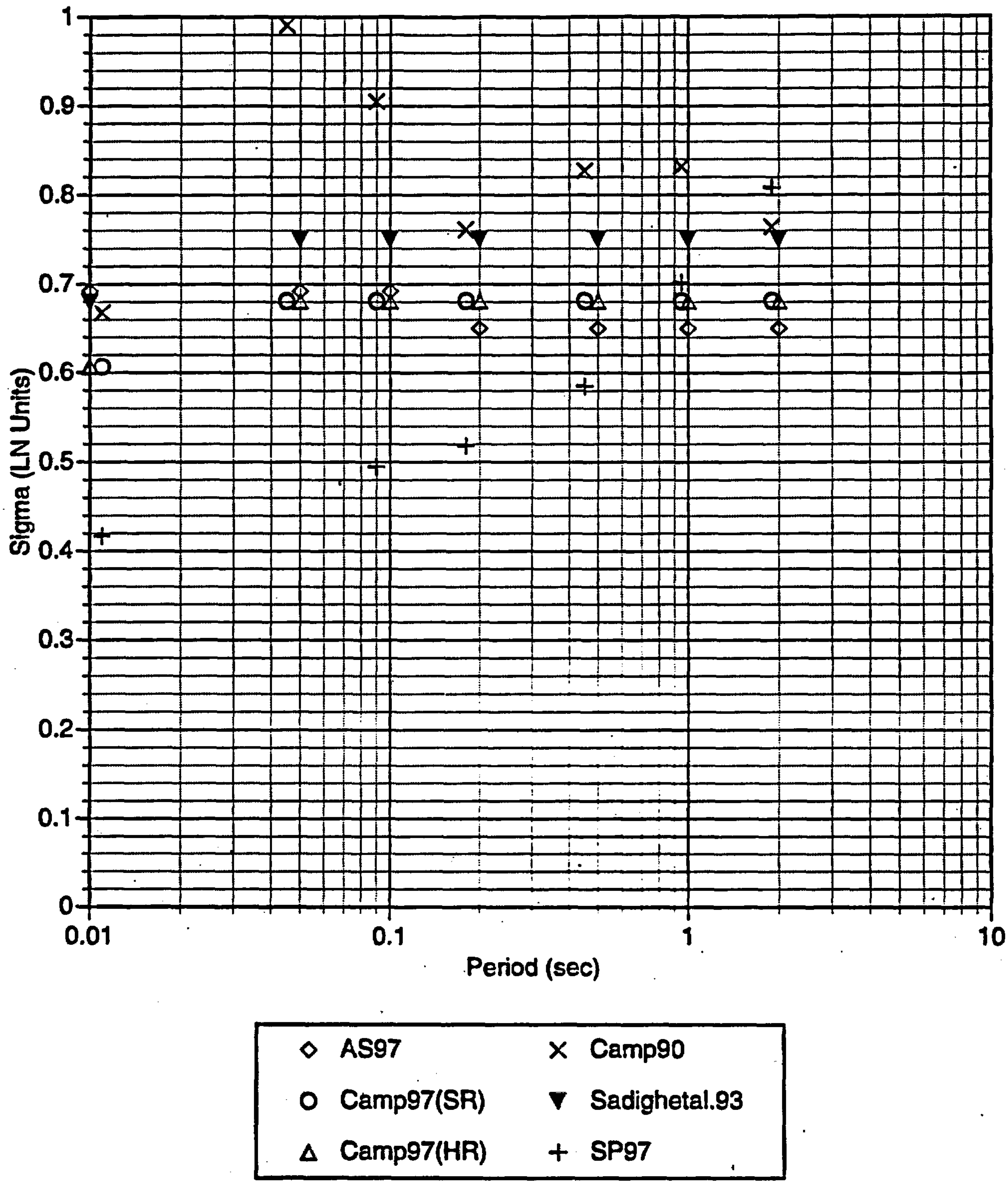
M=5.8, Hanging Wall, Deep, Horizontal, Case 6

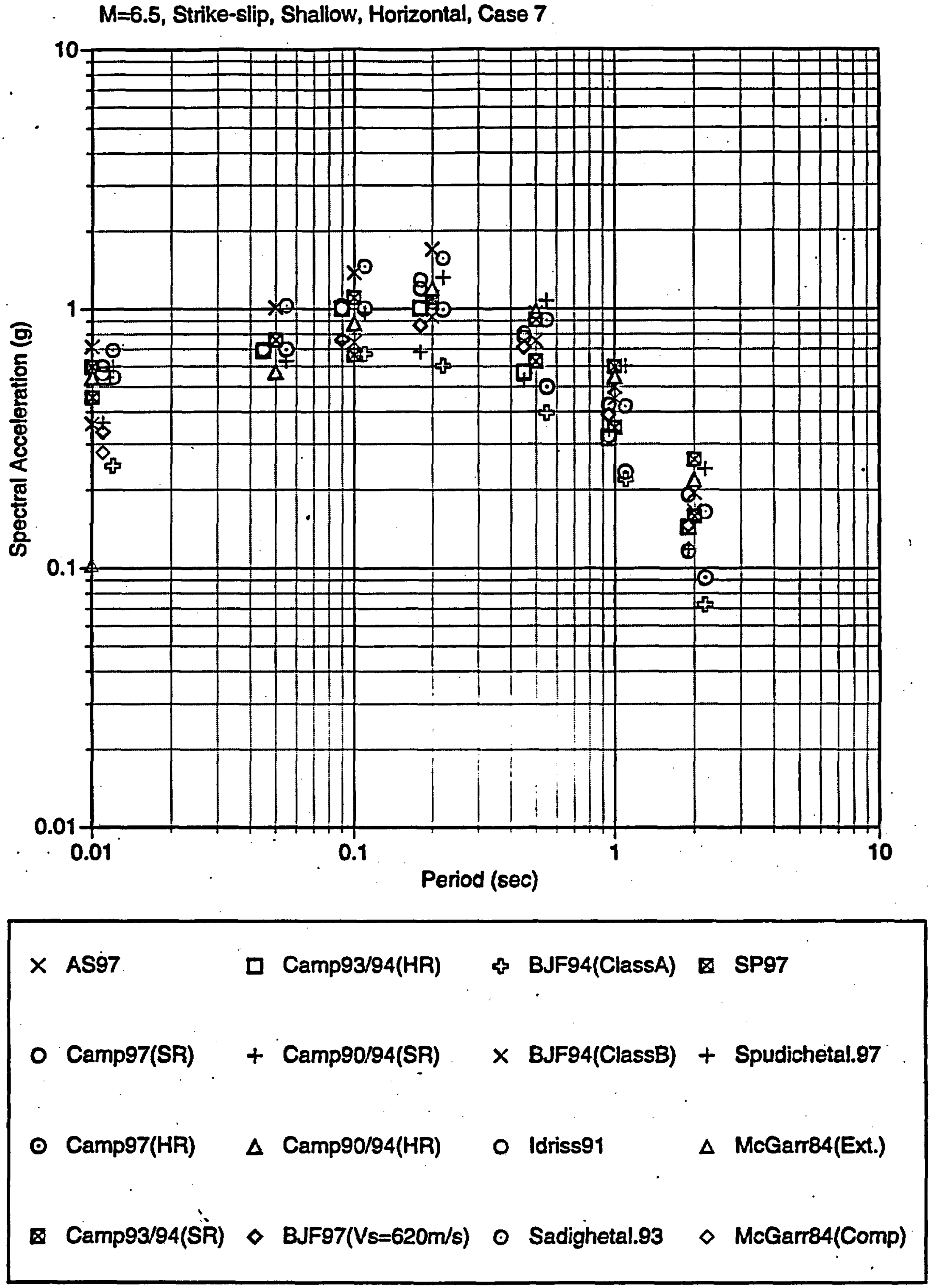


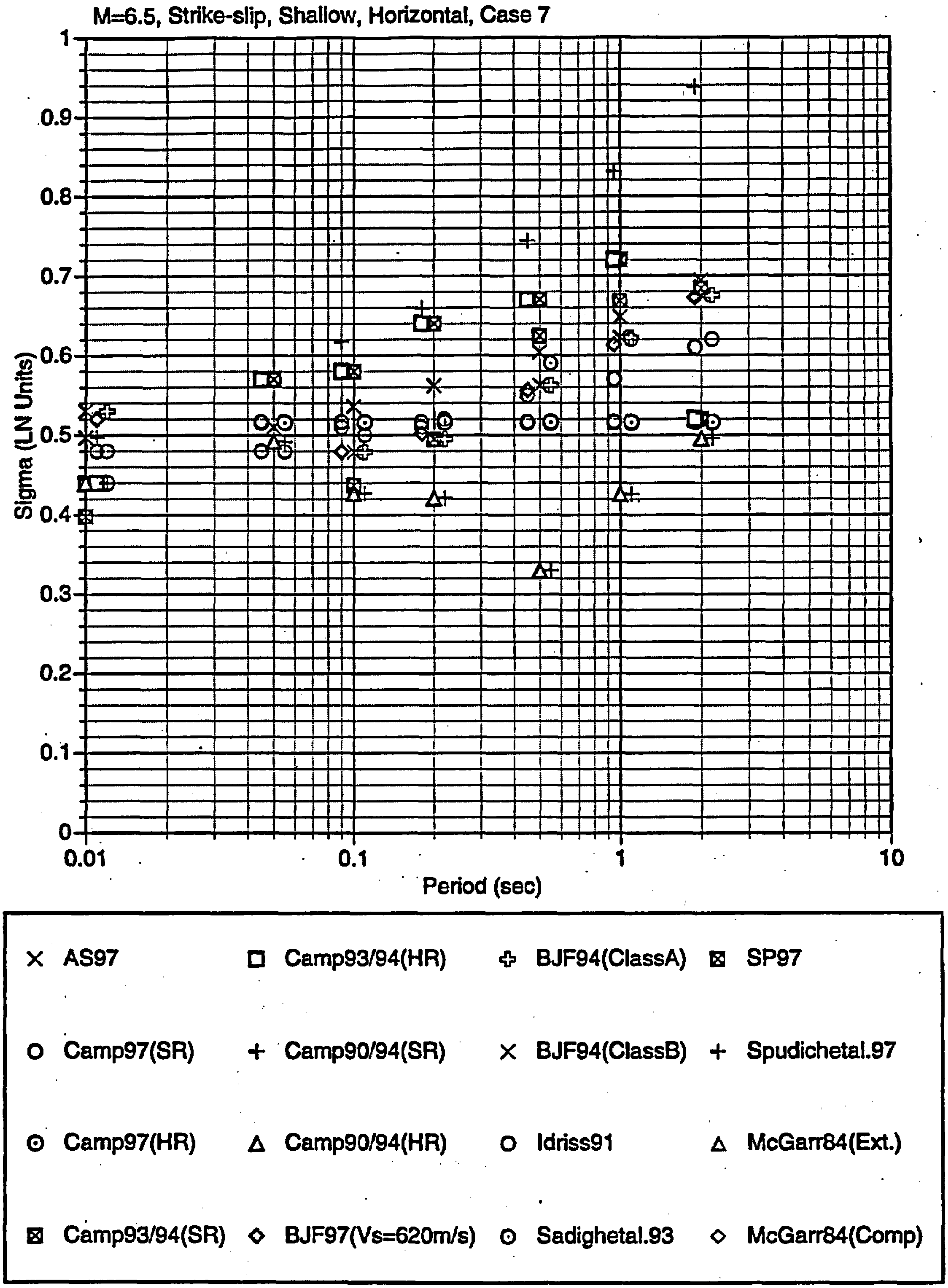
M=5.8, Hanging Wall, Deep, Vertical, Case 6



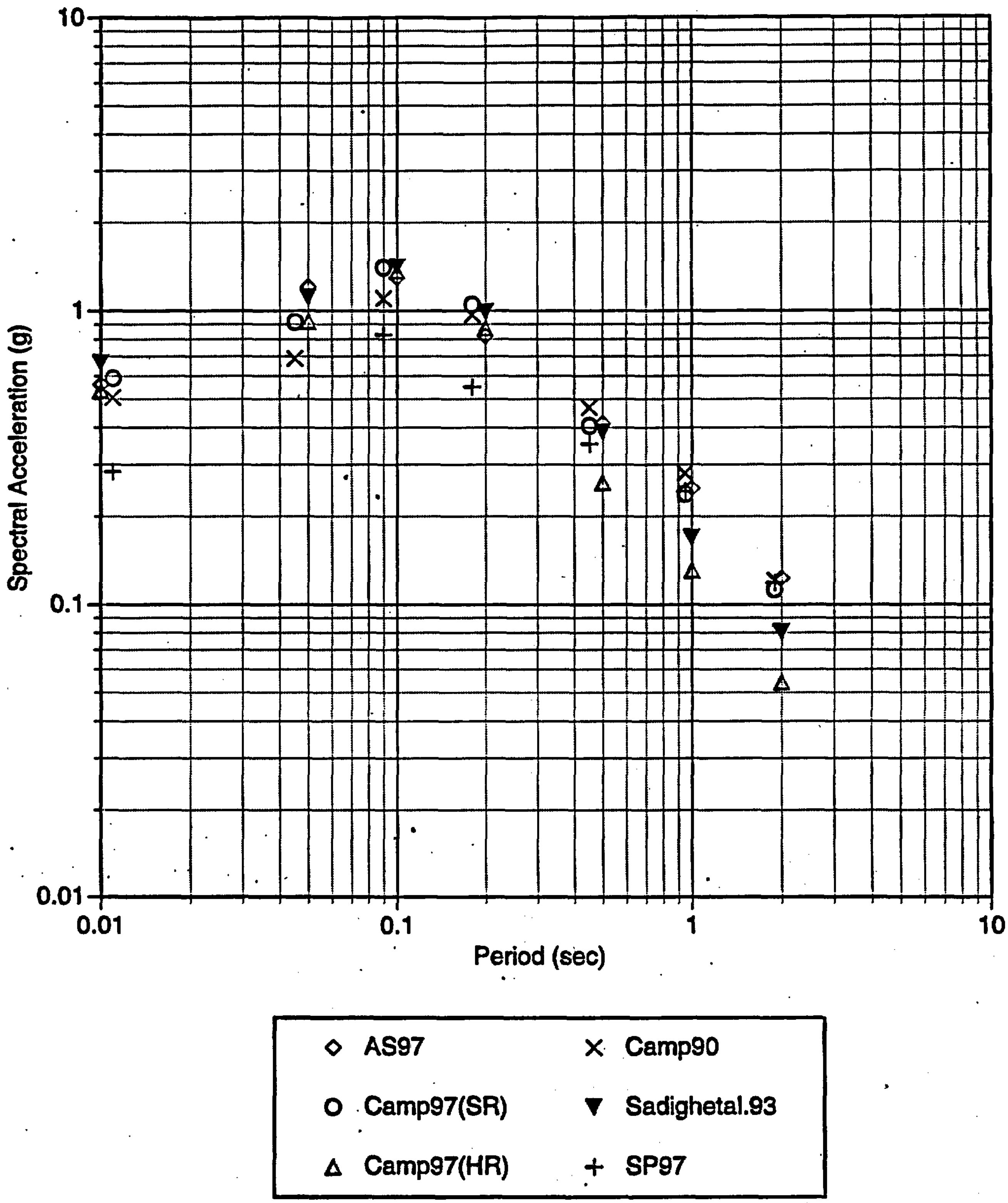
M=5.8, Hanging Wall, Deep, Vertical, Case 6



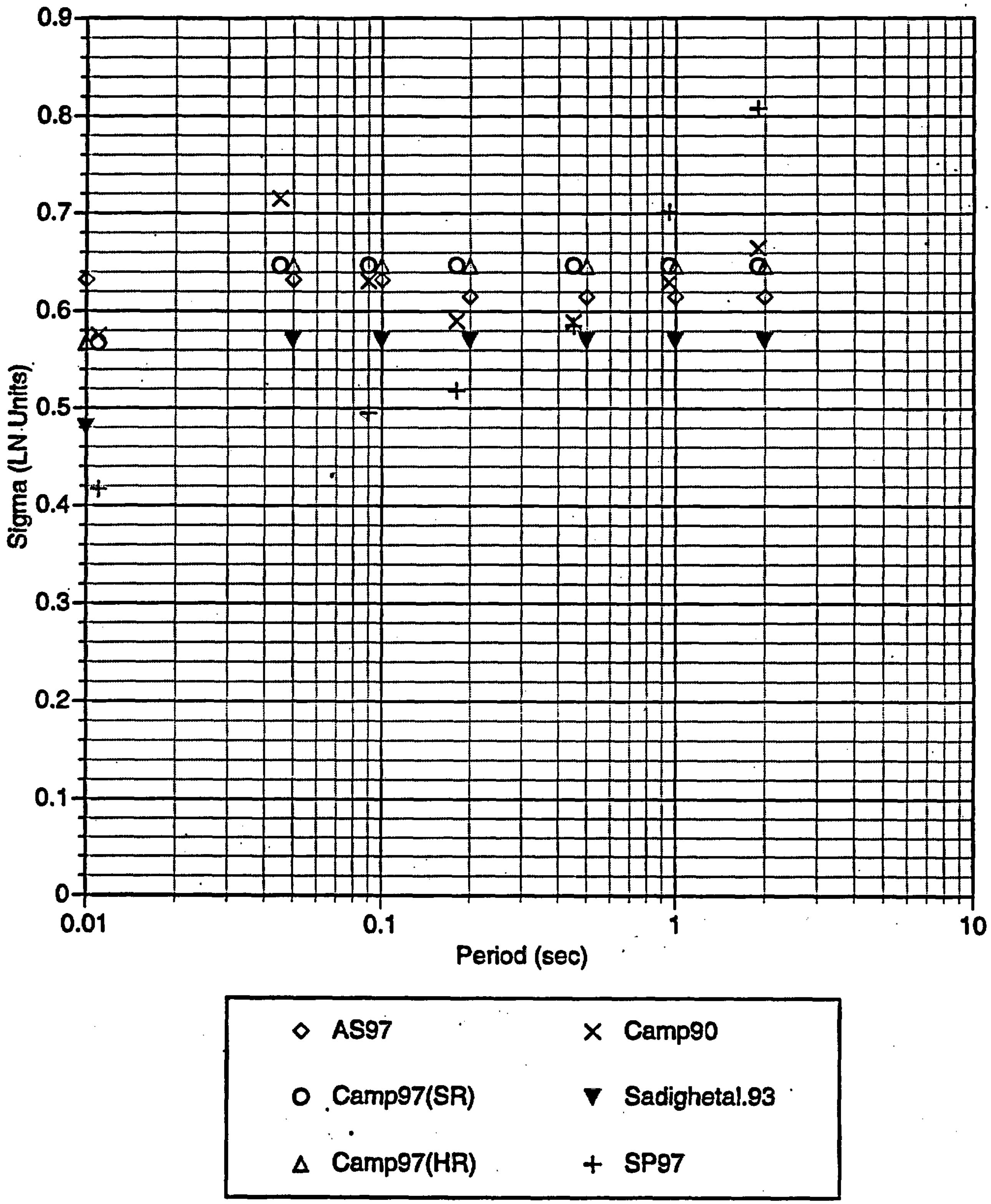

M=6.5, Strike-slip, Shallow, Horizontal, Case 7
10
1
0.1
0.01
Spectral Acceleration (g)
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

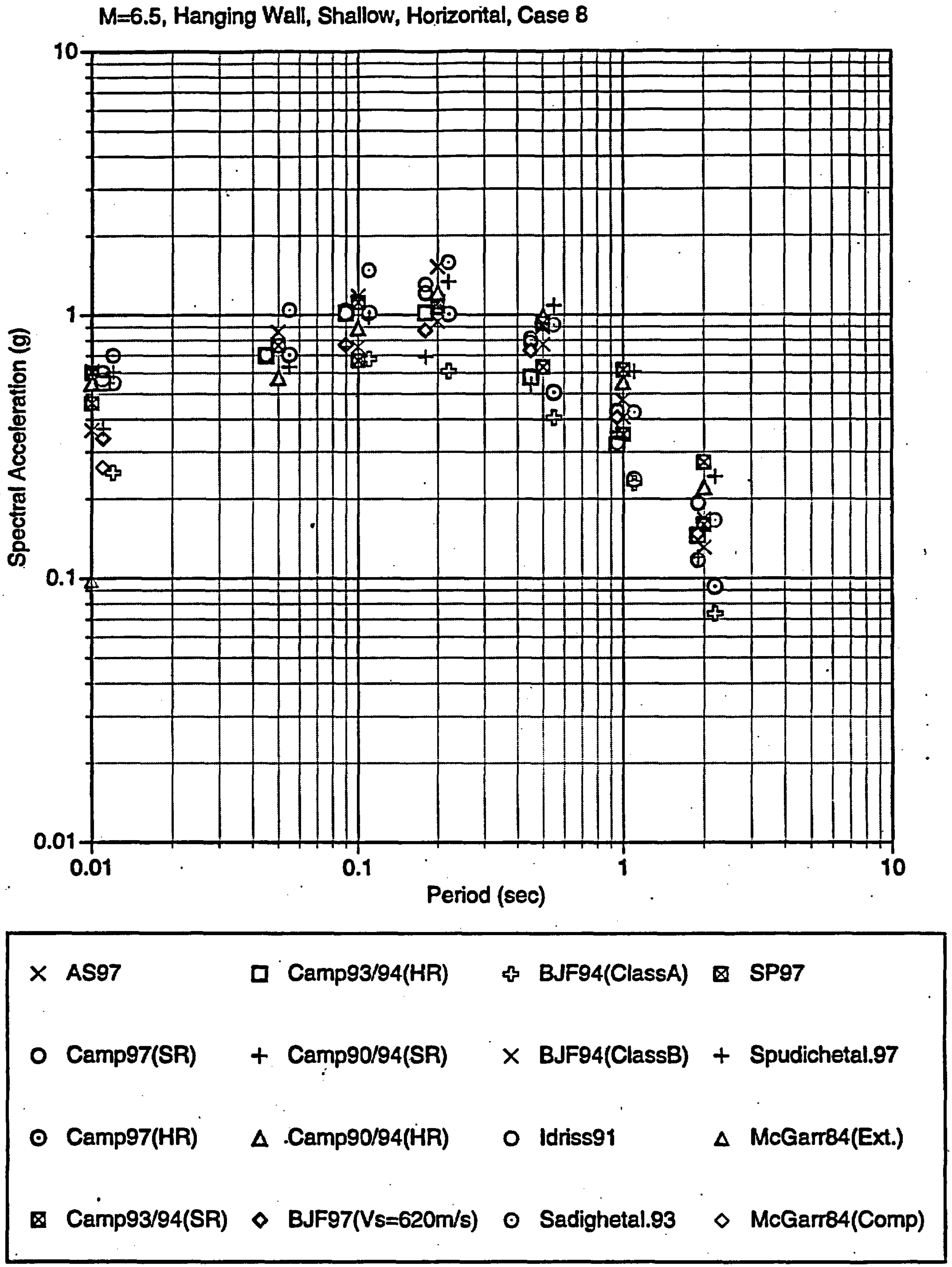

M=6.5, Strike-slip, Shallow, Horizontal, Case 7
Sigma (LN Units)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=6.5, Strike-slip, Shallow, Vertical, Case 7

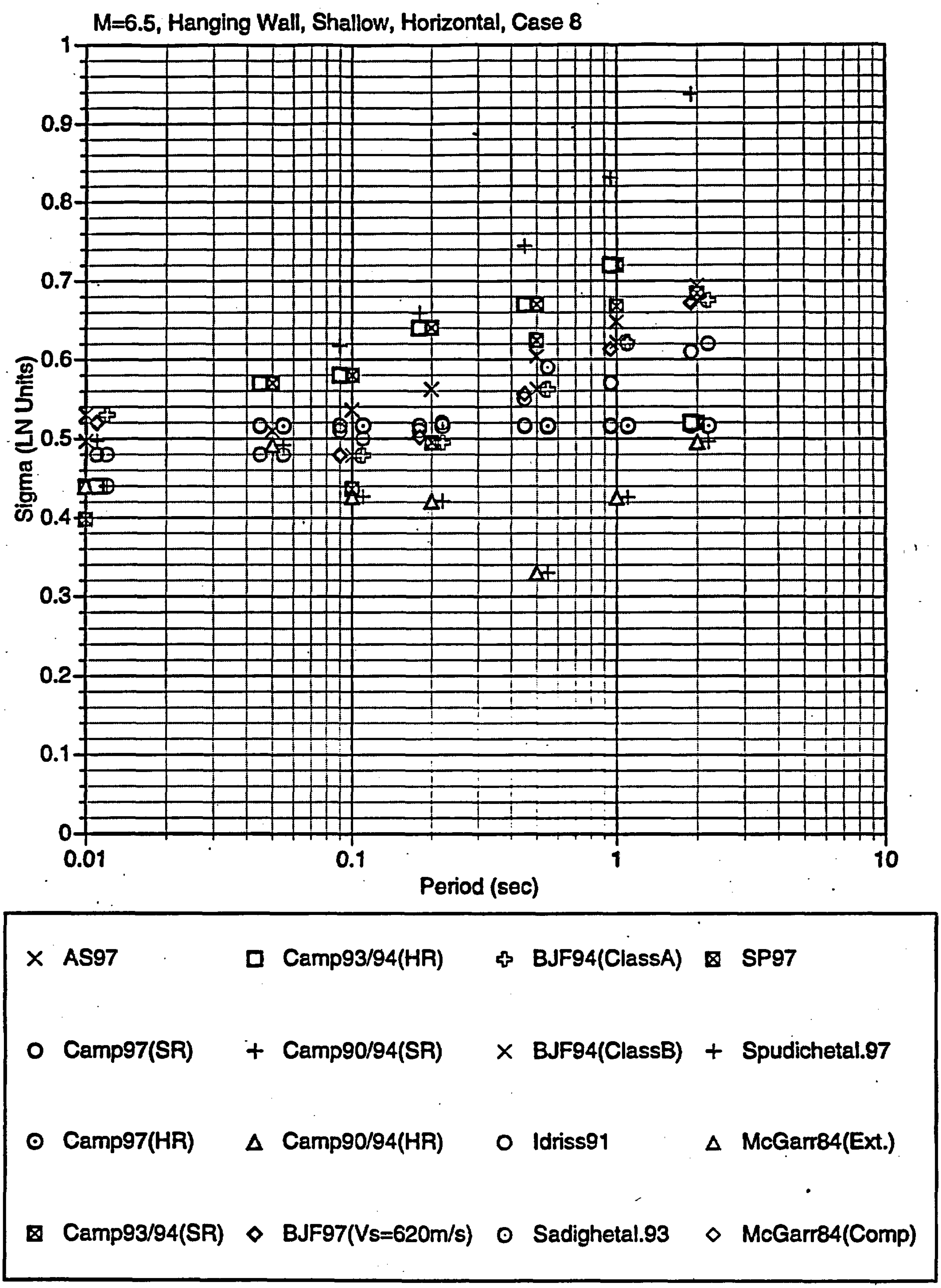


M=6.5, Strike-slip, Shallow, Vertical, Case 7

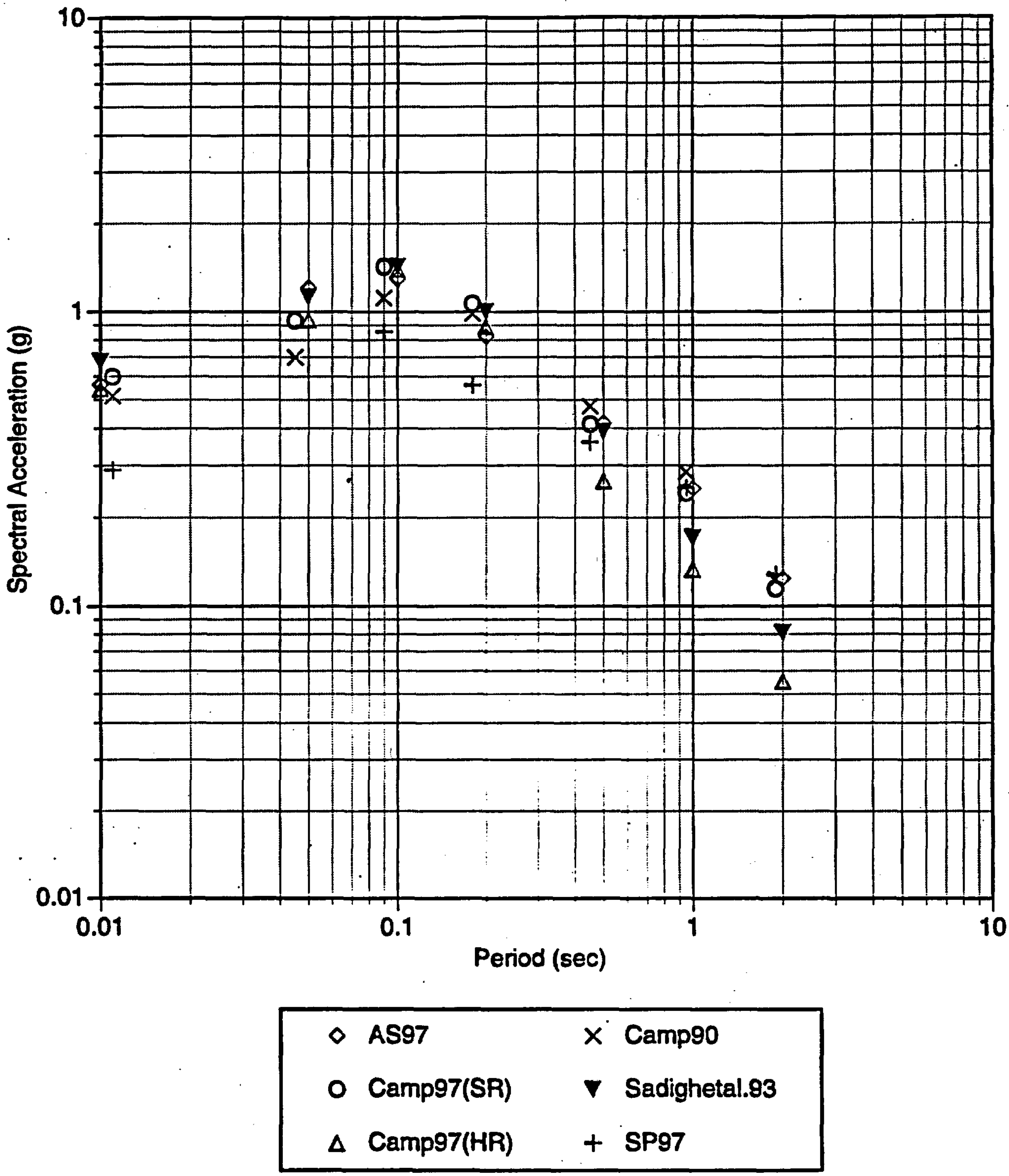




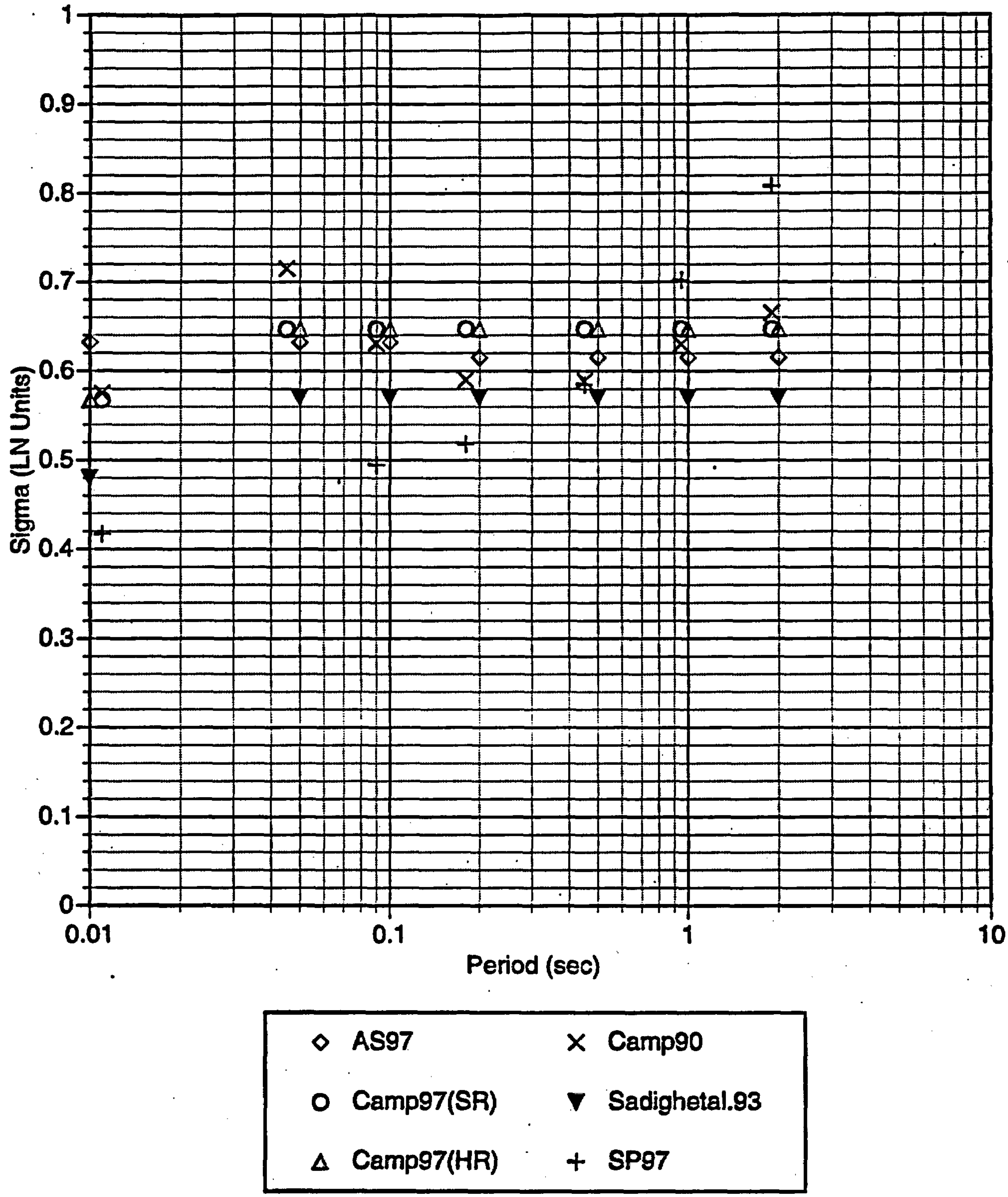
M=6.5, Hanging Wall, Shallow, Horizontal, Case 8
10
1
0.1
0.01
Spectral Acceleration (g)
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

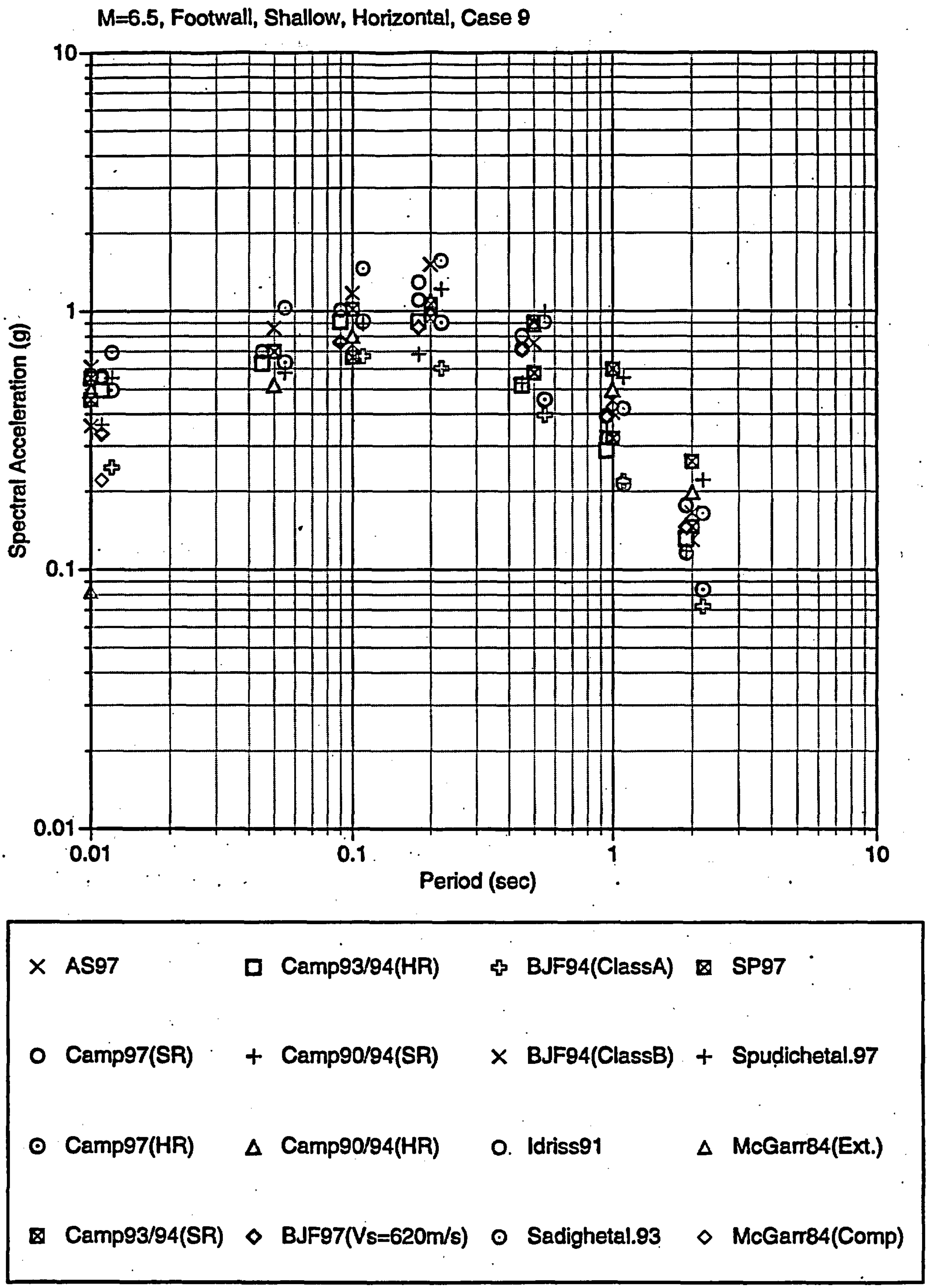

M=6.5, Hanging Wall, Shallow, Horizontal, Case 8
Sigma (LN Units)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=6.5, Hanging Wall, Shallow, Vertical, Case 8

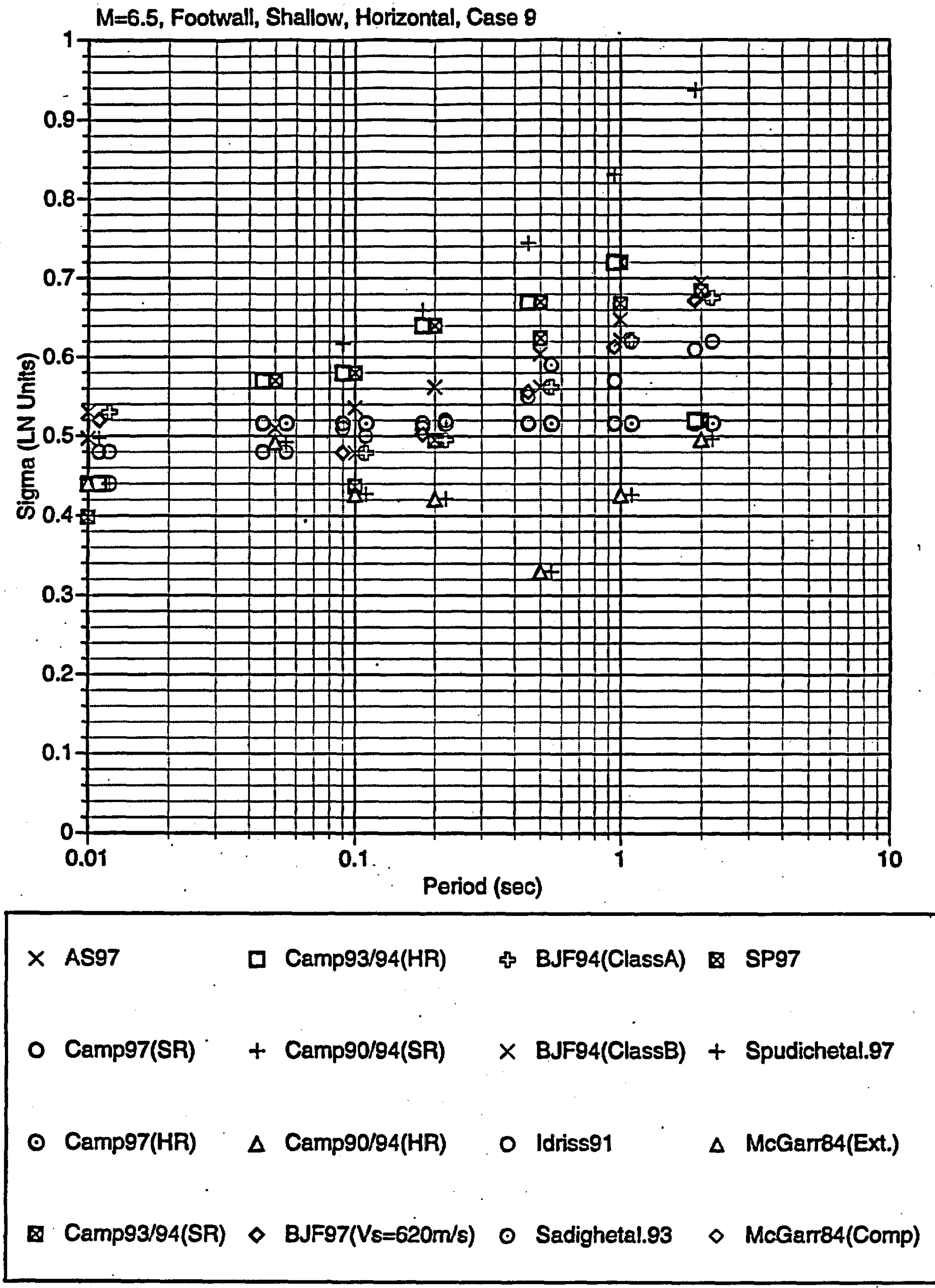


M=6.5, Hanging Wall, Shallow, Vertical, Case 8

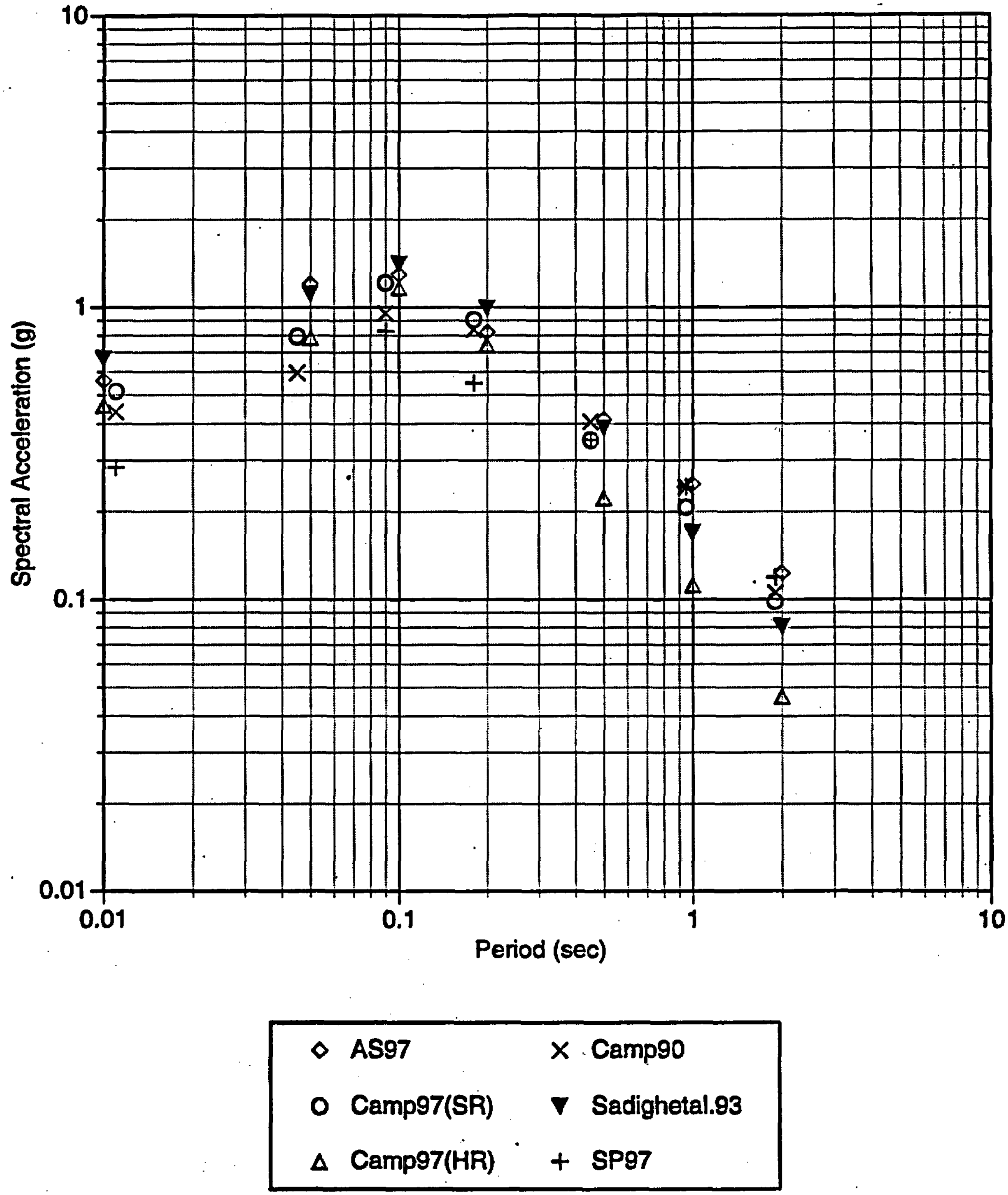




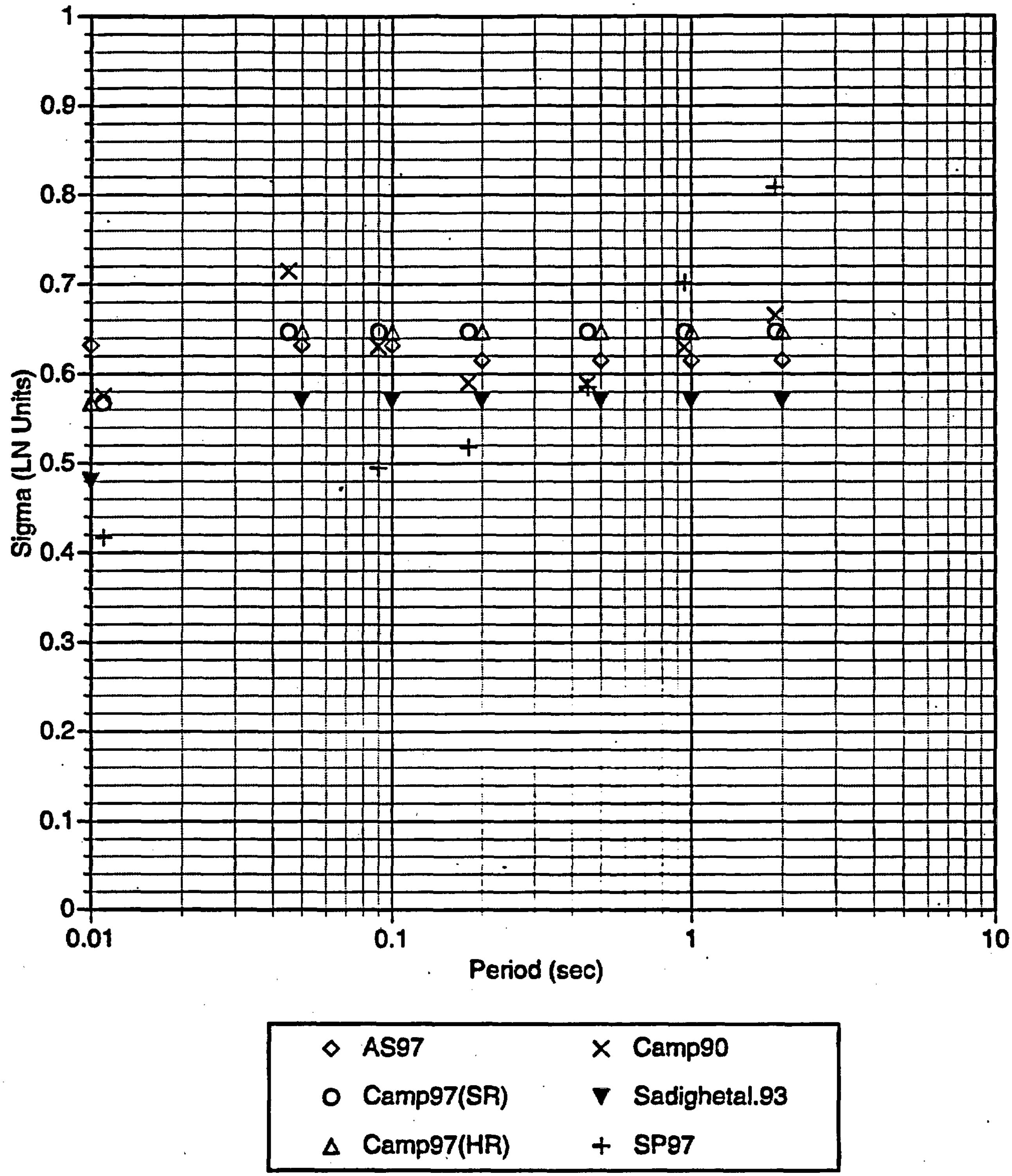
M=6.5, Footwall, Shallow, Horizontal, Case 9
Spectral Acceleration (g)
10
1
0.1
0.01
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

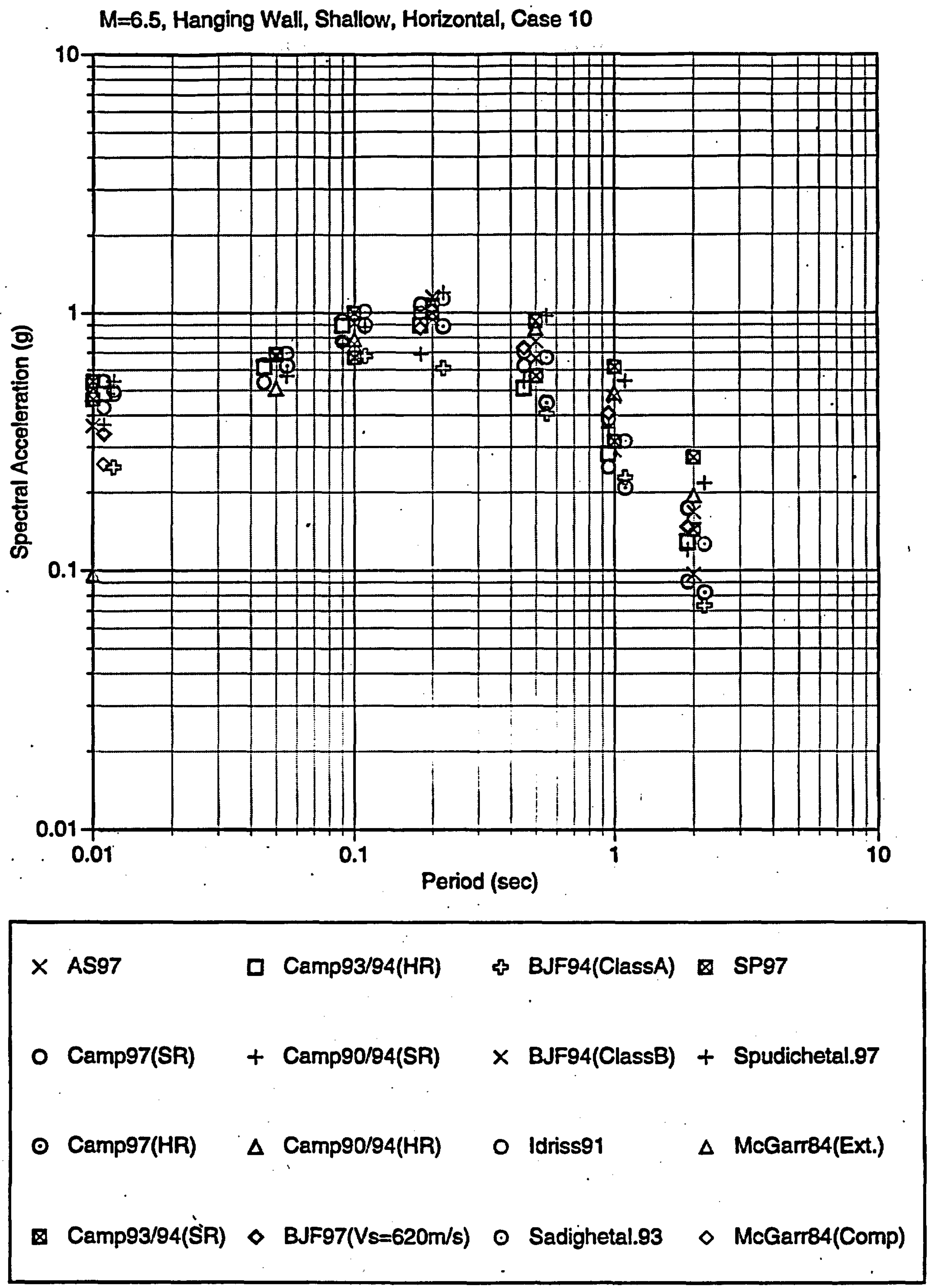

M=6.5, Footwall, Shallow, Horizontal, Case 9
Sigma (LN Units)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

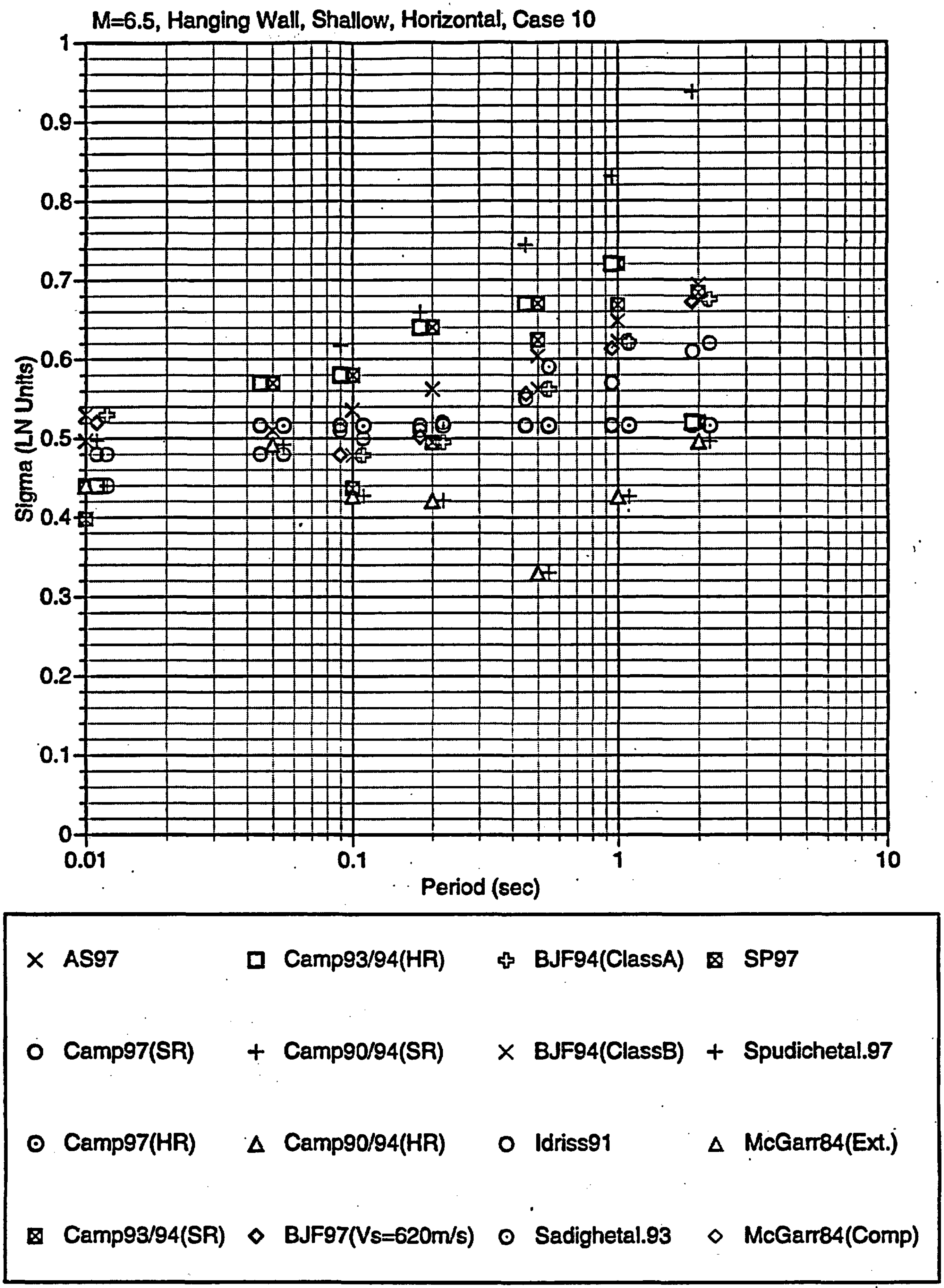
M=6.5, Footwall, Shallow, Vertical, Case 9



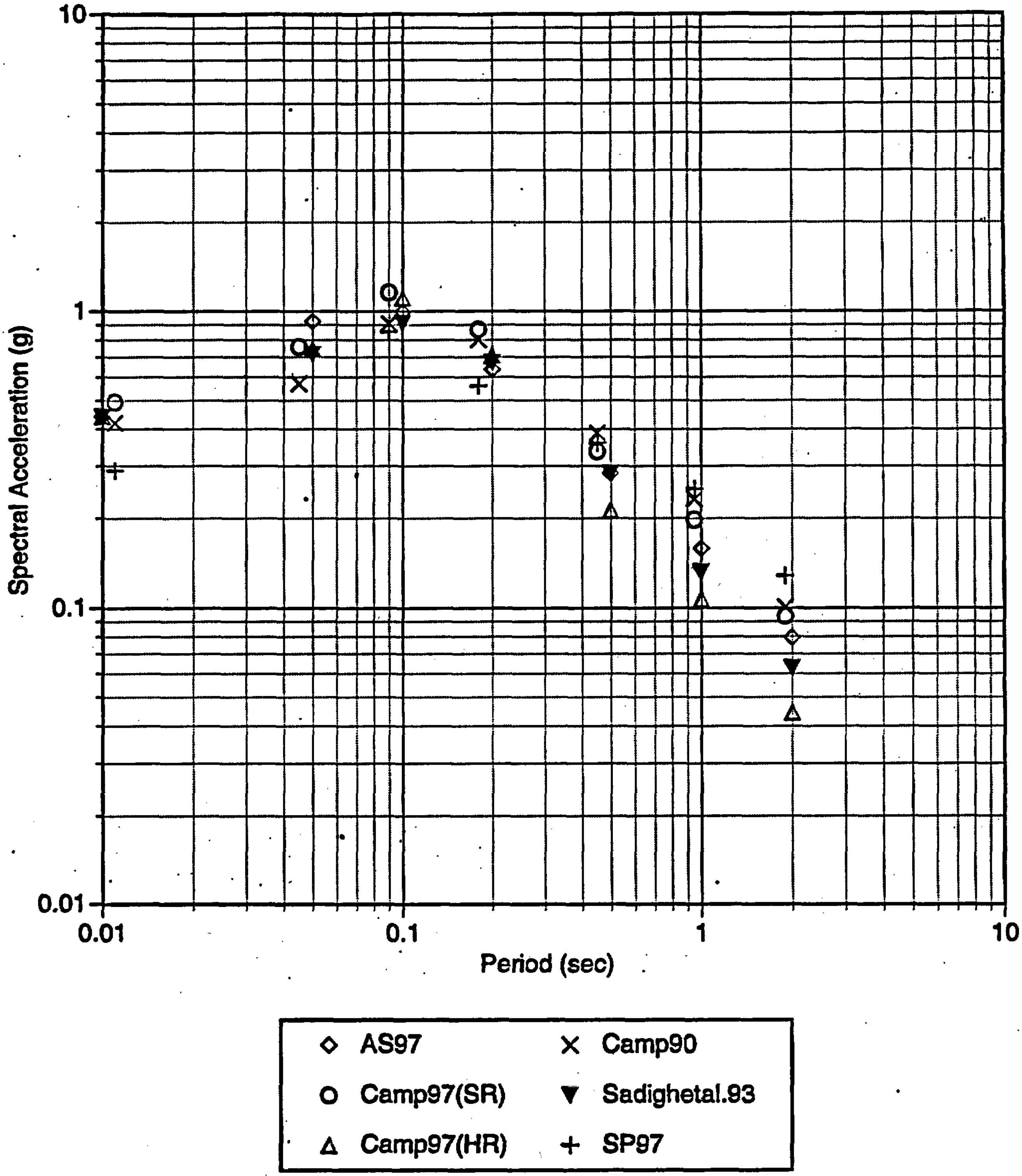
M=6.5, Footwall, Shallow, Vertical, Case 9



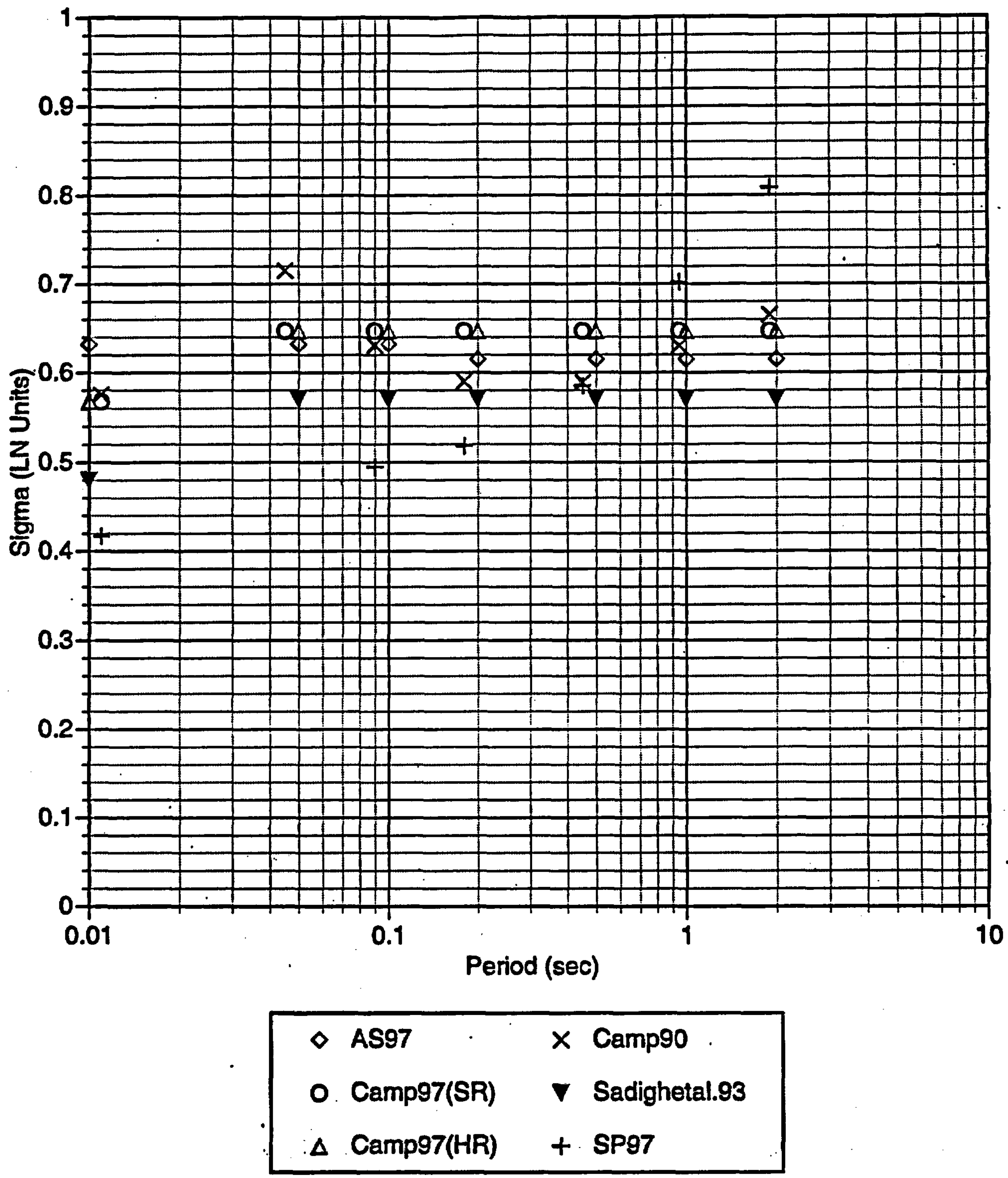

M=6.5, Hanging Wall, Shallow, Horizontal, Case 10
Spectral Acceleration (g)
10
1
0.1
0.01
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

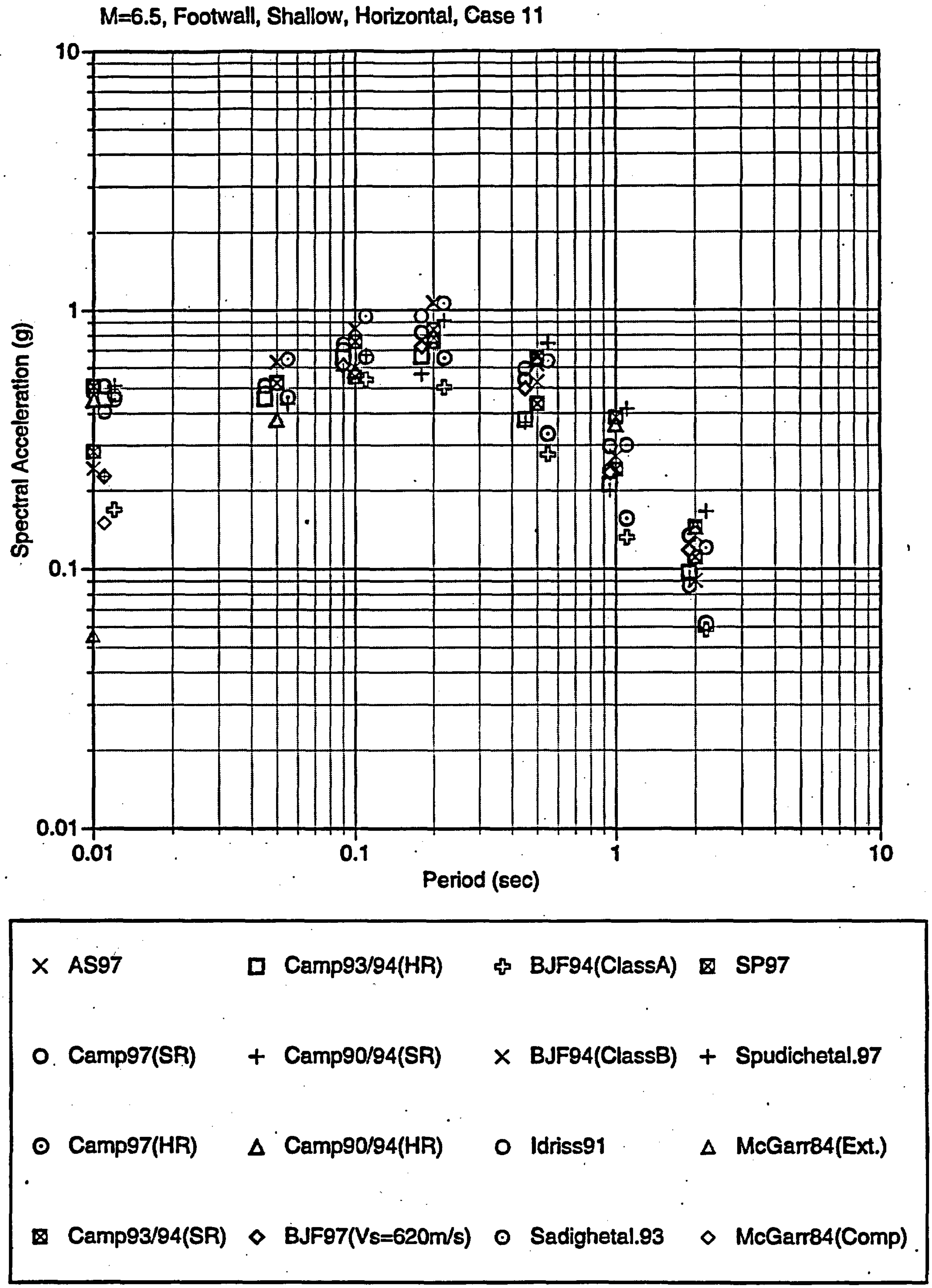

M=6.5, Hanging Wall, Shallow, Horizontal, Case 10
Sigma (LN Units)
Period (sec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=6.5, Hanging Wall, Shallow, Vertical, Case 10

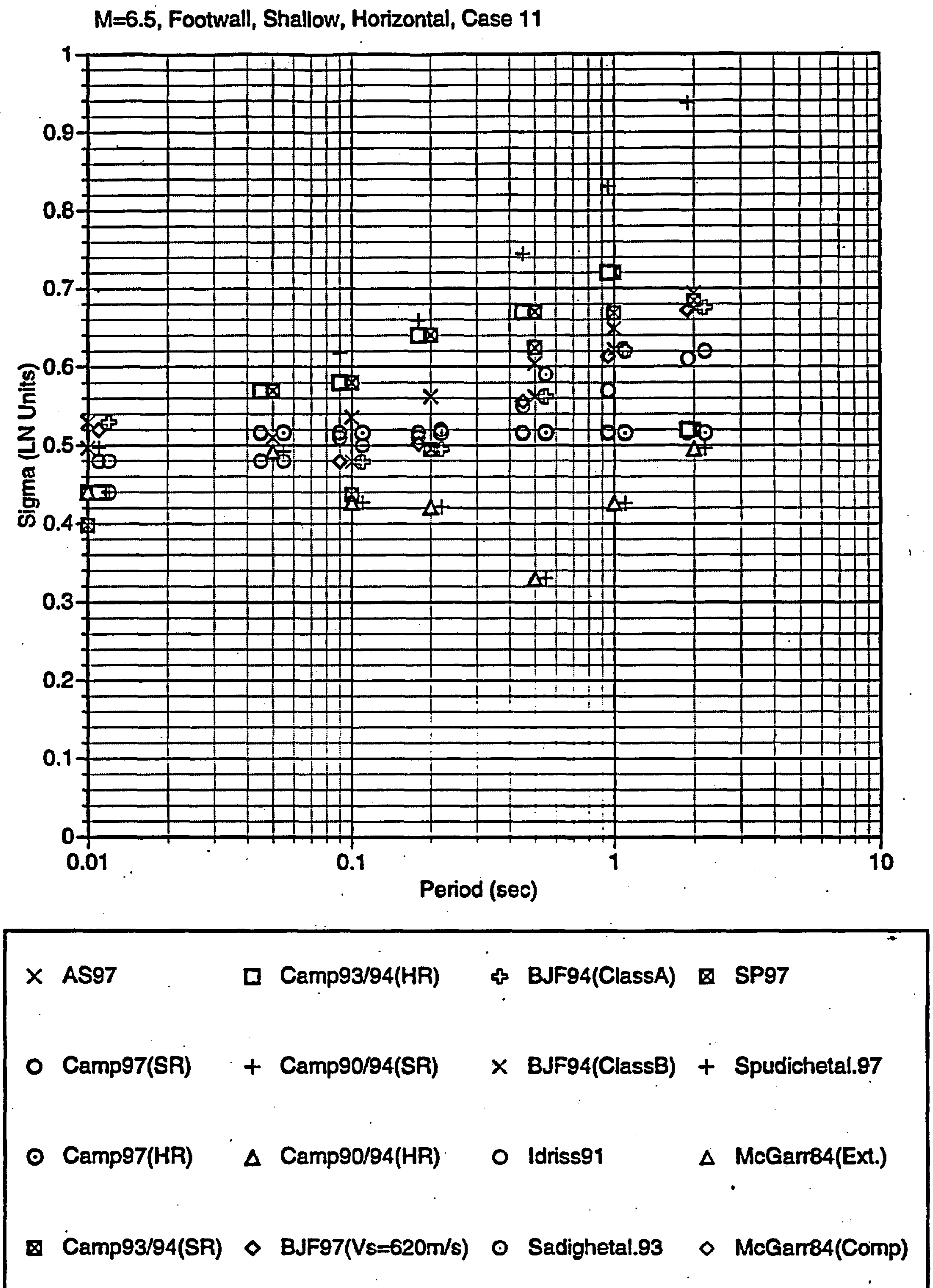


M=6.5, Hanging Wall, Shallow, Vertical, Case 10

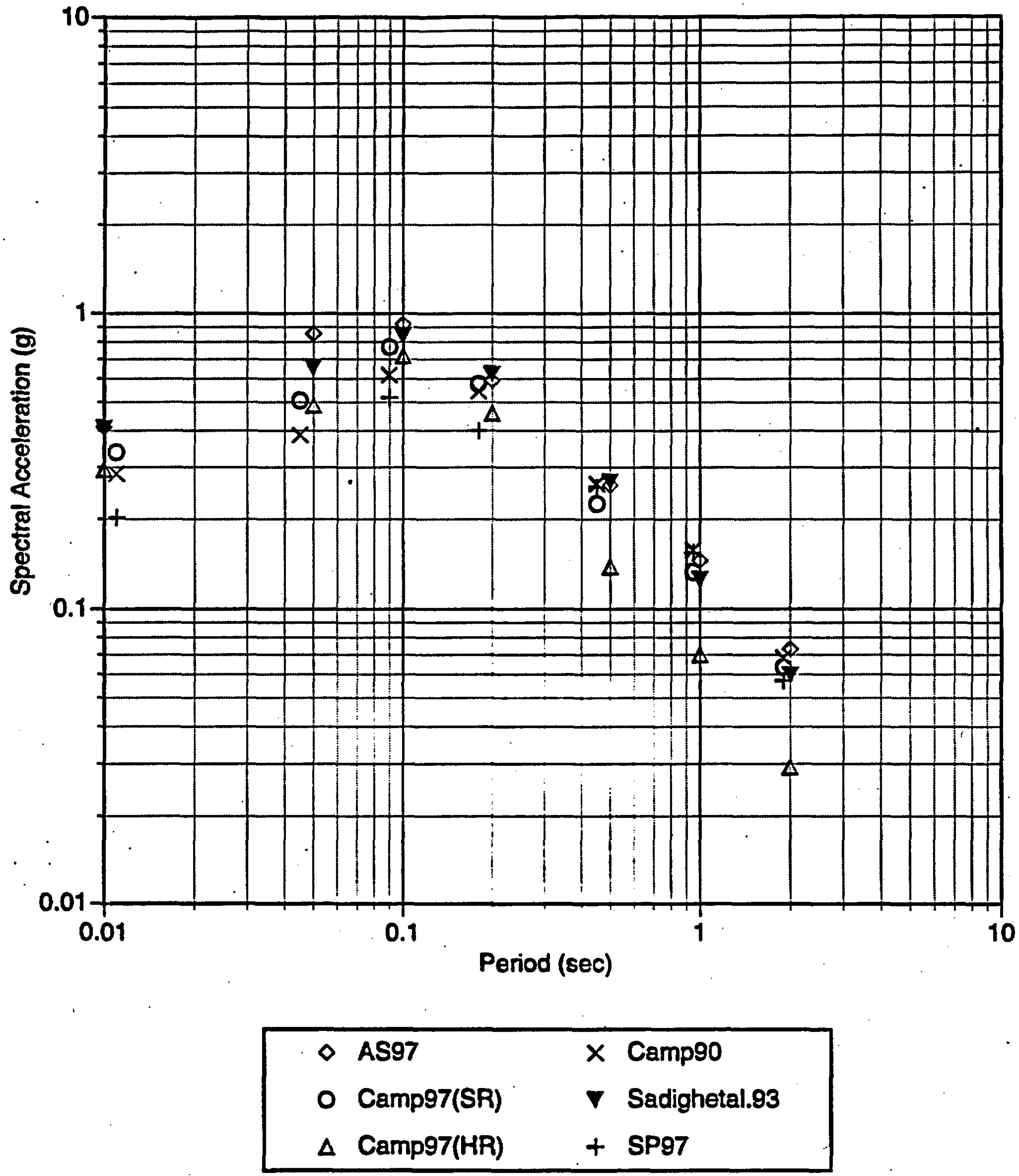




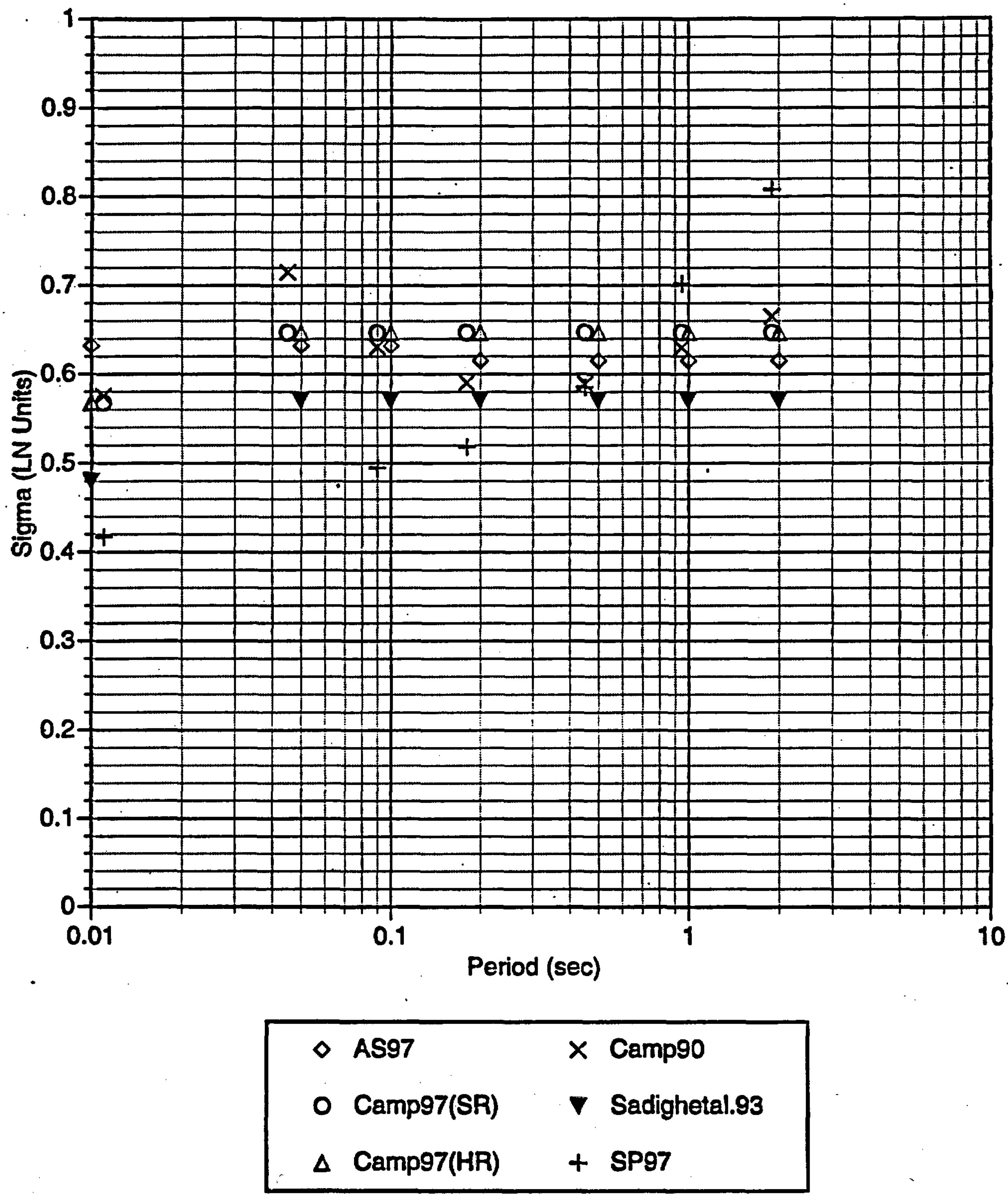
M=6.5, Footwall, Shallow, Horizontal, Case 11
10
1
0.1
0.01
Spectral Acceleration (g)
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

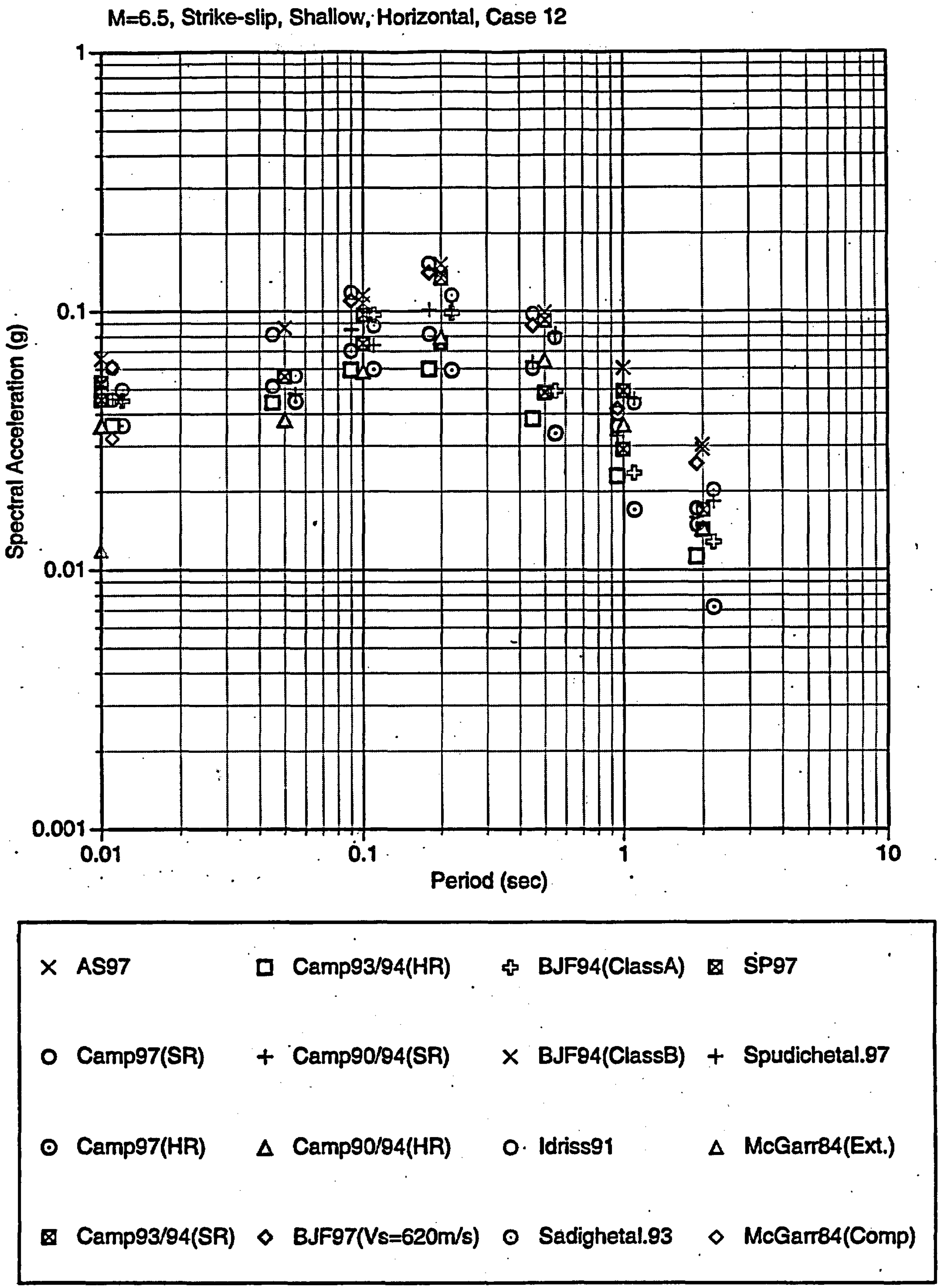

M=6.5, Footwall, Shallow, Horizontal, Case 11
Sigma (LN Units)
Period (sec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

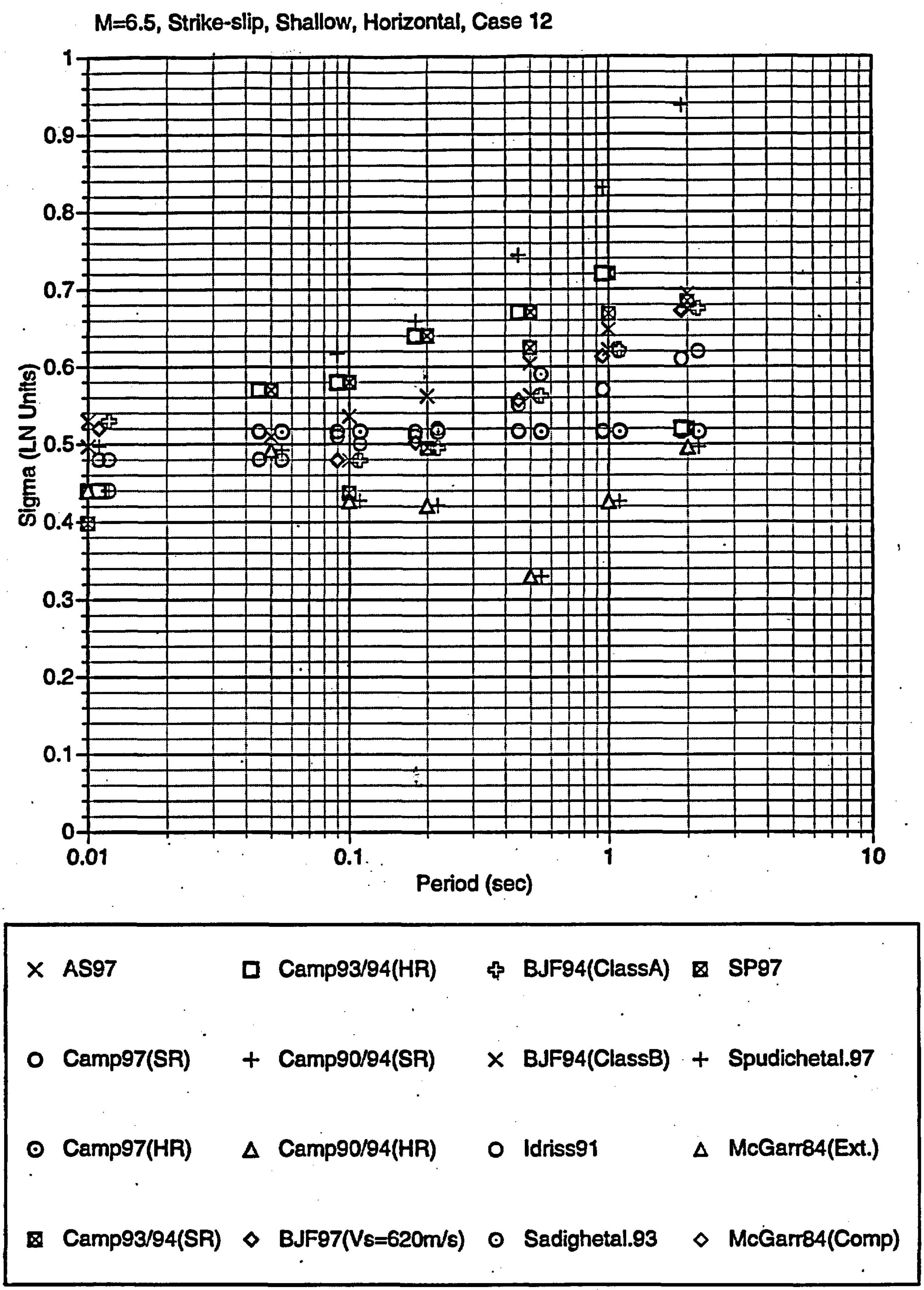
M=6.5, Footwall, Shallow, Vertical, Case 11



M=6.5, Footwall, Shallow, Vertical, Case 11

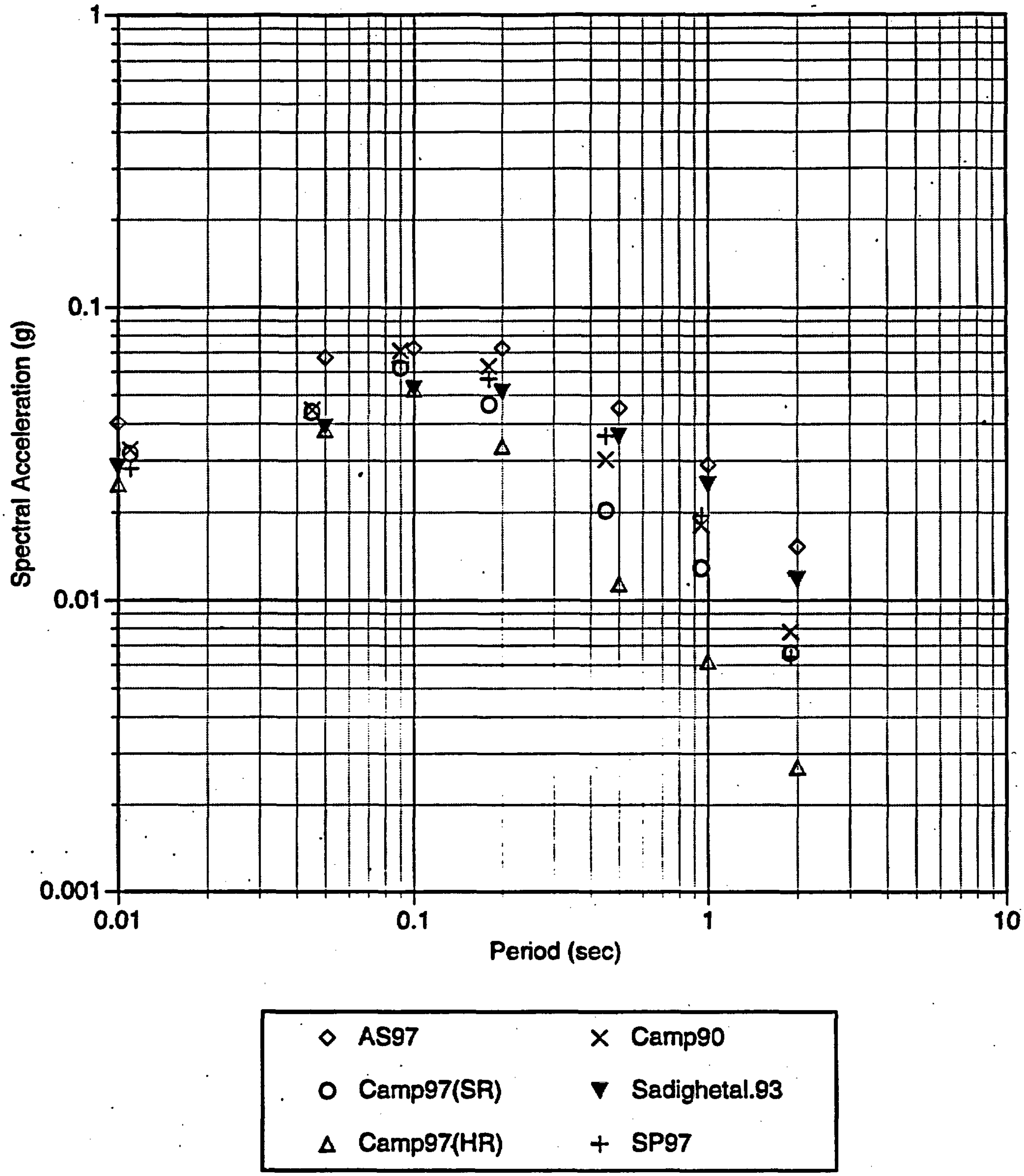



M=6.5, Strike-slip, Shallow, Horizontal, Case 12
1
0.1
0.01
0.001
Spectral Acceleration (g)
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

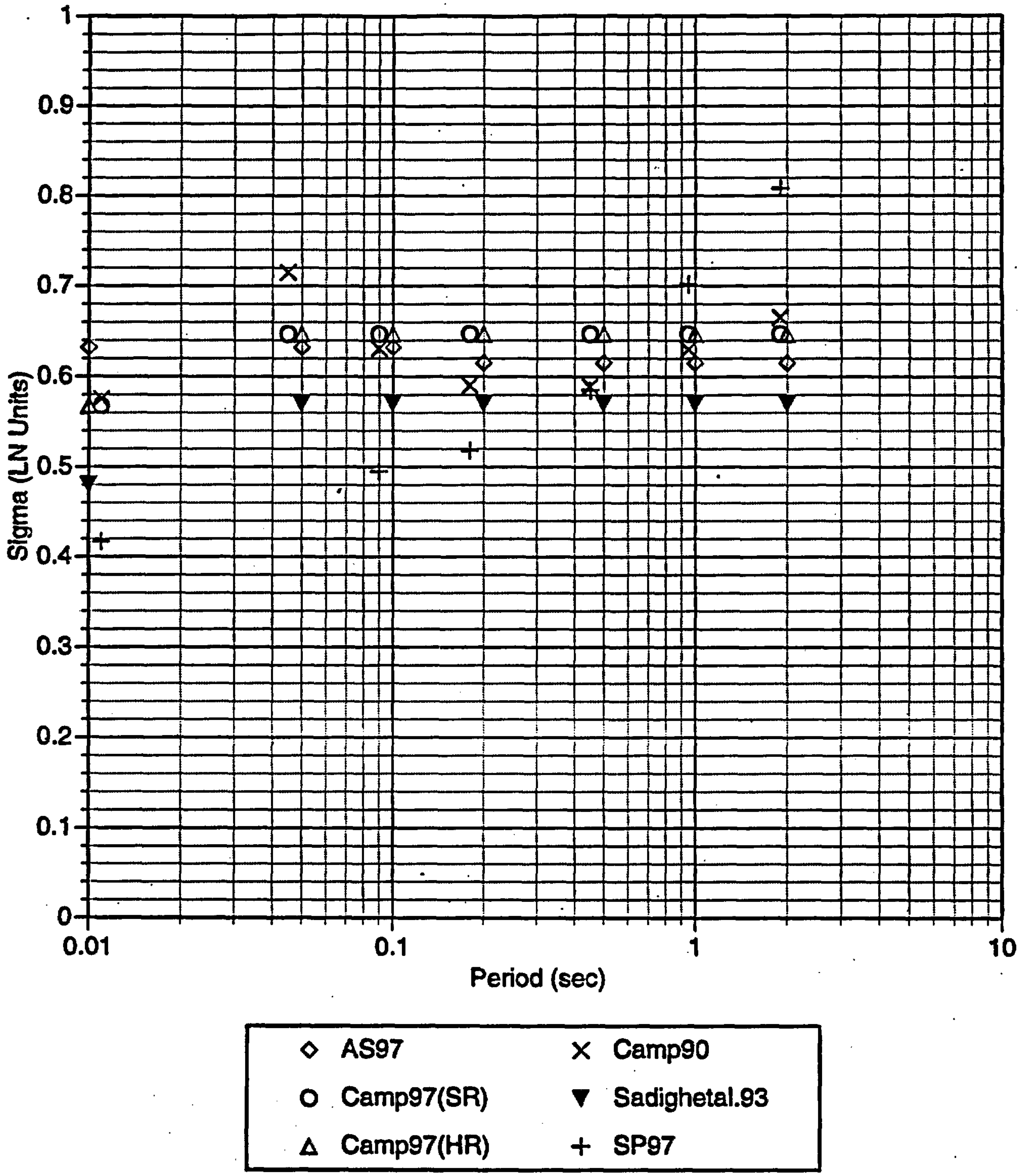


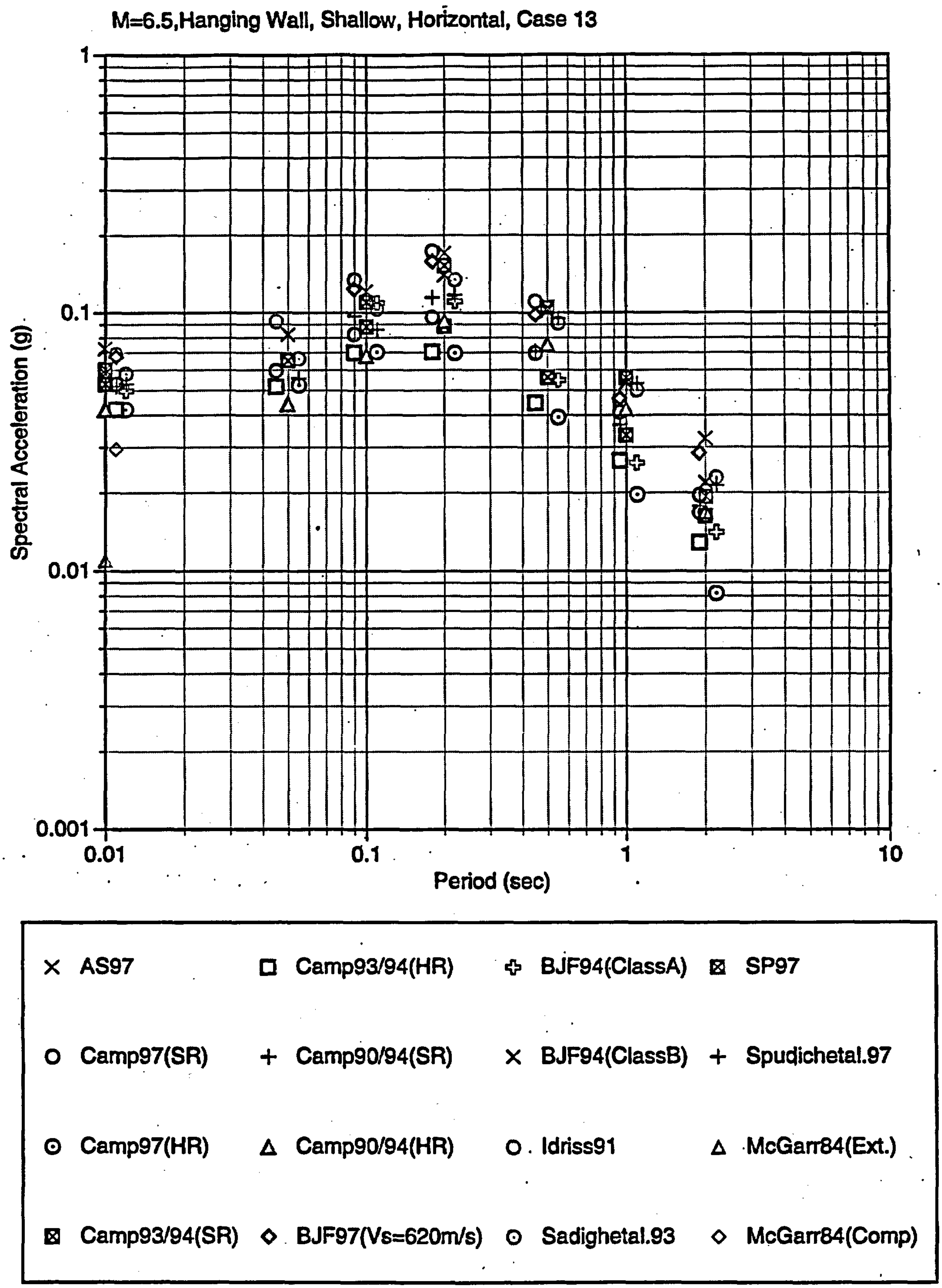
M=6.5, Strike-slip, Shallow, Horizontal, Case 12
Sigma (LN Units)
Period (sec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

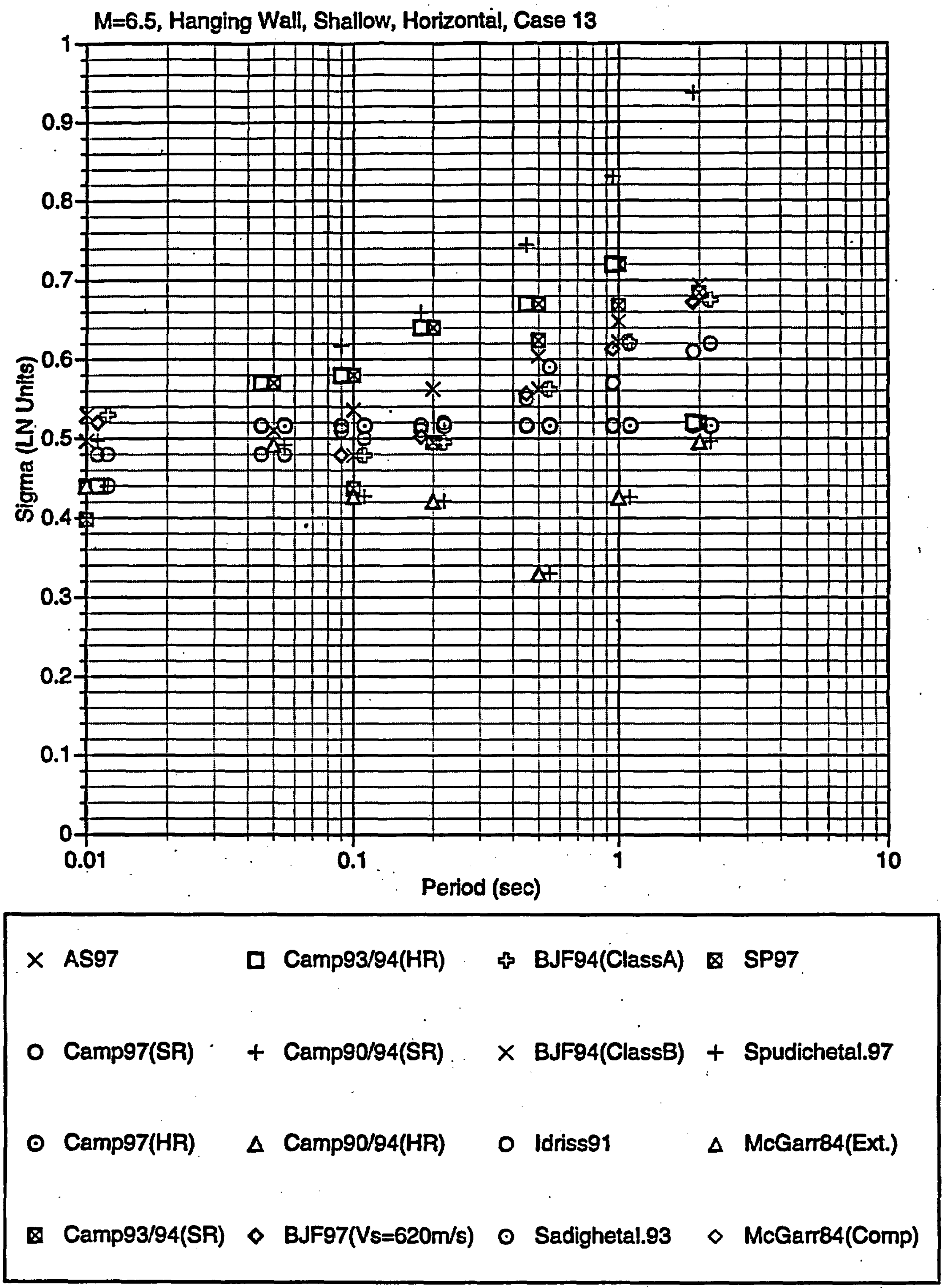
M=6.5, Strike Slip, Shallow, Vertical, Case 12



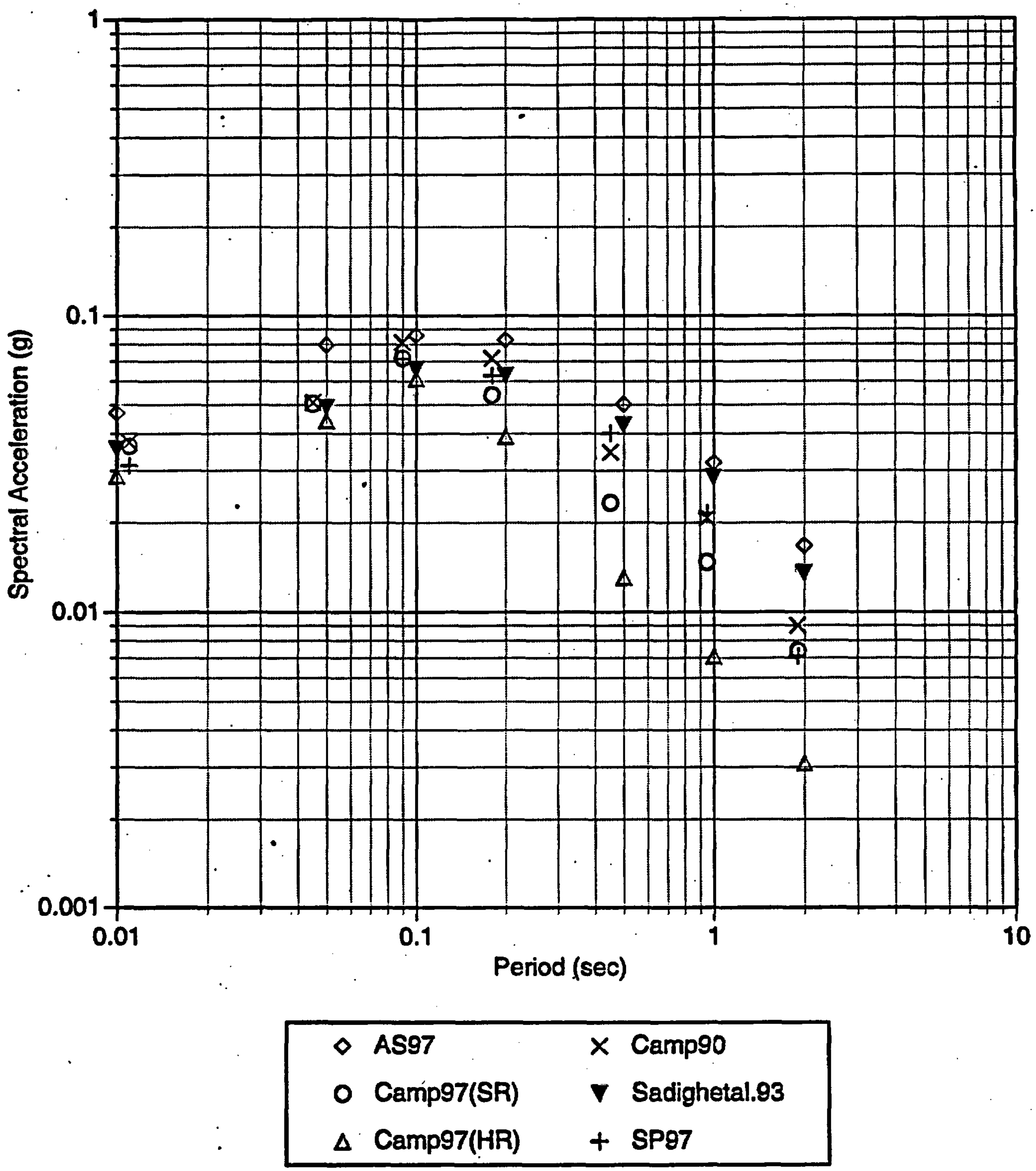
M=6.5, Strike-slip, Shallow, Vertical, Case 12



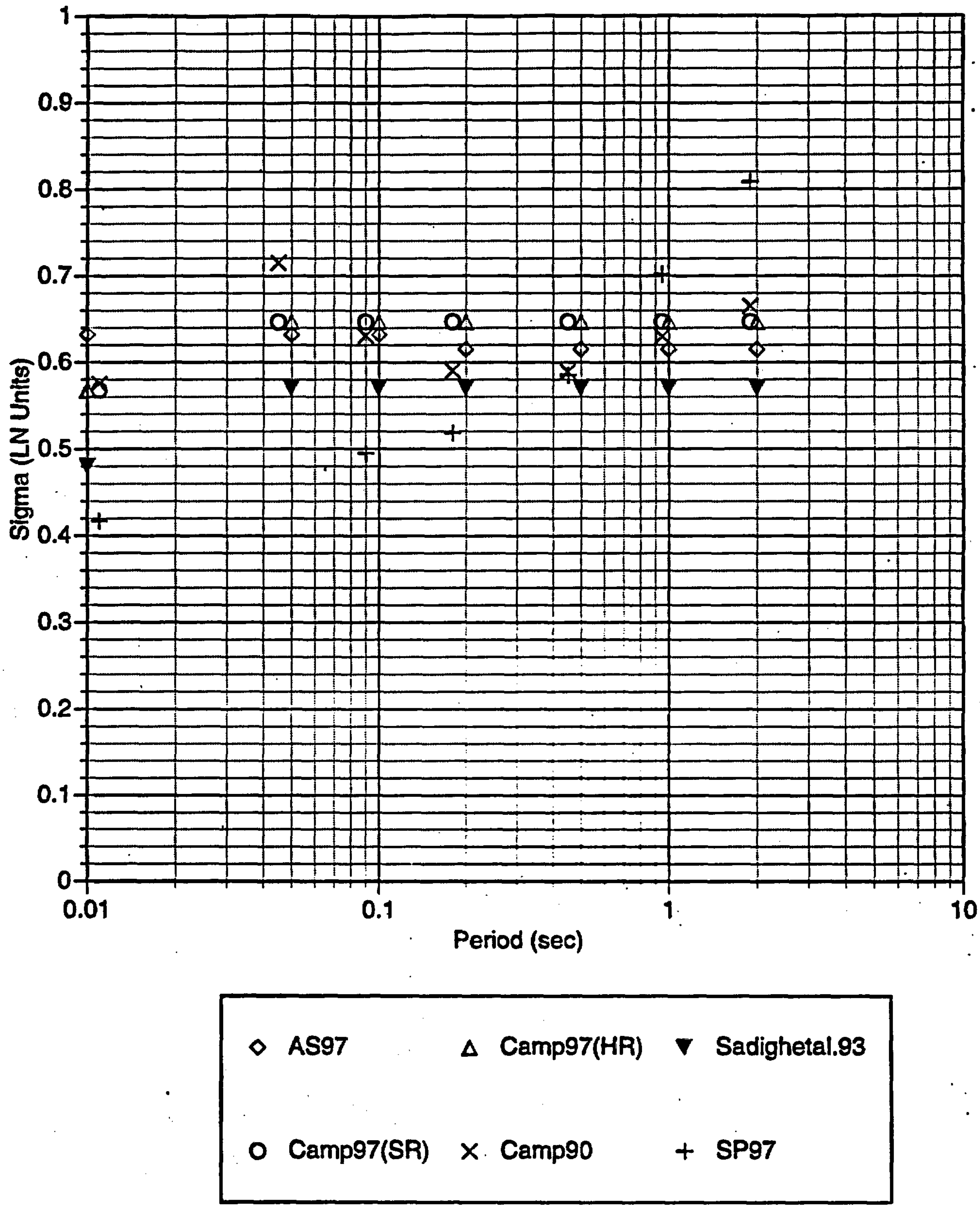

M=6.5,Hanging Wall, Shallow, Horizontal, Case 13
Spectral Acceleration (g)
1
0.1
0.01
0.001
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)


M=6.5, Hanging Wall, Shallow, Horizontal, Case 13
Sigma (LN Units)
Period (sec)
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

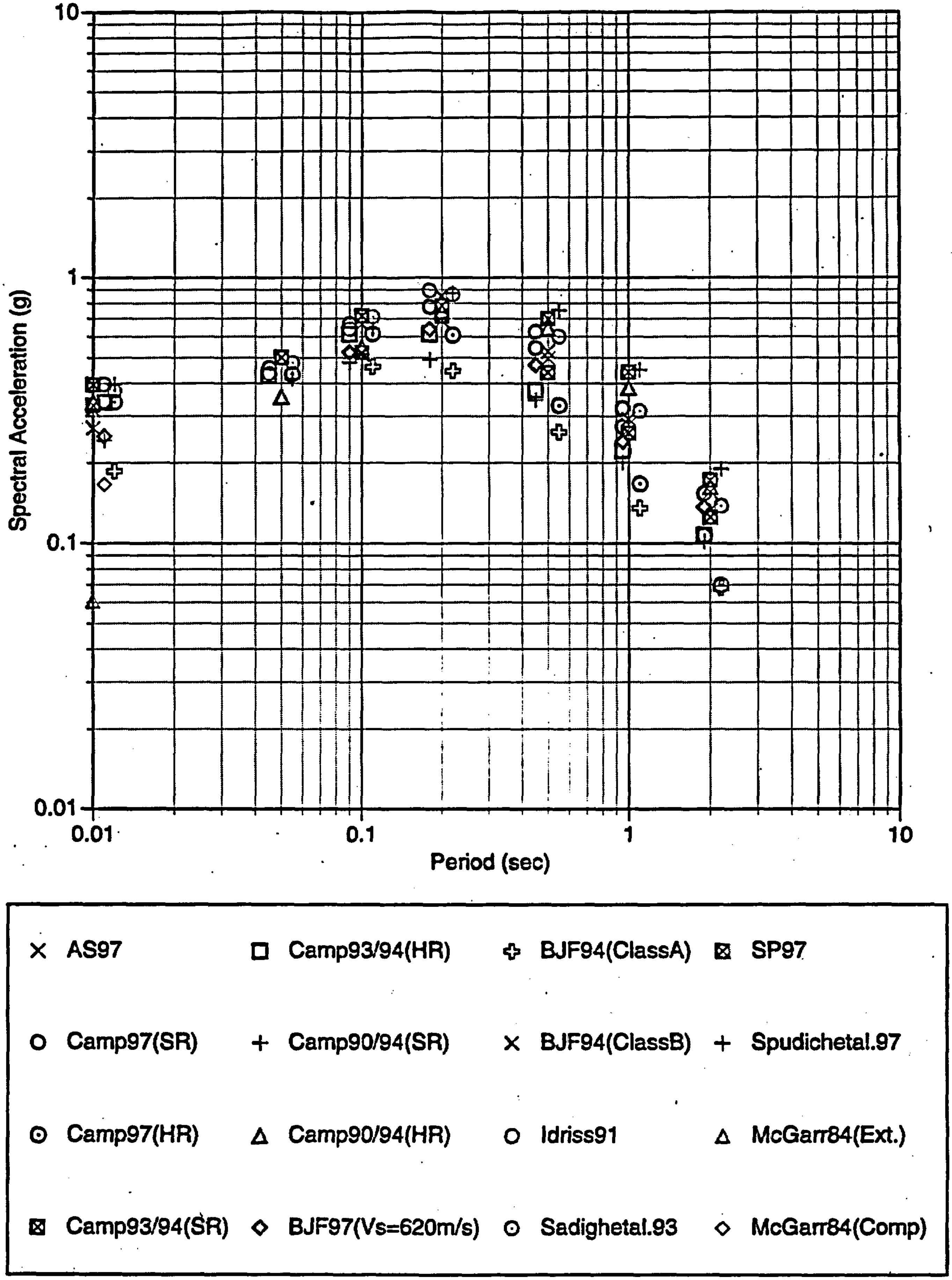
M=6.5, Hanging Wall, Shallow, Vertical, Case 13

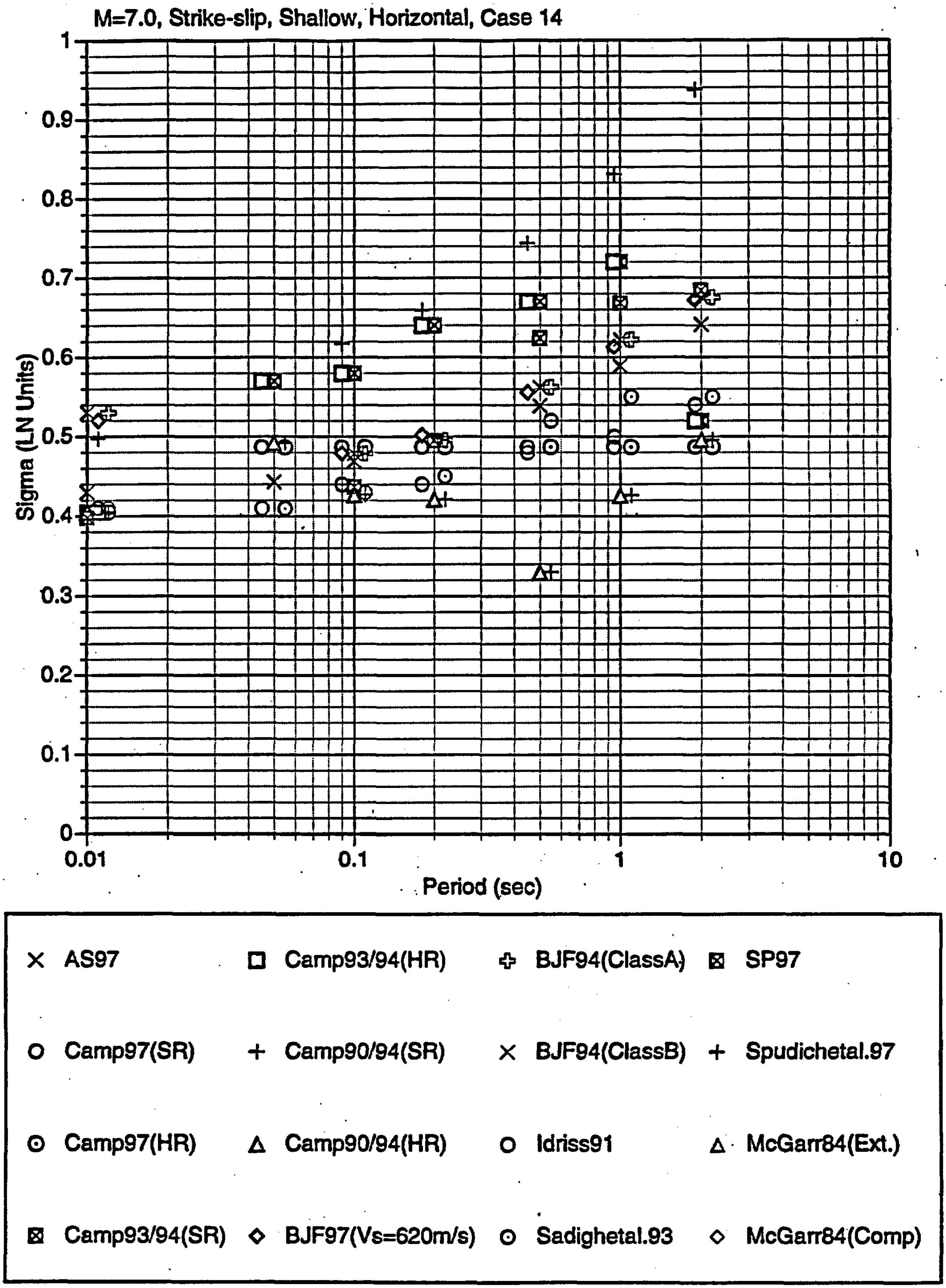


M=6.5, Hanging Wall, Shallow, Vertical, Case 13



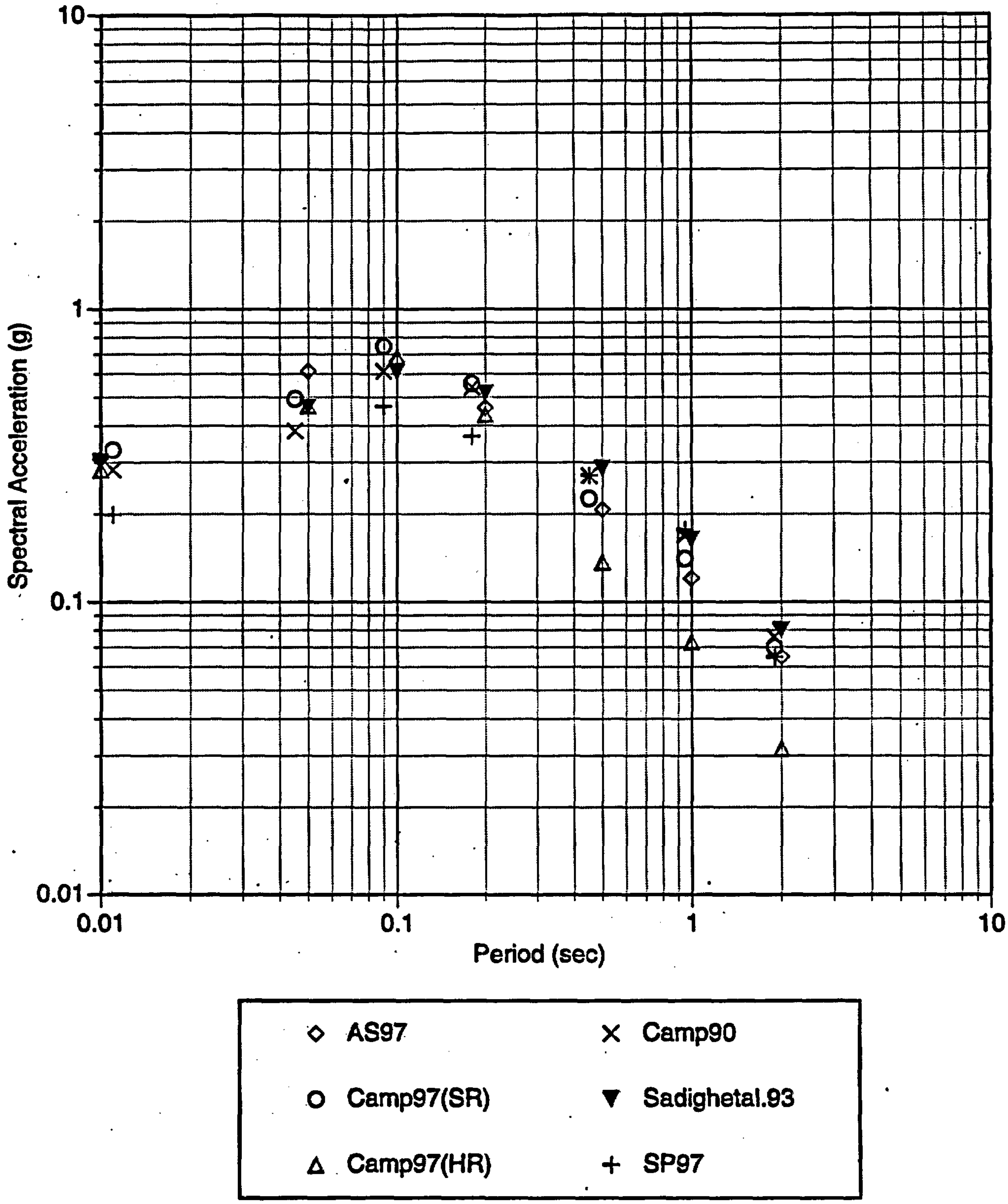
M=7.0,Strike-slip, Shallow, Horizontal, Case 14



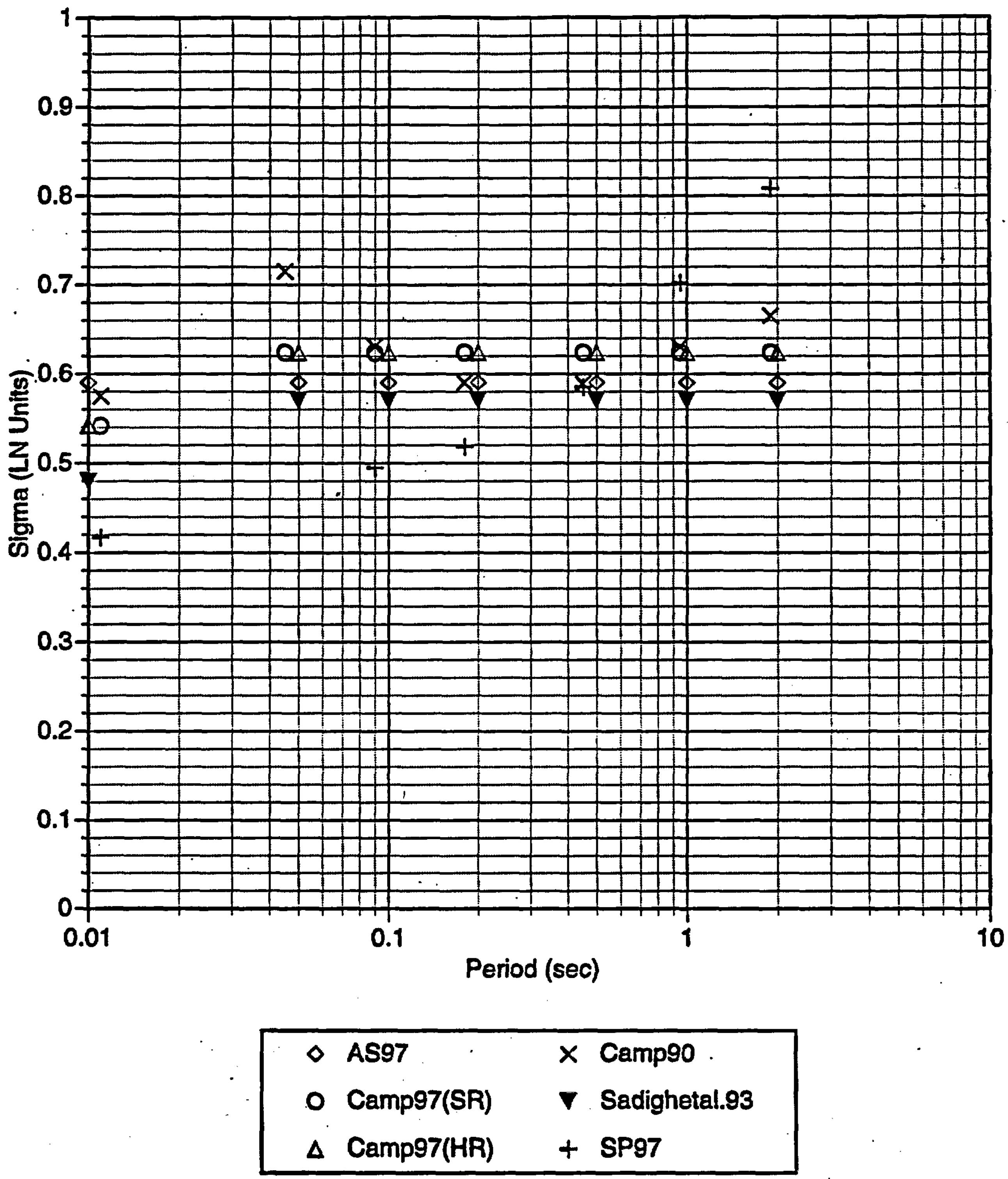


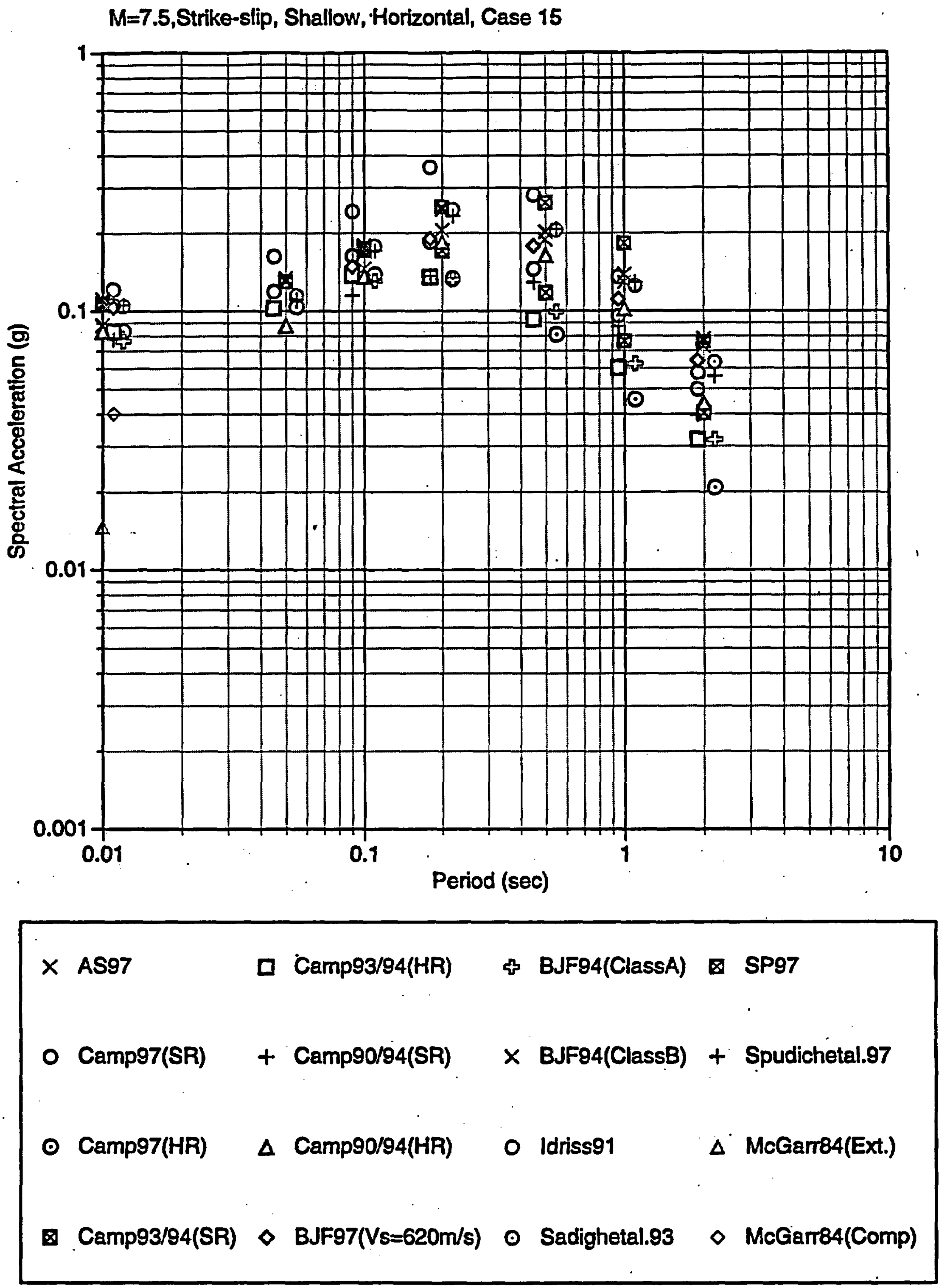
M=7.0, Strike-slip, Shallow, Horizontal, Case 14
Sigma (LN Units)
Period (sec)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

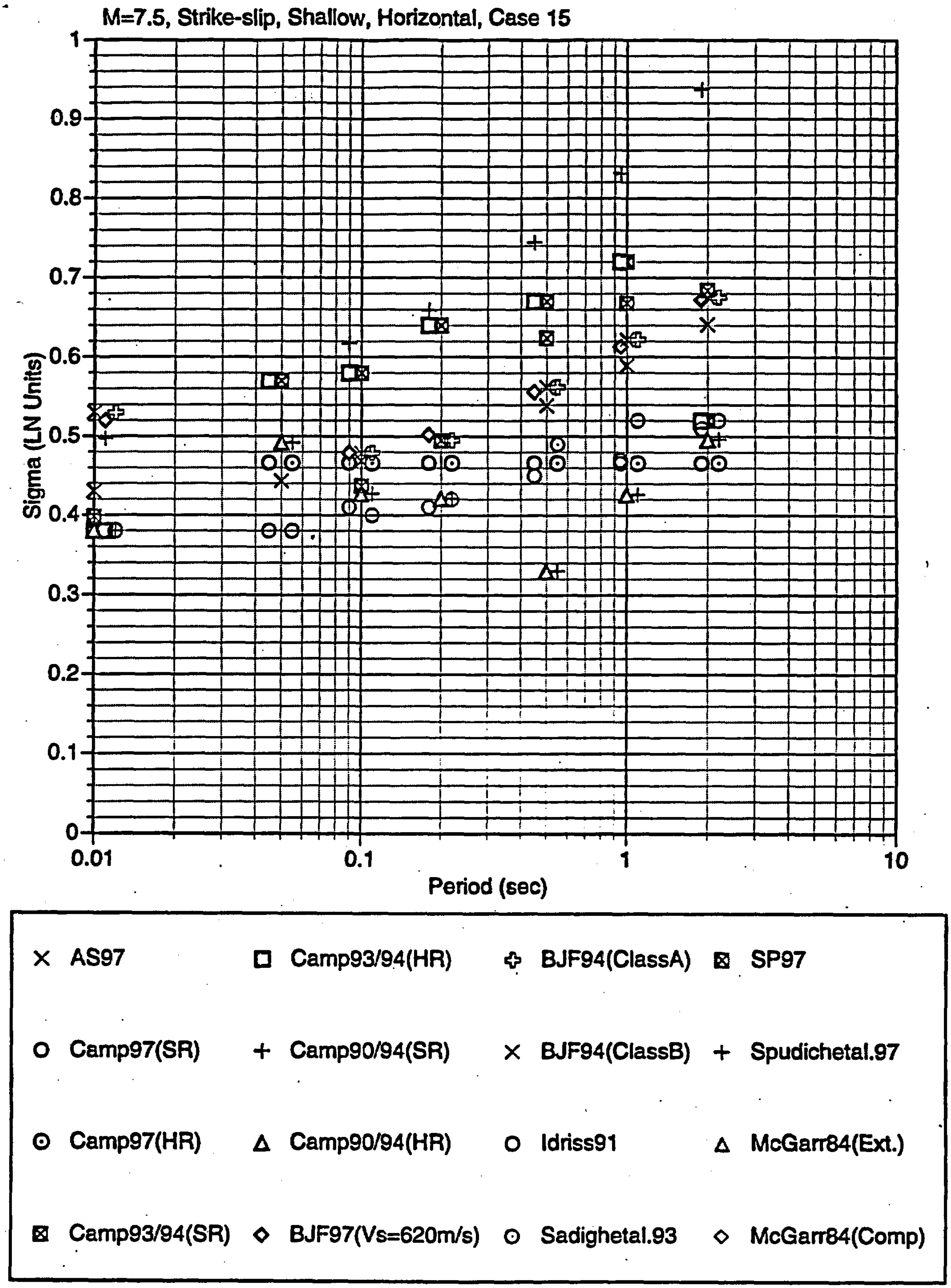
M=7.0, Strike-slip, Shallow, Vertical, Case 14



M=7.0, Strike-slip, Shallow, Vertical, Case 14

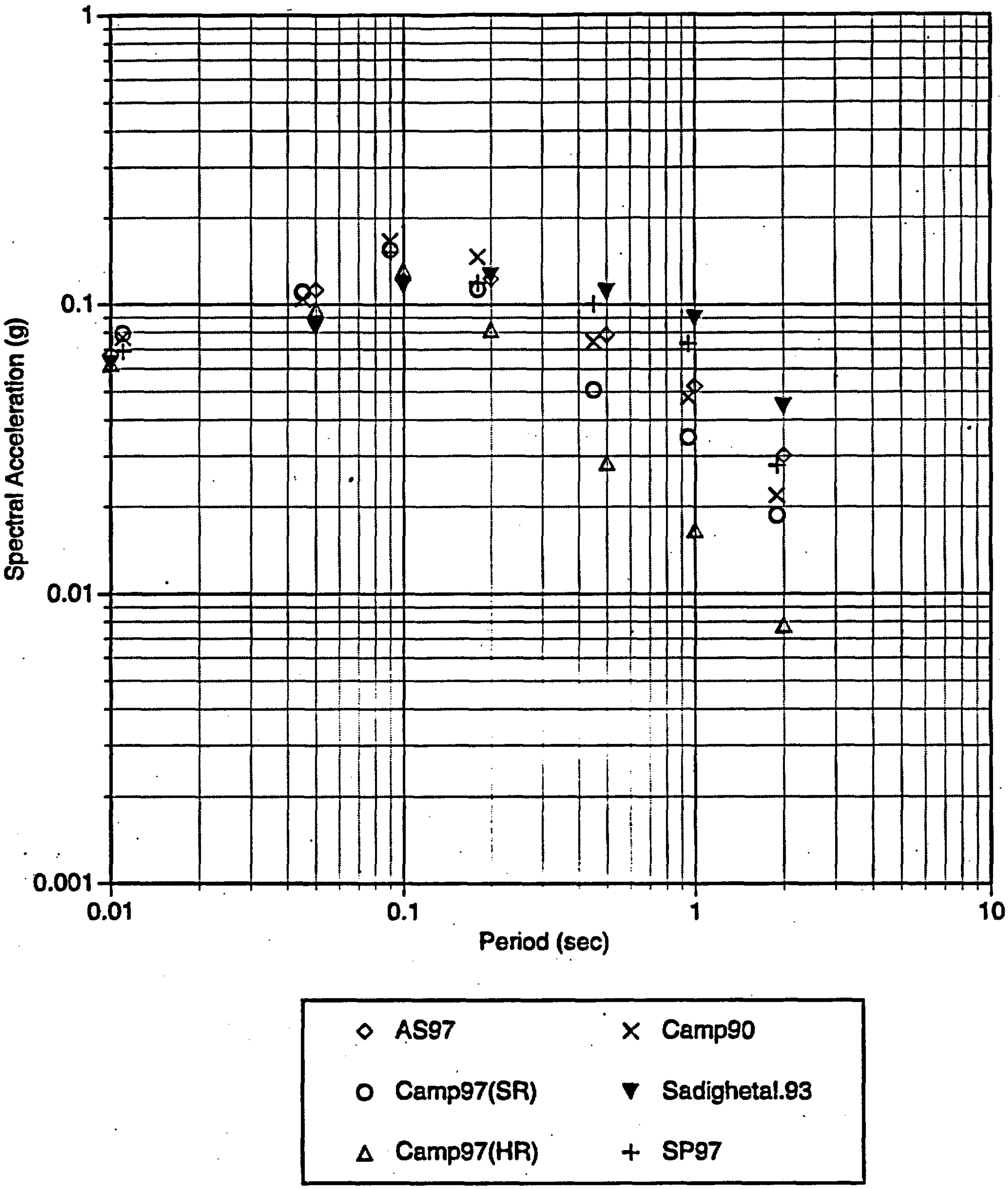



M=7.5,Strike-slip, Shallow, Horizontal, Case 15
1
0.1
0.01
0.001
Spectral Acceleration (g)
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

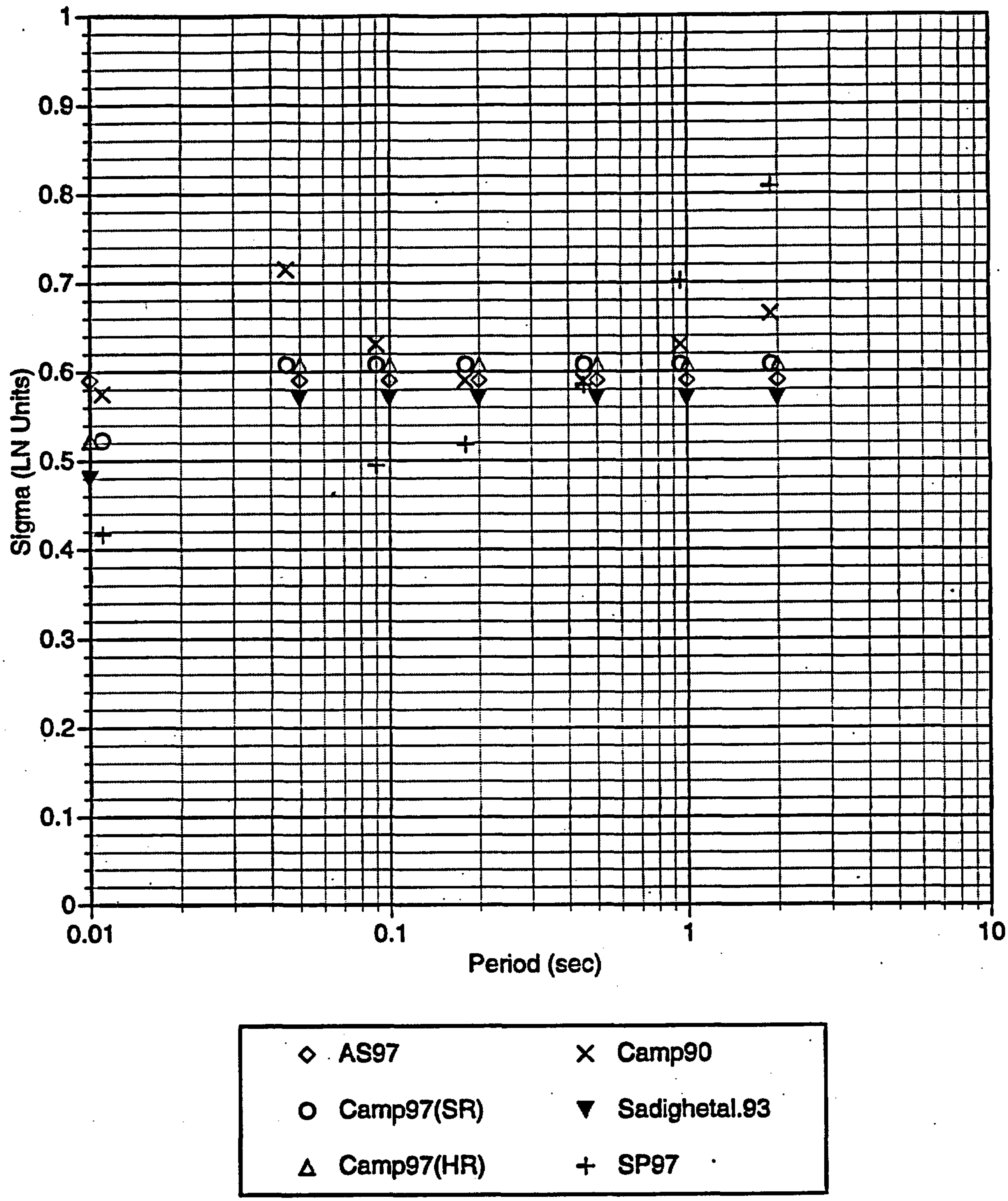


M=7.5, Strike-slip, Shallow, Horizontal, Case 15
Sigma (LN Units)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

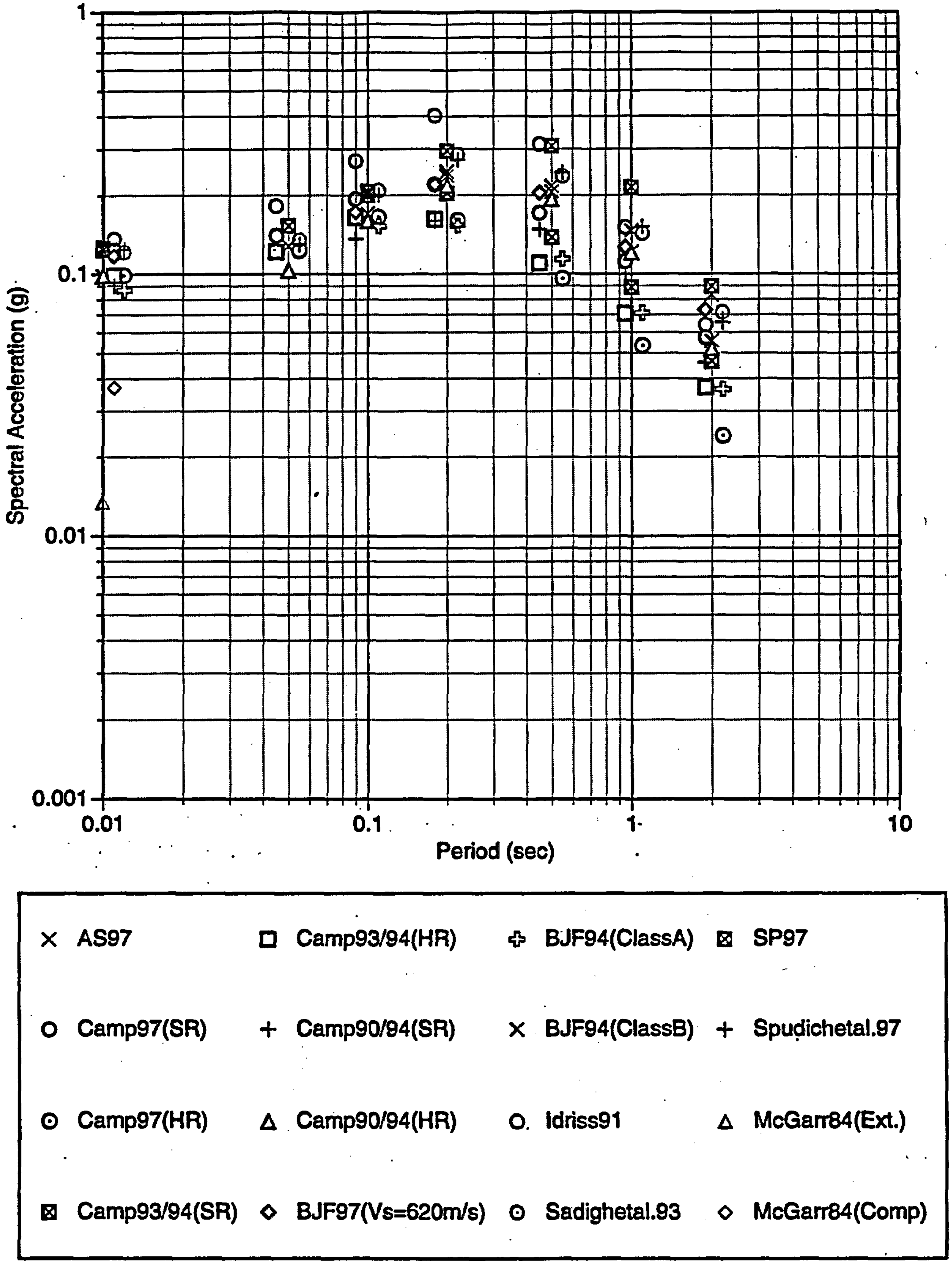
M=7.5, Strike-slip, Shallow, Vertical, Case 15

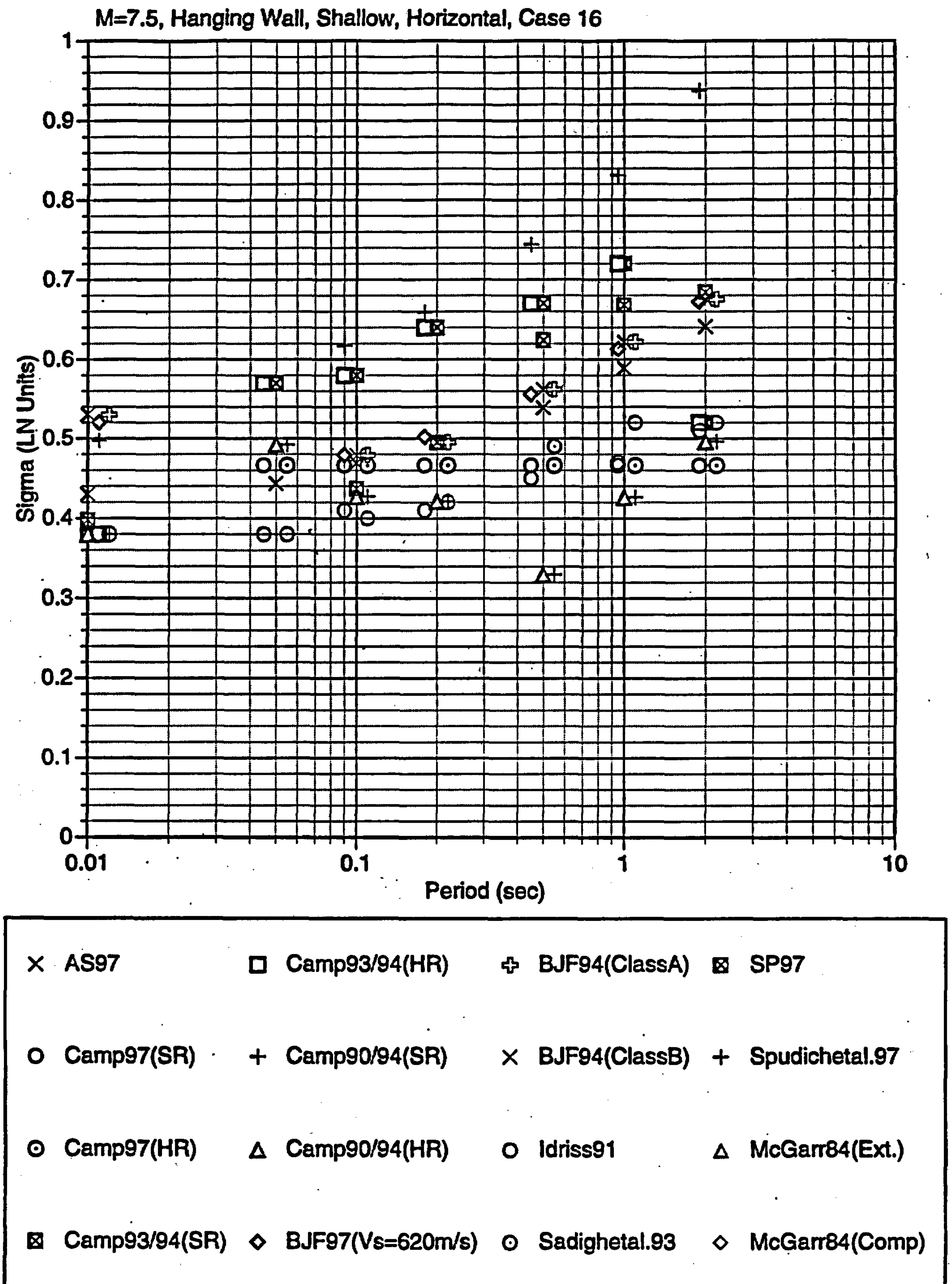


M=7.5, Strike-slip, Shallow, Vertical, Case 15

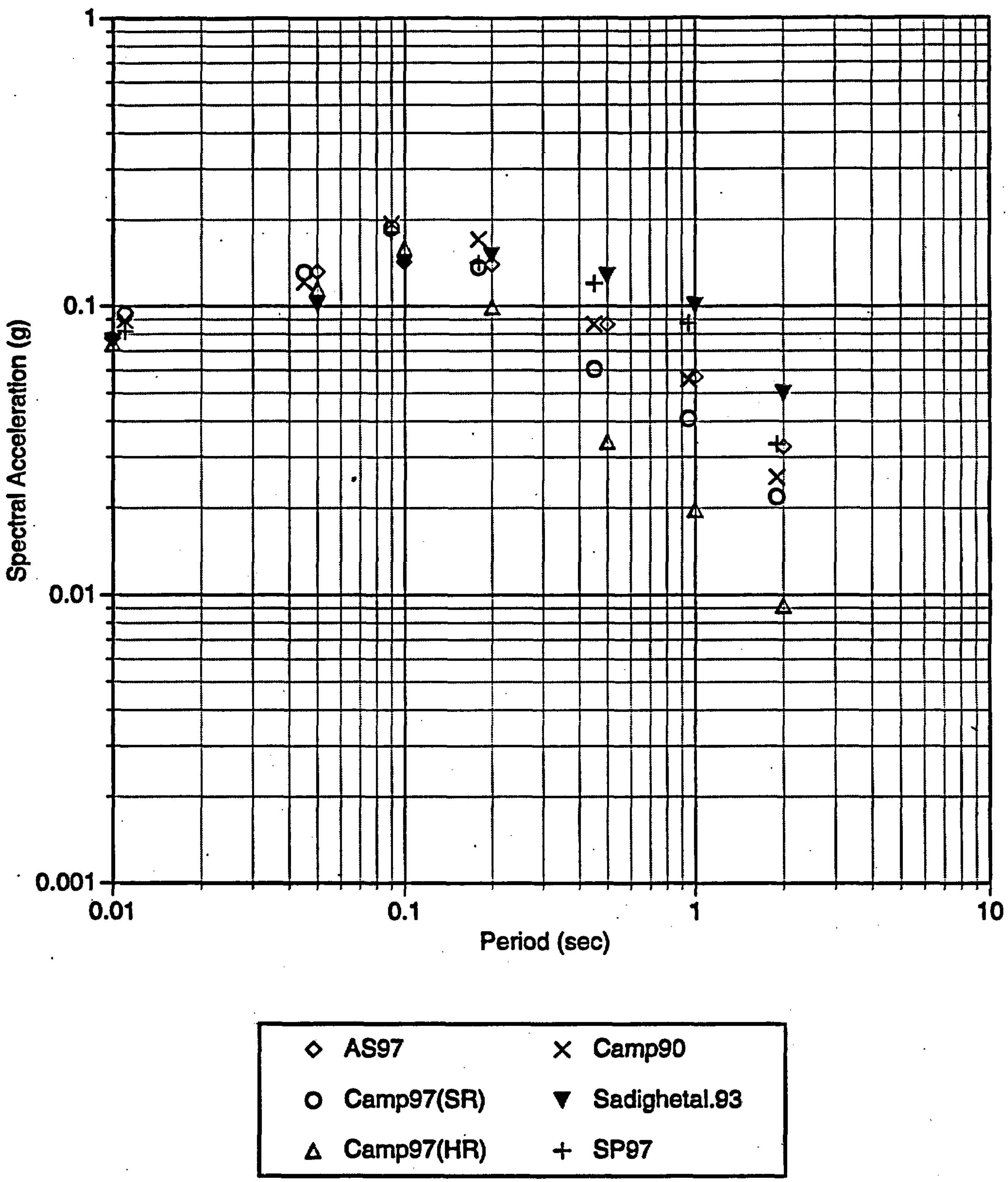


M=7.5,Hanging Wall, Shallow, Horizontal, Case 16




M=7.5, Hanging Wall, Shallow, Horizontal, Case 16
Sigma (LN Units)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
Period (sec)
AS97
Camp93/94(HR)
BJF94(ClassA)
SP97
Camp97(SR)
Camp90/94(SR)
BJF94(ClassB)
Spudichetal.97
Camp97(HR)
Camp90/94(HR)
Idriss91
McGarr84(Ext.)
Camp93/94(SR)
BJF97(Vs=620m/s)
Sadighetal.93
McGarr84(Comp)

M=7.5, Hanging Wall, Shallow, Vertical, Case 16



M=7.5, Hanging Wall, Shallow, Vertical, Case 16