COSMOS Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations

COSMOS Guidelines

07.01.2001

—

COSMOS
www.strongmotion.org
2443 Fillmore Street #380-6131
San Francisco, CA 94115

Consortium of Organizations for
Strong-Motion
Observation Systems

Guidelines for Installation of Advanced National Seismic System Strong-Motion Reference Stations

COSMOS
1301 South 46th Street
Richmond, California 94804

1 July 2001

Abstract

The purpose of earthquake strong-motion measurements within the Advanced National Seismic System (ANSS) is to quantitatively document large-amplitude earthquake ground shaking for use in various applications, including emergency response alerting, assessment, and research applications. This document provides specific guidance for the installation of ANSS strong-motion stations to be considered "strong-motion reference stations."

A strong-motion station is an earthquake strong-motion measurement system installed at a particular location. Such strong ground motion stations are to accurately record the combined effects of earthquake source, propagation path, and site effects within the range of amplitudes (.001 - 2g) and frequencies (0 – 50 Hz) needed for the various public safety, engineering, and scientific applications. In urban areas, a goal of seismic monitoring is to measure ground motions that are representative of the ground shaking experienced by the built environment (i.e., buildings, other structures, infrastructure) near the strong-motion station. Useful strong-motion reference stations can be installed with careful consideration to minimize contamination of ground motions by soil-structure interaction effects. Some urban strong-motion reference stations will be installed in open ground, away from buildings; these are denoted SMRS-OG. Some may be installed within small buildings and are denoted SMRS-SB. Of necessity, some stations in dense urban areas may be installed at ground level in or near larger structures and will be denoted SMBRS-DU. All three types of installations can provide valuable information for a variety of applications.

The following document provides detailed information regarding strong-motion reference station siting, construction, site characterization, and documentation. This guideline is intended to assist engineers and/or seismologists responsible for deploying new ANSS strong-motion stations. Although its primary application is to ANSS stations, the document can be useful to other programs, especially those becoming active in strong-motion measurements.

For further information about this document or to obtain additional copies, contact:

COSMOS
Pacific Earthquake Engineering Research Center
University of California, Berkeley
Bldg. 454, Rm. 121
1301 South 46th Street
Richmond CA 94804-4698

Phone: (510) 231-9436
FAX: (510) 231-9471
e-mail: cosmos@eerc.berkeley.edu

Acknowledgments

This document is a COSMOS effort in support of the U.S. Geological Survey and their Advanced National Seismic System. Funding was provided by the U.S. Geological Survey under Contract Award No. 00HQR0079. The team that produced these Guidelines consisted of Robert L. Nigbor of the University of Southern California (Principal Author), J. Carl Stepp (Principal Investigator), and Anthony F. Shakal (Review Committee Chair). Members of both the COSMOS Strong-Motion Programs Board and General Membership provided review input.

Table of Contents

1. Introduction

The purpose of earthquake strong-motion measurements within the Advanced National Seismic System (ANSS) is to quantitatively document large-amplitude earthquake ground shaking. Most strong-motion stations of the ANSS will be located in urban areas with significant seismic risk. Data obtained from these stations will be used for emergency response, performance assessment, improvement of building codes, and research. Standardization of measurement methods is needed to insure that ANSS data are suitable for these varied applications and are consistent across the entire system.

This guideline builds on the important concept of a *strong-motion reference station,* which is defined in the COSMOS document titled *Urban Strong Motion Reference Station Guidelines: Goals, Criteria and Specifications for Urban Strong-Motion Reference Stations* (included in Appendix A), and is intended to assist engineers and/or seismologists responsible for installing new ANSS strong-motion stations. Recommendations are provided for strong-motion reference station siting, station design, site characterization, and documentation. Although written for ANSS, the document can also be useful to other earthquake measurement programs. Figure 1-1 below is an example of such a strong-motion reference station.

Fig. 1-1: Example of a strong-motion reference station on open ground

1.1 DOCUMENT SCOPE

This document is intended to guide those responsible for ANSS strong-motion station deployment in their planning and construction efforts. It is a guideline—not a standard—and describes the major issues related to the installation of ANSS strong-motion stations and presents recommendations for each.

- Section 2 defines three types of strong-motion reference stations and the criteria for each. It also defines station data and information within the context of strong-motion stations;
- Section 3 discusses siting criteria and station design for strong-motion reference stations located on open ground;
- Section 4 discusses siting criteria and station design for strong-motion reference stations located in small buildings;
- Section 5 discusses siting criteria and station design for strong-motion reference stations located in dense urban areas;
- Section 6 presents recommendations for the geological and geotechnical characterization of strong-motion reference stations. Costs are also discussed to assist the user in the incorporation of site characterization in station planning; and
- Section 7 contains recommendations for strong-motion reference station documentation including basic station data and auxiliary station information. Sample station information forms are provided in Appendix B.

1.2 IMPORTANT ISSUES IN STRONG-MOTION STATION SITING AND DESIGN

Perhaps the three most important technical issues related to the topic of strong-motion station siting and design are as follows: 1) minimization of effects of structures on recorded motions; 2) design of instrument foundation to minimize its effect on recorded motions; and 3) the need for characterization of the station site. Background for these three issues is briefly summarized below.

1.2.1 Building Foundation Motions

A goal of strong ground motion measurements is to accurately record the combined effects of earthquake source, propagation path, and geological/geotechnical site effects at a particular location within the range of amplitudes (<.001-2g) and frequencies (0-50 Hz) needed for various applications, including coordinating emergency response efforts, damage assessment, and research studies. Localized effects on the measurements of man-made features of the particular location, including the station itself, should be minimized.

Unfortunately, this goal cannot be met explicitly if the strong-motion station is located within a building. The famous strong-motion record from El Centro 1940, recorded on a massive building foundation was found to be not representative of free-field ground motions at frequencies above about 2 Hz [Agbabian Associates, 1980]. Measurements made by Tajima [1984] show that a large imbedded foundation will de-amplify ground motions at frequencies above 1 Hz, as shown in Figure 1-2. Based

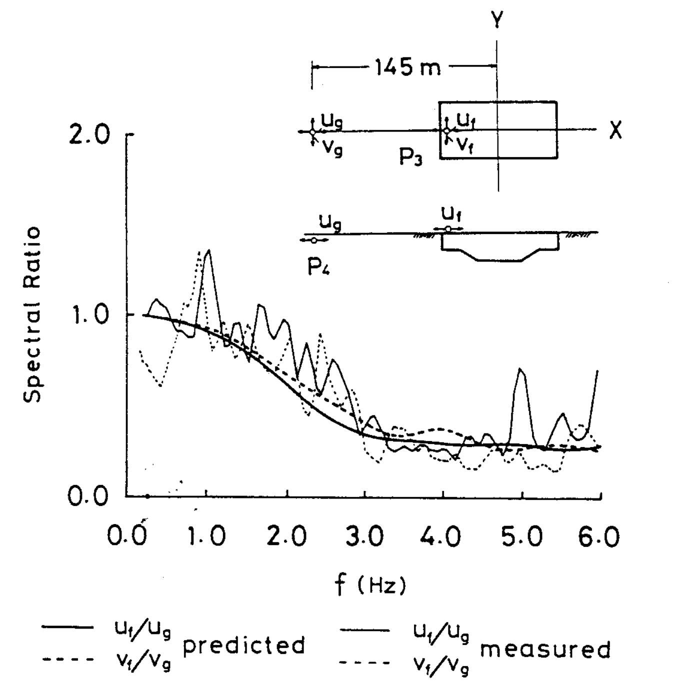

Fig. 1-2: De-amplification of ground motions by a 91m x 45m foundation at a station on alluvium [Tajima, 1984]

on observations from strong-motion data, Stewart [2000] demonstrated that horizontal foundation motion can provide an estimate of free-field ground motions if the foundation is shallowly imbedded, the frequency range of interest is low (f<1 Hz), and the frequency range is distinct from the fundamental mode of the structure; otherwise, horizontal foundation motion is a poor estimator of free-field ground motion. This effect can be significant at alluvial stations, but is less important at stations located on rock.

It is also known that earthquake ground motions near a building may be affected by the interaction between the structure and the soil. Therefore, it may not be possible to find completely uncontaminated sites for strong-motion stations located in urban areas. As opposed to a free-field station, the concept of an *Urban Reference Station* accepts this limitation. The user should, however, attempt to minimize the effects of the built environment on recorded motions when siting a strong-motion reference station.

1.2.2 Instrument Foundation Motions

When a strong-motion station is located away from buildings on soil, it will have its own small foundation for supporting the recorder and/or sensor. It is known that the instrument foundation can affect the recorded motions at high frequencies and at frequencies as low as 10 Hz if the soil is soft. Crouse and Hushmand [1989] showed this experimentally and analytically for two California accelerograph foundations; the first resonance of the Imperial Valley #6 station was 12 Hz, and the first resonance of the Cholame 1E station was 25 Hz. Figure 1-3 shows the measured and calculated transfer functions of a free-field accelerograph station in Jenkinsville, South Carolina, from Crouse et al. [1984]; this foundation affected recorded motions above about 10 Hz. The physical sizes of the Imperial Valley #6 and Jenkinsville stations were fairly large, larger than the generic station design presented in this document; however, the size of the Cholame 1E station was comparable to the size of this document's proposed generic open ground station.

The ANSS and other strong-motion station designs, especially those on open ground, should consider this issue of instrument foundation response and strive to create a station that has horizontal and vertical transmissibilities of 1.0 over the 0-50 Hz frequency range.

1.2.3 The Need for Site Characterization

The engineering properties of the soil or rock under a strong-motion station can have a large effect on the recorded motions. Mainly because of the cost associated with such studies, most strong-motion network operators do not routinely perform extensive site characterization studies for new stations. One exception is the Kyoshin-Net strong-motion network in Japan, which has characterized all 1000 of their station sites. Figure 1-4 shows a sample of the available site information.

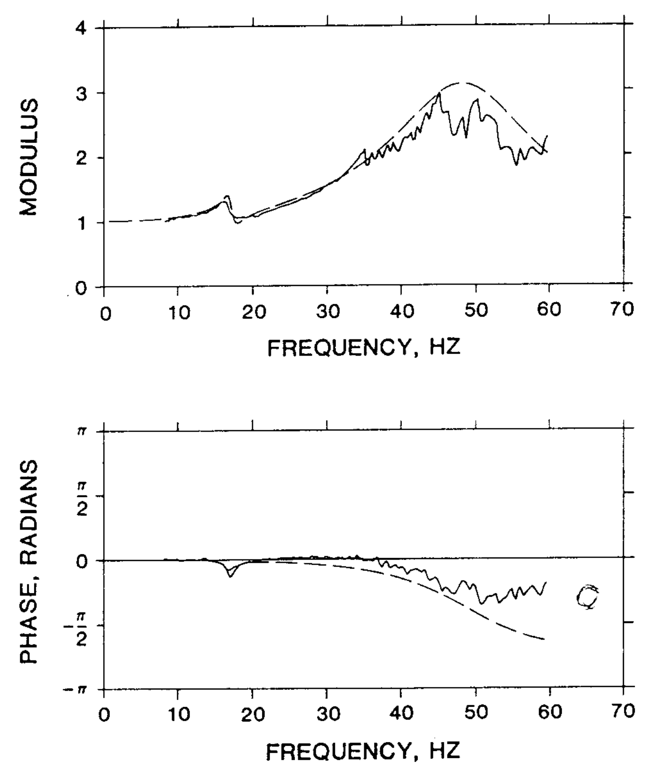

Fig. 1-3: Response of Jenkinsville, South Carolina, accelerograph foundation. Shown are computed (solid) and measured (dashed) transfer functions for the N50E direction [Crouse et al., 1984]

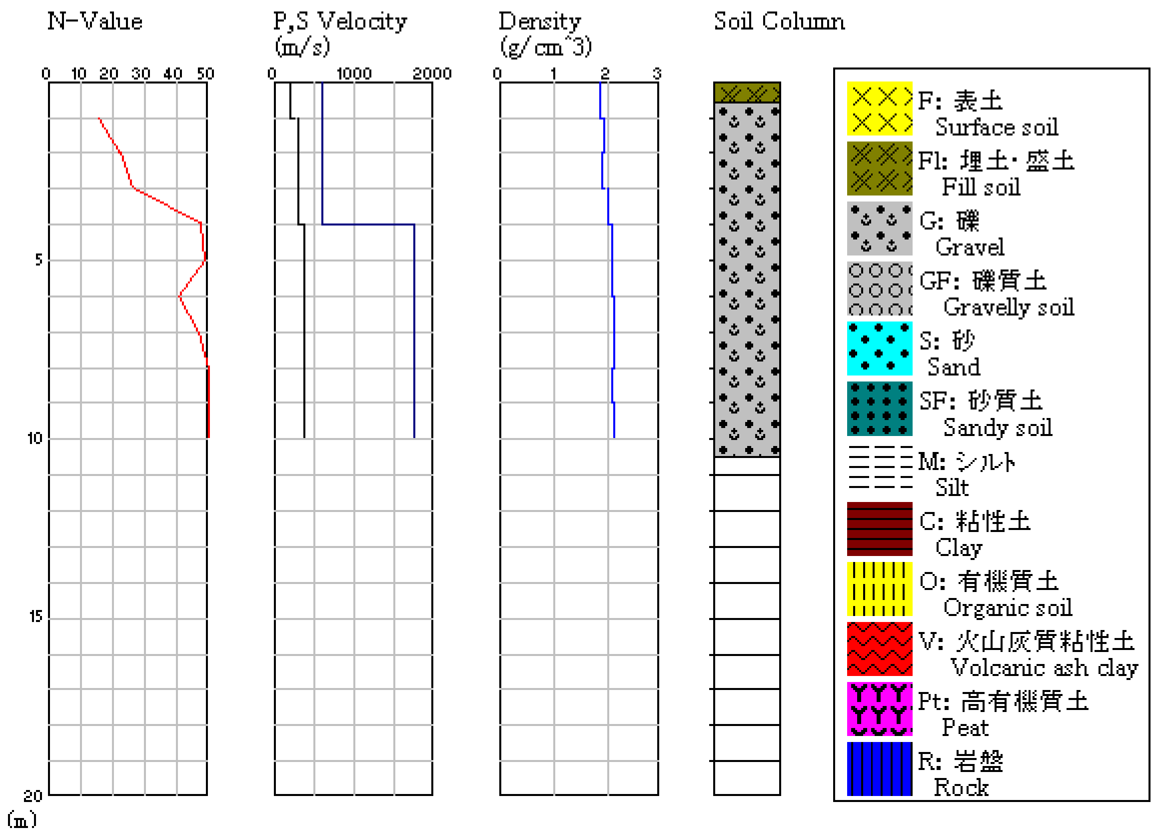

Fig. 1-4: Site characterization information for Kyoshin-Net site HYG020 near Kobe

Strong-motion station sites are often characterized by surface geology. The recent ROSRINE project (http://geoinfo.usc.edu/rosrine) has shown that surface geology alone is a poor predictor of subsurface engineering properties. A detailed understanding of the subsurface geology and soil/rock properties at a strong-motion station is important for understanding of the contribution of site response to the measured ground motions. Site characterization studies are needed at every ANSS strong-motion reference station. Section 6 of this document provides basic guidelines for such studies.

2. Definitions and Criteria

2.1 STRONG-MOTION STATIONS

A *strong-motion station* is an earthquake shaking measurement system installed at a particular location that is designed to measure large-amplitude shaking, typically with peak accelerations larger than 0.01g. Within the context of broadband seismic monitoring, a strong-motion station is also called a *low-gain* station. Strong-motion stations include free-field, borehole, reference, and structural response stations.

A *free-field strong-motion station* is a strong-motion station intended to measure ground surface motions not contaminated by structural response or soil-structure interaction. Because this type of station may not be present in an urban area, criteria and design details are not within the scope of this document.

Most surface strong-motion reference stations located in urban areas will be contaminated by soil-structure interaction of the built environment. Data from these stations may not be appropriate for use as input motions to nearby structures, however they may be very important in characterizing the actual motion that occurred in the built environment. If uncontaminated input motions in urban areas are desired, installation of strong-motion sensors in boreholes should be considered. In some areas, data from such *borehole strong-motion stations* can be used (with appropriate care) as input to a soil column under a nearby structure and the data obtained used to estimate the input motion to the structure. Details of such borehole strong-motion stations are beyond the scope of this document.

Many strong-motion stations will be located within buildings or other structures for measuring structural response to earthquake ground shaking. While important for scientific and engineering purposes, these *structural response strong-motion stations* cannot be directly considered as reference data for ground shaking within the local geographic region. Details of structural response stations are beyond the scope of this document.

Strong-Motion Reference Stations are the subject of this document and are discussed in the following sections.

2.2 URBAN STRONG-MOTION REFERENCE STATIONS

In urban areas it is critical to measure earthquake ground motions representative of the ground shaking experienced by the built environment (i.e., buildings, other structures, infrastructure). Strong-motion stations designed to meet this need are called *urban strong-motion reference stations* or simply *strong-motion reference stations*. Figure 1-1 is a photograph of an urban reference station located on open ground (in a parking lot) at the University of Southern California. The COSMOS document *Urban Strong-Motion Reference Station Guidelines*, included in Appendix A, provides detailed goals, criteria, and specifications for strong-motion reference stations. These are summarized below.

2.2.1 Overall Goals

The goals of urban strong-motion reference stations are as follows:

- Quantitatively document ground motions in high-risk urban regions for evaluation and improvement in the performance of buildings and other man-made structures during damaging earthquakes;
- Provide reliable information for accurate, effective characterization of earthquake shaking by ShakeMap and other rapid post-earthquake alerting or assessment tools;
- Provide empirical basis for long-term improvements in the seismic provisions of building codes and construction guidelines; and
- Augment seismological data from non-urban stations to improve the understanding of earthquake generation and seismic wave propagation in areas with inadequate measurements.

2.2.2 Global Siting Criteria

Urban strong-motion reference stations should be located to record representative ground motions in the vicinity of significant business districts or groups of structures. When planning a network of strong-motion reference stations in an urban area, both the above criteria and following global siting considerations should be considered to optimize the location of stations:

- Probability of shaking: consider the highest likelihood of shaking, both short-period and long-period shaking;
- Probability of property damage: consider areas with elevated risk related to the type or number of structures or facilities;
- Probability of loss of life and indirect losses: consider areas with elevated probability of loss, even though they are not areas of highest shaking or damage probability, because of their increased likelihood for casualties, death, or human suffering resulting from the fragility of the infrastructure;
- Probability of learning: consider areas of major uncertainty in knowledge about earthquake generation, seismic wave propagation, ground motion attenuation, or site response in order to improve understanding of the hazard in those areas; and
- Value for emergency response - consider locations of strategic value for providing effective ground shaking information for emergency response.

2.2.3 Local Siting Criteria

In the urban environment it is difficult to find true free-field sites because ground motions contaminated by local interaction of ground shaking with the built environment. Useful urban strong-motion reference stations can be installed with careful consideration to minimize such interaction effects. Some urban strong-motion reference stations may be installed on open ground, others within small buildings. Both can provide valuable information for many public safety, engineering, and scientific applications. Three types of strong-motion reference stations are defined as follows and discussed in more detail below: (1) Strong-Motion Reference Stations on Open Ground, (2) Strong-Motion Reference Stations in Small Buildings, and (3) Strong-Motion Reference Stations in Densely Urbanized Areas.

2.2.3.1 SMRS-OG

A strong-motion station located on open ground will be considered a *Strong-Motion Reference Station: Open Ground* (SMRS-OG) if it meets the following criteria:

- It is not sited on locally anomalous soft or hard soils that might produce ground motions not expected to be experienced by nearby sites of interest;
- It is not sited in or on a localized topographic feature such as a hill, ridge, or valley that might create ground motions not expected to be experienced by nearby sites of interest (e.g, the Tarzana station in Los Angeles would not be representative of ground motions experienced by structures away from this hill location);
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any large building (>4000 ft^2 in plan or >2 stories in height) or any building with a significant basement or foundation;
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any non-building structures likely to cause significant soil-structure interaction effects that will contaminate the data; and
- Station construction is designed to minimize soil-structure interaction in the frequency range 0-50 Hz.

2.2.3.2 SMRS-SB

A strong-motion station will be considered a *Strong-Motion Reference Station: Small Building* (SMRS-SB) if it meets all of the following criteria:

- It is located within a small building (<4000 ft^2 in plan and <2 stories in height);
- It is installed on grade;
- It is located in a building without significant basement;
- It is located in a building with a small foundation (flat slab preferred, no pile foundations or deep spread footings);
- It is located in a building of relatively lightweight construction (wood frame preferable, but reinforced masonry acceptable);
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any large building (>4000 ft^2 in plan or >2 stories in height) or any building with a significant basement or foundation; and
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any non-building structures likely to cause significant soil-structure interaction effects that will contaminate the data.

Technical requirements for SMRS-SB stations are detailed further in Appendix A.

2.2.3.3 SMBRS-DU

A strong-motion station will be considered a *Strong-Motion Building Reference Station: Densely Urbanized Area* (SMBRS-DU) if it meets the following criteria:

- It is located to measure representative base floor motions in densely urbanized areas;
- It is located within a building 10 stories or less in height; and
- It is located on the base floor of the building (i.e., the lowest floor level, whether parking or basement).

Reference stations located in densely urbanized areas should be sited with SMRS-SB criteria wherever possible. In densely urbanized areas for which SMRS-SB type sites are not available, SMBRS-DU criteria should be used. If possible, the building in which an SMBRS-DU station is located should also be instrumented for structural response to allow the building response to be removed from the ground or ground floor motions. Data from SMBRS-DU stations will be used for comparison with those of nearby reference stations located on open ground or in small buildings.

For densely urbanized areas with high seismic hazard where it is not possible to site either SMRS-OG or SMRS-SB stations, it is suggested to have one SMBRS-DU station for every 2 million ft^2 of building space or at a density to ensure documenting any rapid changes that might occur in underlying geology, e.g., in the lower Market Street area of San Francisco, California. Near the base of Telegraph Hill in San Francisco, California, is one location where rapid changes may occur in the thickness of soft soils from 0 to over 90 ft within a distance of two-three city blocks, thereby requiring spacings of less than this distance to document expected significant changes in ground motion. Density of stations based on the 2 million ft^2 guideline translates into spacing dependent upon the type of zoning. For zones densely populated with high-rise buildings, this may be one to two square blocks, one to two square miles for zones of low-rise industrial buildings, and several square miles or more for urban residential zones. A combination of geologic and zoning criteria is required to determine spacing. In densely urbanized areas with moderate or low seismic hazard, a rational risk-based approach should be considered for optimization of SMBRS-DU station locations.

2.3 BASIC STATION DATA AND AUXILIARY STATION INFORMATION

Two other definitions are needed for use of this document. These are *Basic Station Data* and *Auxiliary Station Information*. Basic Station Data consists of descriptive, alphanumeric data accompanying a strong-motion station. These data include the station name, station ID, address, coordinates, and geological site description. Auxiliary Station Information is defined here as additional alphanumeric and non-alphanumeric data that may accompany a strong-motion station. This can include photos, maps, plots of site characterization data, and other descriptive information that augments the basic station data.

3. Reference Stations on Open Ground

Ideally, an urban strong-motion reference station (either the entire station or just the sensor) should be installed on open ground in an attempt to minimize contamination of the recorded motions by structural response. This section contains siting criteria, a discussion of siting issues, and recommended station designs for strong-motion reference stations on open ground. Figure 1-1 is a photograph of a strong-motion reference station on open ground.

3.1 SITING CRITERIA

A strong-motion station located on open ground will be considered a *Strong-Motion Reference Station: Open Ground* (SMRS-OG) if it meets the following criteria:

- It is not sited on locally anomalous soft or hard soils that might create ground motions not expected to be experienced by nearby sites of interest;
- It is not sited in or on a localized topographic feature such as a hill, ridge, or valley that might create ground motions not expected to be experienced by nearby sites of interest (e.g., the Tarzana station in Los Angeles would not be representative of ground motions experienced by structures away from this hill location);
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any large building (>4000 ft^2 in plan or >2 stories in height) or any building with a significant basement or foundation;
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any non-building structures likely to cause significant soil-structure interaction effects that will contaminate the data; and
- Station construction is designed to minimize soil-structure interaction in the frequency range 0-50 Hz.

3.2 SITING ISSUES

Of the many issues to be considered in the location of a strong-motion station, perhaps the most important are those of site availability, permission, and permitting. A discussion of these issues and many other siting issues is beyond the scope of these guidelines. Four other important siting issues for SMRS-OG stations are briefly discussed below. These topics and discussions are not comprehensive, but are intended to raise main issues for further consideration.

3.2.1 Background Vibration

Although not as serious a problem as with high-gain broadband stations, SMRS-OG stations should be kept away from potential sources of vibration. These can include:

- Large motors, pumps, or generators;
- Large pipelines with active flow;
- Large masts, poles, or trees;
- Heavy vehicle traffic; and
- Industrial activities.

When in doubt, it is suggested that the background vibrations at a potential site be monitored. Peak ground vibrations should be less than 0.001g.

Even if the steady-state background vibrations are small, care must be taken to avoid locations where large vibrations could be induced during a strong earthquake. Large valves, pumps, or other mechanical or electrical devices that could activate or fail during earthquake shaking and transmit abnormal energy pulses should also be avoided.

3.2.2 Security

In both urban and remote areas, vandalism can be a problem for SMRS-OG stations. Provisions for security must incorporated in station design. This can be accomplished using stout enclosures, locks, tamper-proof external hardware, and fenced enclosures. If fencing is used, care must be taken to minimize contamination of ground motions by the vibration of the fence; lightweight fencing is best. The best security measure is to design a low profile for the station.

3.2.3 Power

Modern strong-motion instrumentation, especially with real-time digital communications, will require a reliable power source of as much as a few tens of watts. Providing an adequate power source can be a significant challenge for an SMRS-OG station. Solar power options are available, but note that several large solar panels will be required for most strong-motion reference stations. The question of the power source should be carefully considered during planning and design for strong-motion reference stations on open ground. One must also take care to minimize contamination of ground motions with vibrations from large solar panels and their supports. In any case, a battery system with enough capacity for four days of operation without power is needed (see Appendix A).

3.2.4 Communications

Most, if not all, of the ANSS strong-motion reference stations will be connected to some form of digital communications for data transfer and maintenance purposes. The availability of appropriate communications should be considered during the planning phase of a new station. If it proves difficult to connect wire or fiber-based communications to a self-contained open ground station, wireless options should be considered. Care must also be taken to minimize contamination of ground motions with vibrations from large antennae masts near the strong-motion sensor.

3.3 RECOMMENDED STATION DESIGN

There are many different strong-motion station designs currently available. Note: some of these designs use large foundation blocks or piers that may be inappropriate according to the definition of a strong-motion reference stations contained in these guidelines.

Installation at open ground locations requires constructing a reinforced concrete mounting pad with a lightweight enclosure. A small concrete slab/pad and a lightweight enclosure will help meet the goal that the transmissibility of the installed strong-motion station be 1.0 over the frequency range 0-50 Hz.

To provide a standardized design for ANSS strong-motion reference stations, the following two subsections present recommended station designs for both self-contained stations (containing all electronics within one enclosure) and remote sensor stations (containing only the sensor, all other electronics are remote). If using other station designs, they should be experimentally or analytically studied to verify that the completed station does not significantly affect the recorded ground motions. Studies by Crouse et al. [1984] provide examples of how these studies can be accomplished.

3.3.1 Self-Contained Stations

Figures 3-1 and 3-2 show the recommended design for ANSS strong-motion reference stations when all of the strong-motion station electronics (sensor, recorder, power, and communications) are to be located in the same enclosure.

3.3.2 Remote Sensor Stations

For some stations it may be possible and desirable to install the station electronics (recording, power, communications) inside a building and to install the sensor away from the building. Such an installation can meet all the criteria and recommendations for a strong-motion reference stations on open ground if the sensor is located far enough from the building.

When only the sensor is to be installed at an open ground location, there are many options for sensor installation, including surface enclosures, subsurface vaults, or direct burial. Figure 3-3 is a design example of a surface enclosure. Any station design should be experimentally or analytically studied to verify that the completed station does not significantly affect the recorded ground motions. Studies by Crouse et al. [1984] provide examples of how these studies can be accomplished.

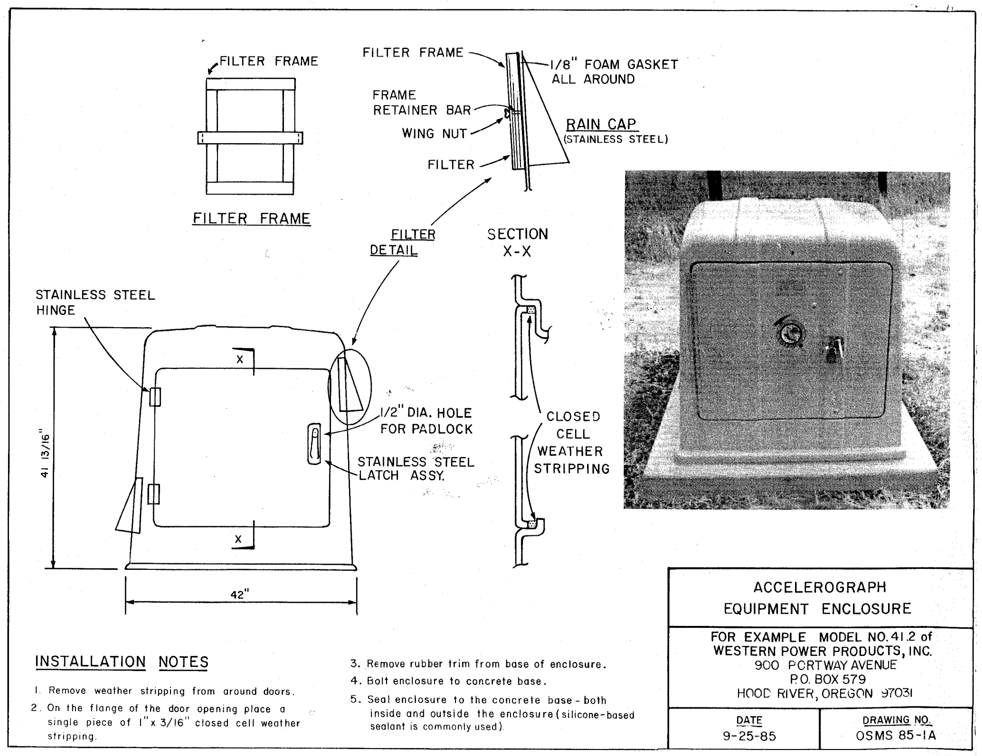

Fig. 3-1: Recommended lighweight enclosesure design for an open ground reference station

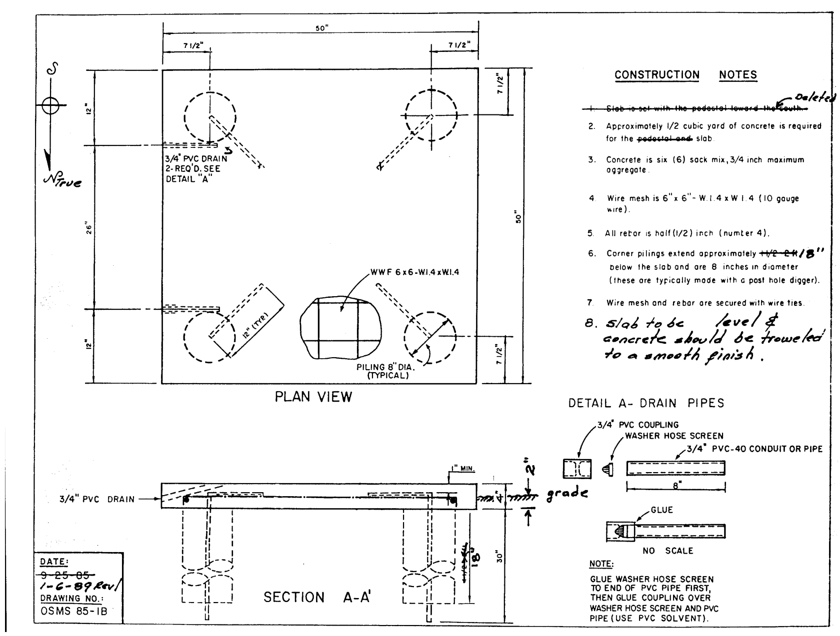

Fig. 3-2: Recommended foundation design for an open ground reference station

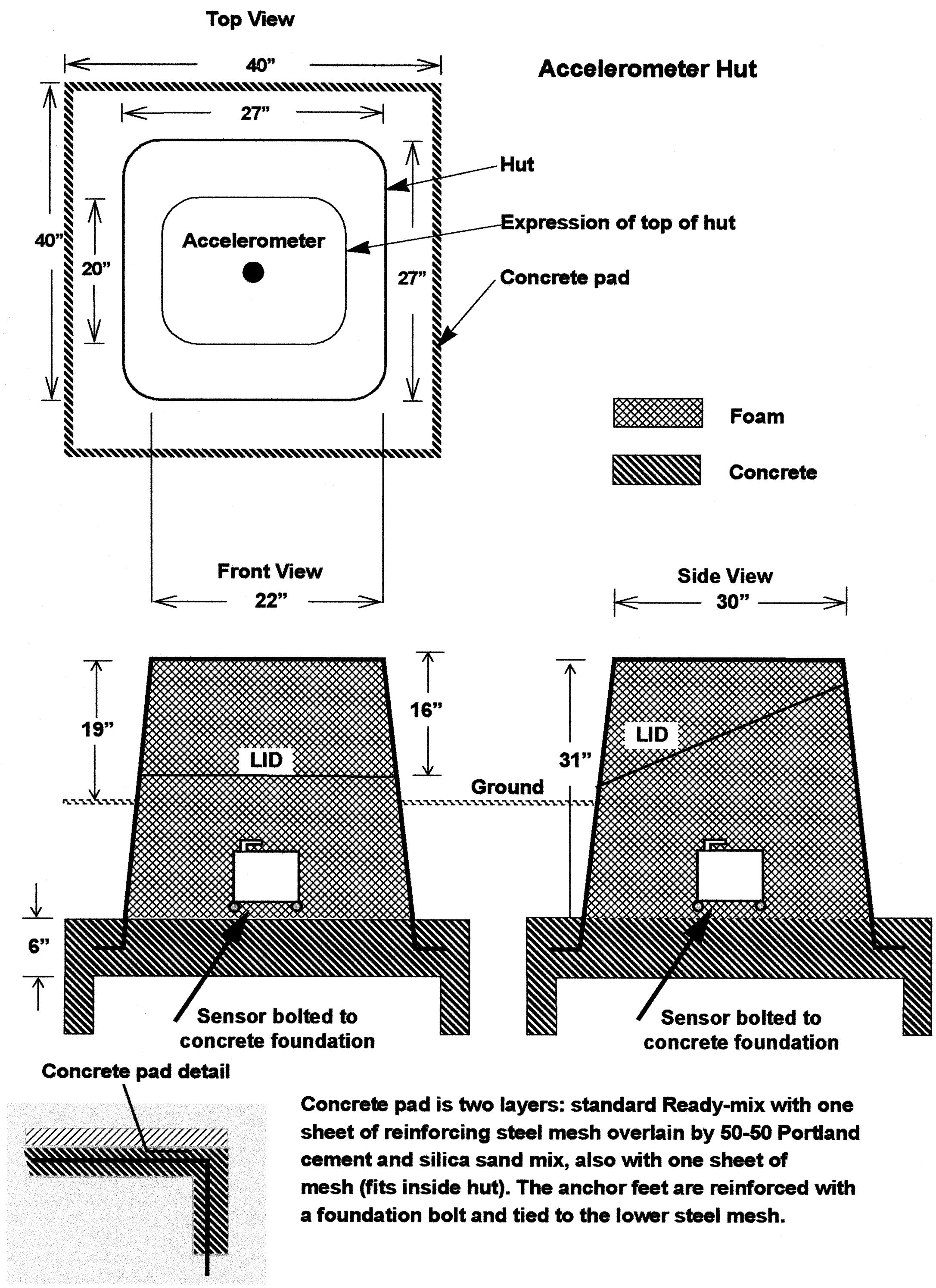

Fig. 3-3: Sample surface enclosure for a remote sensor open ground reference station

4. Reference Stations in Small Buildings

An acceptable strong-motion reference station can also be installed within a building small enough to have minimal effect upon the earthquake shaking. This section contains siting criteria and a discussion of siting issues for strong-motion reference stations in small buildings. Figures 4-1 and 4-2 show an example of an SMRS-SB station.

4.1 SITING CRITERIA

A strong-motion station will be considered a *Strong-Motion Reference Station: Small Building* (SMRS-SB) if it meets all of the following criteria:

- It is located within a small building (<4000 ft^2 in plan and <2 stories in height);
- It is installed on grade;
- It is located in a building without significant basement;
- It is located in a building with a small foundation (flat slab preferred, no pile foundations or deep spread footings);
- It is located in a building of relatively lightweight construction (wood frame preferable, but reinforced masonry acceptable);
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any large building (>4000ft^2 in plan or >2 stories in height) or any building with a significant basement or foundation; and
- It is located a distance of at least one major structural dimension (height or length, whichever is greater) from any non-building structures likely to cause significant soil-structure interaction effects that will contaminate the data.

4.2 SITING ISSUES

Of the many issues to be considered in the location of a strong-motion station, perhaps the most important are those of site availability, permission, and permitting. A discussion of these issues and many other siting issues is beyond the scope of these guidelines. Four other important siting issues are briefly discussed below. These topics and discussions are not comprehensive, but are intended to raise main issues for further consideration.

4.2.1 Background Vibration

Strong-motion reference stations in buildings should be kept away from potential sources of ground and structural vibration. These can include:

- Large motors, pumps, or generators;
- Unsupported floor slabs;
- Localized human activity;
- Heavy vehicle traffic outside; and
- Industrial activities.

When in doubt, it is suggested that the background vibrations at a potential site be monitored. Peak ground vibrations should be less than 0.001g.

Even if the steady-state background vibrations are small, care should be taken to avoid locations where large vibrations could be induced during a strong earthquake, such as large valves, pumps, or other mechanical or electrical devices that could activate or fail during earthquake shaking and transmit abnormal energy pulses.

Care should also be taken to protect the sensor from impact of falling objects. It is recommended that a clear space of 2 m (minimum) be maintained around the sensor, and that the general area of the sensor be maintained free of furniture or contents that could move during an earthquake and contaminate the measured motions with impact vibrations.

4.2.2 Security

Vandalism can be a problem for strong motion stations in buildings. Provisions for security must be included in the design of a strong-motion station. A dedicated room with a locked door is recommended. Some installations also have a steel fence cage around the sensor within a non-dedicated room.

4.2.3 Power

Modern strong-motion instrumentation, especially with real-time digital communications, will require a reliable power source of as much as a few tens of watts. For a strong-motion station in a building, power may not be a major issue; however, sufficient power reserve should be provided in case of power failure through batteries or a UPS for operation for up to four days. Power conditioning is also recommended.

4.2.4 Communications

Most, if not all, ANSS strong-motion reference stations will be connected to some form of digital communications for data transfer and maintenance purposes. During the planning phase of a new station, the availability of appropriate, robust communications must be considered. Although this may not be as major issue as with stations located on open land, it still must be considered.

4.3 RECOMMENDED STATION DESIGN

There is no single recommended design provided here for a strong-motion reference station within a small building because each building situation will be different; however, the following are several strongly recommended features of a building installation:

- The sensor, recorder, and all auxiliary components must be bolted or fastened securely to a major part of the structure, preferably the floor slab;
- Other instrumentation components (recorder, communications, etc.) should be secured to prevent sliding or falling during motions that could exceed 1g;
- The location within a building should be as secluded as possible away from human traffic;
- The location within a building should be as far as possible from any structural or nonstructural building components that may strongly amplify the ground shaking. When in doubt, an experienced structural engineer should be consulted for appropriate location; and
- The location should not be in the center of an unsupported floor slab.

Fig. 4-1: Exterior view of strong-motion reference station in small building

Fig. 4-2: Interior view of a strong-motion reference station in a small building

5. Reference Stations in Densely Urbanized Areas

Risk to life and property is often greatest in the densely urbanized areas of large metropolitan areas such as downtown and high-rise areas of San Francisco, Los Angeles, Seattle, and New York. These areas often include older structures built prior to modern building codes and in many cases may include structures on soft soils near embayment and coastal areas. Soil-structure interaction effects of tall structures, bridges, and other transportation structures in the downtown areas will likely contaminate ground motions in these areas. Seismic background noise in these areas will be variable and especially high during rush hours and construction periods. Nevertheless, it is these areas for which thorough measurements of ground motion and the performance of structures is of highest priority and critical for improvements in public earthquake safety.

Photos of San Francisco, California (Figs. 5-1 and 5-2), emphasize the importance of closely spaced measurements in a densely urbanized metropolitan area in order to adequately document levels of shaking experienced by major structures of varying heights and plan dimensions. As is clear from the photographs, in many cases it is not possible to site strong-motion reference stations in areas of highest risk areas without planning for densely space stations to adequately document spatial variations due to induced building vibrations.

Fig. 5-1: Aerial view of San Francisco, California, emphasizing the need for closely spaced strong-motion reference stations in densely urbanized areas

Fig. 5-2: Aerial view of San Francisco, California, emphasizing the variety and type of structures in a densely urbanized area

5.1 SITING CRITERIA

A strong-motion station will be considered a *Strong-Motion Building Reference Station: Densely Urbanized Area* (SMBRS-DU) if it meets the following criteria:

- It is located to measure representative base floor motions in the densely urbanized areas;
- It is located within a building 10 stories or less in height; and
- It is located on the base floor of the building (i.e., the lowest floor level, whether parking or basement).

Reference stations located in densely urbanized areas should be sited with SMRS-SB criteria wherever possible. In those densely urbanized areas for which SMRS-SB-type sites are not available, SMBRS-DU criteria should be used. If possible, the building in which an SMBRS-DU station is located should also be instrumented for structural response to allow the building response to be removed from the ground or ground floor motions. Data from SMBRS-DU stations will be used for comparison with those of nearby reference stations located on open ground or in small buildings.

A suggested goal for a densely urbanized area with high seismic hazard in which SMRS-OG or SMRS-SB stations are not possible is to have one SMBRS-DU station for every 2 million ft^2 of building space or at a density to ensure documenting any rapid changes that might occur in underlying geology, e.g., in the lower Market Street area of San Francisco, California. Near the base of Telegraph Hill in San Francisco, California, is one location where rapid changes may occur in the thickness of soft soils from 0 to over 90 ft within a distance of two-three city blocks, thereby requiring spacings of less than this distance to document expected significant changes in ground motion. Density of stations based on the 2 million ft^2 guideline translates into spacing depending upon the type of zoning. For zones densely populated with high-rise buildings, this may be one to two square blocks, one to two square miles for zones of low-rise industrial buildings, and several square miles or more for urban residential zones. A combination of geologic and zoning criteria is required to determine spacing. In densely urbanized areas with moderate or low seismic hazard, a rational risk-based approach should be considered for optimization of SMBRS-DU station locations.

5.2 OTHER SITING ISSUES

Of the many issues to be considered in the location of an SMBRS-DU station, perhaps the most important are those of site availability, permission, and permitting. A discussion of these issues and many other siting issues is beyond the scope of these guidelines. Four other important siting issues are briefly discussed below. These topics and discussions are not comprehensive, but are intended to raise main issues for further consideration.

5.2.1 Background Vibration

Strong-motion reference stations in buildings should be kept away from potential sources of ground and structural vibration to the extent possible. In general, seismic background noise levels will be much higher in a densely urbanized downtown area than in an area located in a park or away from local cultural noise sources. Listed below are local sources that should be avoided as much as possible:

- Large motors, pumps, or generators;
- Unsupported floor slabs;
- Localized human activity;
- Heavy vehicle traffic outside; and
- Industrial activities.

When in doubt, it is suggested monitoring background vibrations at a potential site to determine feasible locations within a city block area with the smallest levels of peak acceleration during rush hours.

Even if the steady-state background vibrations are small, care should be taken to avoid locations where large vibrations could be induced during a strong earthquake, such as large valves, pumps, or other mechanical or electrical devices that could activate or fail during earthquake shaking and transmit abnormal energy pulses. Care should also be taken to protect the sensor from impact of falling objects. It is recommended that a clear space of 2 m (minimum) be maintained around the sensor and that the general area around the sensor be maintained free of furniture or contents that could move during an earthquake and contaminate the measured motions with impact vibrations.

5.2.2 Security

Vandalism can be a problem for strong-motion stations in densely urbanized areas. Provisions must be included for security in the design and installation of these strong-motion stations. A locked door is recommended. Some installations have also installed a steel fence cage around the sensor.

5.2.3 Power

Modern strong-motion instrumentation, especially with real-time digital communications, will require a reliable power source of as much as a few tens of watts. For a strong-motion station located in a building, power may not be a major issue; however, sufficient power reserve should be provided in case of power failure, through batteries or an UPS for operation for up to four days. Power conditioning is also recommended.

5.2.4 Communications

Most, if not all, of the ANSS strong-motion reference stations will be connected to some form of digital communications for data transfer and maintenance purposes. The availability of appropriate, robust communications must be considered during the planning phase of a new station. Although this may not be a major issue as with stations located on open land, it still must be considered. Finding locations for GPS antennas in downtown areas so that tall buildings will not block signals can be an especially challenging problem for downtown reference stations. This problem needs to be considered in the initial site permitting process for the instruments.

5.3 RECOMMENDED STATION DESIGN

Recommendations for station design for SMBRS-DU stations are similar to those for SMRS-SB stations (see Section 4.3). The recommendations are not repeated here.

6. Site Characterization

Detailed understanding of the subsurface geology and soil/rock properties at strong-motion reference stations is important for understanding of the contribution of site response to measured ground motions and for classification of measured ground motion parameters. A good review of methods for site characterization is found in ASTM Standard D420-98 *Guide to Site Characterization for Engineering, Design, and Construction Purposes*.

For ANSS strong-motion reference stations, some level of site characterization studies should be required for every station. At a minimum, surface geology should be determined and available site information from previous local or regional studies should be obtained and added to the station's auxiliary information. Surface geology provides a primary description of the site and should be obtained from geology maps or observations by a knowledgeable person. Note that surface geology can be a poor estimator of subsurface soil or rock properties, especially for sites geologically classified as rock. Suggestions for obtaining existing site-related information are included in Section 6.1 below.

In addition to thorough geologic descriptions, site-specific characterization information should also be obtained. At a minimum, the NEHRP/IBC site category should be determined. The NEHRP/IBC site category is important for comparison of measured ground motions with building code seismic design levels. These site categories, denoted A-F, are formally described in the 2000 International Building Code's seismic design provisions as follows:

A. Hard rock with measured shear wave velocity V30>1500 m/s

B. Rock with 760m/s<V30<1500m/s

C. Very dense soil and soft rock with 360m/s<V30<760m/s

D. Stiff soil with 180m/s<V30<360m/s

E. A soil profile with V30<180m/s

F. Soils requiring special investigations (liquefiable soils, sensitive clays, or very weak soils)

V30 is the effective average shear wave velocity (1/average slowness) in the upper 30 m. NEHRP/IBC categorization will require some kind of measurement of V30; recommended methods are described in Section 6.2.

A more complete understanding of the contribution of site response to the measured earthquake shaking at a strong-motion reference station will require a detailed subsurface site characterization. These additional detailed measurements are considered optional with respect to these guidelines, but are strongly recommended for all SMRS-OG stations and should be considered for SMRS-SB and SMBRS-DU stations as well. A good example of the kinds of site characterization data needed for more detailed, site-specific strong-motion site response analysis can be found in the ongoing project

Resolution of Site Response Issues in the Northridge Earthquake - ROSRINE (see http://geoinfo.usc.edu/rosrine). In addition to site geology, dynamic soil and rock properties are needed for modeling both linear and nonlinear earthquake site response. The primary modeling properties are density, dynamic modulus, and damping (Q). The latter two properties are nonlinear functions of strain. These properties are obtained by laboratory testing of undisturbed samples and by one or more surface or borehole geophysical measurements of shear wave velocity. Section 6.3 provides recommendations for these detailed site characterizations. To assist in planning, an estimate of costs for site characterization is provided in Section 6.4.

6.1 OBTAINING EXISTING SITE INFORMATION

In most populated areas there will have been previous geological studies of the region and perhaps even local environmental, ground water, or planning studies. These studies can contain a wealth of information to assist in strong-motion site characterization. Planning for a strong-motion reference station installation should include a literature search for such previous studies and can be a very inexpensive source of information on site geology and even subsurface soil and rock properties.

Potential sources of information on a regional basis are government geological or natural resources agencies, i.e., the U.S. Geological Survey. For local studies, sources of information might include the local government planning agency, local universities, private water companies, and even local water well drilling companies. If the strong-motion station is near a building, it is possible that the construction documents will contain some soils reports.

6.2 V30 DETERMINATION FOR NEHRP CATEGORIZATION

V30, the average shear-wave velocity in the upper 30 m, can be estimated using noninvasive surface methods or can be directly measured using either a minimally-invasive seismic cone penetrometer or more invasive drilling and logging methods. The more invasive drilling and logging methods have the added advantage that subsurface geology can be directly observed during drilling.

6.2.1 Estimation Using Surface Methods

There are some surface geophysical methods that can be used to obtain an estimate of the shallow shear-wave velocities and, therefore, an estimate of V30. The document ASTM Standard D6429-99 *Standard Guide for Selecting Surface Geophysical Methods* (see http://www.astm.org) provides good general background material, as does Ishihara [1996]. These can often provide a relatively inexpensive way of obtaining the data needed for determination of the NEHRP site category.

Two available methods for estimation of V30 are 1) surface wave methods and 2) seismic refraction. Performed properly, each of these methods can provide a good estimate of V30 at many sites. Unfortunately, these methods can provide erroneous or biased data at sites when improperly performed or when site characteristics are not optimal (i.e., not flat layering). Direct measurement methods at a site should be used if these indirect surface measurements at a site are suspect.

Surface wave methods, most commonly called the Spectral Analysis of Surface Wave (SASW) method, measure surface wave dispersion and from this infer a shear wave velocity profile. Active methods are widely used, with energy sources ranging from hammers to bulldozers. Figure 6-1 shows SASW measurements using a sledgehammer source. It is fairly easy to reach 30 m depth with SASW, but is more difficult to image deeper and very difficult to image below 100 m depth. Spectral Analysis of Surface Wave services are available commercially and through several universities; an Internet search on "spectral analysis of surface waves" will produce a list of sources.

Seismic refraction is a traditional geophysical method using surface measurements of wave travel time to determine the seismic wave velocity structure of the subsurface geology. Inverse analysis of travel times provides an estimate of the seismic wave velocities of soil and rock layers and can be a cost-effective way to determine general soil/rock layer properties, bedrock depth, and water table depth over a wide area. Seismic refraction services are available commercially, and many universities have these capabilities. It should be noted that while P-wave refraction is fairly simple, S-wave refraction requires some experience and can produce incorrect results if the site geology is complex or layering is not flat.

6.2.2. Measurement Using Seismic CPT

The methods described above have all been noninvasive surface techniques. Initial geological studies of a SMRS site can also include using the invasive technique of the seismic cone penetrometer. This method can inexpensively provide direct measurement of shear wave velocities and V30. A cone penetrometer (CPT, a metal probe pushed into the soil) can be used to obtain information about shallow (< 30 m) soils. Cone penetrometer services are available commercially as well as through several

Fig. 6-1: Spectral Analysis of Surface Wave measurements using a hammer source

universities. If a *seismic cone* tool is used, shear wave velocity can be directly measured using a method equivalent to the downhole method [Ishihara, 1996].

While the seismic cone does provide accurate measurement of the shallow shear wave velocity profile, it may be limited in depth of penetration at rock, stiff soil, or gravely sites. It may not be possible to reach 30 m depth and, therefore, not possible to accurately measure V30. If this is the case, V30 measurement using drilling and logging, described in the next section, will be required.

6.2.3 Measurements Using Drilling and Logging

V30 can be measured at all sites using a combination of drilling and shear-wave velocity logging. Ishihara [1996] provides a thorough discussion of available methods for these shallow geotechnical investigations.

Drilling can be done using the auger method (which is less expensive) if the soils are relatively soft. In many cases, however, the rotary method (mud or air) will be needed to reach 30 m depth. If desired, drive-type (SPT) sampling can be done to obtain disturbed samples for determination the site's lithology.

Once a borehole has been drilled, the shear-wave velocity can be measured using one of the following methods:

- Crosshole
- Downhole
- Suspension

These methods are detailed in Ishihara [1996]. In most cases, the suspension method can be done in an open, uncased borehole, thus saving the cost of installing casing. The downhole method usually requires casing of a single hole. Although the crosshole method requires two or three adjacent, cased boreholes and, therefore, is most expensive, it is standardized (ASTM 4428) and widely accepted.

6.3 DETAILED SUBSURFACE INVESTIGATIONS

Obtaining the most complete site characterization of a strong-motion station will require drilling of an exploratory borehole, obtaining high-quality geotechnical samples for laboratory testing, and borehole geophysical logging. Such investigations have been performed for many strong-motion stations, recently through the ROSRINE project (see http://geoinfo.usc.edu/rosrine).

A detailed site investigation can consist of:

- Drilling a borehole to the depth of "engineering rock" (Vs>750m/s);
- Lithology logging during drilling;
- Obtaining samples for laboratory testing;
- Seismic velocity logging;

Fig. 6-2: Detailed site characteration operations (ROSRINE-Newhall)

- Laboratory testing of samples for index properties; and
- Laboratory testing of samples for nonlinear properties.

These investigations can involve a major effort, requiring heavy equipment and expensive measurements and laboratory testing. Figure 6-2 shows drilling operations at the Newhall strong-motion station as part of the ROSRINE study. Figure 6-3 shows the detailed velocity profile obtained from this study. Further technical information regarding these site investigation components can be found in Ishihara [1996] and in EPRI [1993].

6.4 COSTS FOR SITE CHATERIZATIONS

Approximate commercial costs for the four levels of site characterization are provided in Table 6-1 below. These are budgetary numbers only, based largely upon recent experience in the ROSRINE project. Of course, costs will vary according to site location, site conditions, depth of investigation, economy of scale, and other parameters.

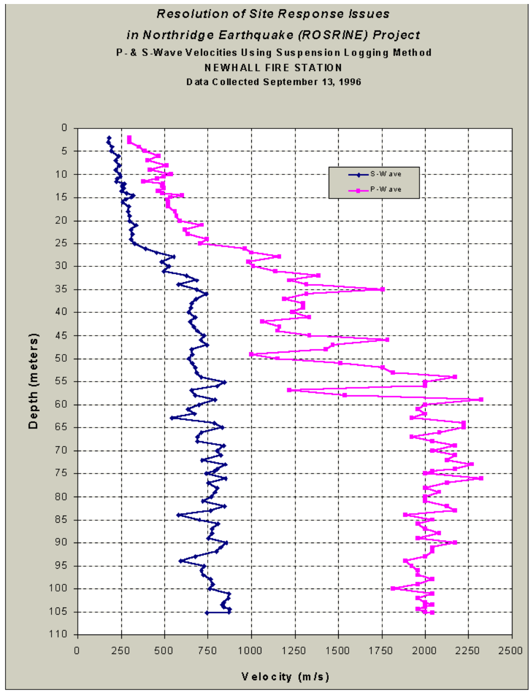

Fig. 6-3: Velocity profile of a strong-motion site

Table 6-1: Estimated costs for site characterization

Investigation	Details	Approximate Commercial Cost, $k (one site)
Literature search	Est. 1 person-day per site	1
Simple V30 estimation	SASW or refraction, to 30m depth	2-4
Simple V30 measurement	CPT with seismic cone, to 30m	2-4
V30 and Vs profile measurement and lithology determination	Drilling to 30m, obtain lithology via disturbed sampling (SPT), S-wave logging using suspension, crosshole, or downhole method	3-10
Detailed subsurface investigation	Drilling & logging to 100m, no sample testing, lithology & PS log only	8-16
Detailed subsurface investigation	Drilling & logging to 100m, sampling & lab testing, lithology & PS logging	15-30

7. Station Documentation

A new or existing ANSS strong-motion reference station should be well documented. A user of the recorded waveform data or derived parametric information should be able to obtain all of the information needed to identify the station, its instrumentation, its station configuration/construction, its site conditions, and any other information which might have an effect on the data.

The following sections detail the Basic Station Data and the Auxiliary Station Information. Appendix B contains sample forms for documenting station data and information during station installation.

7.1 BASIC STATION DATA

The basic documentation of a strong-motion reference station should include the following, defined as the Basic Station Data:

- Station identification (name, ID number, etc.);
- Station location (coordinates, location description within site; detailed information may need to be protected in the property owner's interests);
- Station access information (contacts, keys, etc.; may be protected information);
- Station construction (type, description);
- Site geology;
- NEHRP/IBC category/V30 value;
- Station instrumentation details;
- Station calibration data; and
- Station history (installation date, modification descriptions/dates, etc.).

It is recommended that these data be available in two forms: an online database and a paper archive publication.

7.2 AUXILIARY STATION INFORMATION

Other information about a strong-motion station that should be included in the station's documentation include:

- Photographs of the station construction;
- Photographs of the station instrumentation installation;

- Photographs of the station vicinity (showing nearby buildings, topography, or other features);
- Site map;
- Plots/numeric data for site characterization information; and
- Other descriptive information about the site.

As for the Basic Station Data, it is recommended that the Auxiliary Station Information be available in two forms: an online database and a paper archive publication.

8. References

Agbabian Associates (1980). Site Dependent Response at El Centro, California Accelerograph Station Including Soil/Structure Interaction Effects, *NISEE 262.6/S51/1980*.

American Society for Testing and Materials, *Guide to Site Characterization for Engineering, Design, and Construction Purposes*, ASTM D420-98, http://www.astm.org.

American Society for Testing and Materials, *Standard Guide for Selecting Surface Geophysical Methods*, ASTM D6429-99, http://www.astm.org.

Consortium of Strong Motion Observation Systems (COSMOS), http://www.cosmos-eq.org.

Crouse, C.B., G. Liang, and G. Martin (1984). "Experimental study of soil-structure interaction at an accelerograph station," *BSSA*, 74(5).

Crouse, C.B. and B. Hushmand (1989). "Soil-structure interaction at CDMG and USGS accelerograph stations," *BSSA*, 79(1).

Electric Power Research Institute (1993). *Guidelines for Determining Design Basis Ground Motions*, Report Rp3302, Palo Alto, Calif.

Ishihara, K. (1996). Soil Behaviour in Earthquake Geotechnics (Oxford Engineering Science Series, No 46), Clarendon Press.

Nigbor, R. et al. *Resolution of Site Response Issues in the Northridge Earthquake (ROSRINE)*, http://geoinfo.usc.edu/rosrine.

Stewart, J. (2000). "Variations between foundation-level and free-field earthquake ground motions," *Earthq. Spectra*, 16(2).

Tajima, H. (1984). "Predicted and measured vibrational characteristics of a large-scale shaking table foundation," *Proc.*, 8th World Conf. Earthq. Engrg., Vol. 3.

Appendix A

COSMOS URBAN STRONG-MOTION REFERENCE STATION GUIDELINES: GOALS, CRITERIA AND SPECIFICATIONS FOR URBAN STRONG-MOTION REFERENCE STATIONS

1. GOALS

The goals of urban strong-motion reference stations are to provide:

1.1 Reliable information for accurate, effective characterization of the shaking by ShakeMap and other rapid post-earthquake tools;

1.2 Recorded motion for post-earthquake performance analysis of structures;

1.3 Empirical basis for long-term improvements in the seismic provisions of building codes and construction guidelines; and

1.4 Seismological data and complementing data from non-urban stations to improve the understanding of earthquake generation and seismic wave propagation in areas with inadequate measurements.

2. CRITERIA

As a general optimization strategy, one or a combination of the following measures should be used to optimize the locations of instruments:

2.1 Probability of Shaking: highest likelihood of shaking (percentage in N years), split into two groupings:

2.1.1 *Probability of Short-Period Shaking:* addressing the many short-period structures that occur widely across the country.

2.1.2 *Probability of Long-Period Shaking:* addressing the long-period hazard to tall high-rise buildings that occur in major cities at specific locations in the country.

2.2 Probability of Property Damage: Areas without the highest probability to shaking, but elevated probability of damage because of serious consequences if an event were to occur.

2.3 Probability of Life and Indirect Loss: Areas with elevated probability of loss, even though they are not areas of highest shaking or dam+age probability because of their increased likelihood for casualties, death, or human suffering because of fragility of the infrastructure or wide-spread impact of failure (utilities, transportation, etc.).

2.4 Probability of Learning: Areas of major uncertainty in knowledge about earthquake generation or seismic wave propagation and the attenuation of peak ground motion and spectral levels in order to improve the understanding of the hazard in those areas.

2.5 Value in Emergency Response: Location and areas of strategic, optimal value for providing effective, rapid shaking information for emergency response. In general, the probabilistic maps should serve as a basis for planning, augmented by HAZUS maps of damage and loss that incorporate shaking probabilities, the infrastructure and structure inventory and its fragility, and the impacts of loss of function.

3. INSTRUMENT SPECIFICATIONS

3.1 Overall recording range: Accelerograph system (sensor plus recorder) shall be able to record an acceleration range of +/-2g Full Scale and meet industry-accepted accelerograph specifications.

3.2 Recorder dynamic range: New instrumentation shall have 18-bit or greater resolution (114 dB), and fixed gain (no gain ranging) so that the recorder's resolution (LSB) is 0.015 mg (2g/2 17).

3.3 Noise floor: The noise level of the accelerometer plus recorder system shall be less than 0.02 mg rms in the frequency range of 0-40 Hz.

3.4 Communication: The instrument shall either have reliable, continuous telemetry, or automated dial-out communication that use phone lines upon triggering. A certain number of stations will require real time communication in order to provide the most rapid preliminary ShakeMap. Regardless of communication mode, the instrument shall provide on-site recording for two hours or more of strong-motion recording. The instrument shall also communicate, via real time or dial-out communication, when it encounters state-of-health problems (e.g., low battery, loss of AC, intrusion, etc.).

3.5 Timing accuracy: Within 1/10th of a sampling interval of absolute time (UTC).

3.6 Sample rate: 200 samples per second (5 ms sampling interval). Adequate anti-alias filtering shall be included (filter corner at 80% of the Nyquist frequency, and down by 100 dB at the Nyquist).

3.7 Triggering: Nominal trigger level of 1-5 mg (0.1 - 0.5%g) acceleration, within a pass band of 0.1 to 12 Hz; actual trigger level to be established by noise levels at the site. (A successful trigger level will cause occasional, but not frequent, triggering, thus providing ongoing knowledge of instrument performance between significant recordings).Once triggered, the recorder shall stay triggered for at least 30 secs after the last occurrence of acceleration over 5 mg. Recorders at sites likely to experience significant basin effects or other long-duration motion effects should stay triggered for at least 60 secs after the last 5 mg acceleration.

3.8 Pre-event memory: Recorder shall include pre-event memory of 30 secs or greater and must record, on-site, 2 hours or more of ground motion data.

3.9 Data Format: Recorder may produce event files in a format native to the instrument or manufacturer. However, the manufacturer shall provide conversion utilities to convert the native files to COSMOS and SEED formats. The native files shall include a cyclic redundancy check or other method to verify recorded file integrity.

3.10 Calibration: Instrument shall accommodate and read bi-directional tilt tests to allow calibration of the sensitivity constants of the sensors.

3.11 Pre-Procurement and Post-Deliver Acceptance Testing: Prior to purchase, candidate instruments must be tested to verify that they meet specifications. After purchase, all instruments must be tested, and non-performing instruments repaired by the manufacturer.

3.12 Data Dissemination: Data should be disseminated via a central site with convenient access to the user community.

3.13 Maintenance Program: Adequate maintenance program is essential to the success of an advance seismic system.

4. SITING SPECIFICATIONS

In general, urban strong-motion reference stations should be located in small housings, on grade, and not at subsurface locations or in large buildings, so that the motion recorded corresponds to that on the ground in the surrounding area.

4.1 Location Strategy: Urban strong-motion reference stations should be located to record representative ground motion in the vicinity of significant business districts or groups of structures where possible. Locations should be chosen with site geology representative of the area and preferably within 1 km of a significant business district or structure grouping. Additional stations may be required in areas with unique geologies or expected to experience altered shaking due to other factors (e.g., topography, distance to fault, soil-structure interaction).

4.2 Station Housing: Small building, without significant basement; one to two story light structure, wood frame preferable but reinforced masonry acceptable; building generally less than ~4000 ft^2 in plan.

4.3 Station Housing Foundation: Concrete pad (6 in. or less), on grade, without piles or piers. If a special, light instrument hut is used, the pad should be approximately 4 ft^2, with 6 in. x 18 in. piers to ensure effective coupling, especially in soft soils.

4.4 Nearby Structures: Stations should be sited away from structures likely to cause significant soil-structure interaction effects that may be recorded in the data. A distance of at least one major structure dimension away from all large/massive structures in the vicinity should be maintained where possible.

4.5 Site Conditions: Stations should be sited to avoid highly localized characteristics of the geology or nearby topography unless special documentation is performed.

4.6 Site Geology Documentation: Site geology at stations should be characterized through on-site geologic inspection or special investigations.

5. INSTALLATION SPECIFICATIONS

5.1 Orientation of Recorder: Instrument to be oriented with connector, or other fundamental element, oriented in a cardinal direction, preferably true North. Orientation to be well documented (photographically) and controlled by an effective process making very unlikely, or impossible, mistaken component orientations after an important earthquake. Triaxial acceleration sensors to be fastened securely with fixed, accurate orientation relative to the sensor housing enclosure. Sensors to be no more than 3 degrees out of othogonality

5.2 Orientation of Sensors: Sensors: if not mounted within the recorder, should be mounted orthogonally, within 2 degrees, and oriented with the housing connector of other reference element oriented in a cardinal direction, preferably true North, with orientation well documented and controlled, as for the recorder.

5.3 Station Location Accuracy: Accuracy of one ten-thousandth of a degree in latitude and longitude, with documentation (WGS884 standard) is recommended.

5.4 Anchoring of sensors, recorder and auxiliary components to pad: all elements to be bolted securely, with concrete anchors that remain tight over time.

5.5 Autonomy: Station shall include adequate backup batteries to operate for four days without power in case of loss of AC power. The power connection shall be hardwired or otherwise securely connected to the power source.

COSMOS Strong-Motion Program Board

Anthony Shakal, Chair
Norman Abrahamson
Ralph J. Archuleta
Robert F. Ballard
Bruce A. Bolt (ex-officio)
Roger D. Borcherdt
Gregory L. Fenves
Klaus H. Jacob
Andy Viksne

Adopted after revision at the meeting of the COSMOS Strong-Motion Program Board on 19 January 2000. Participants include N. Abrahamson, J. Anderson, R. Archuleta, B. Bolt, R. Borcherdt, C. Stepp, and A. Shakal (Chair), with additional input by M. Huang, W. Joyner, C. Kircher, and W.H.K. Lee. Earlier versions adopted by the TriNet Technical Advisory Committee (C. Poland, Chair), the TriNet Steering Committee (J. Davis, Chair), and the California Strong Motion Instrumentation Advisory Committee (B. Bolt, Chair).

Appendix B

SAMPLE STRONG-MOTION STATION INFORMATION FORMS

Strong-Motion Accelerograph Station
Basic Station Data

Station Number:	
Dial-up Phone Number	
Site Address:	
Site Contact:	
Business Hours:	
Directions:	
Latitude-Longitude-Elevation:	
Parking:	
Check-in with:	
Structure:	
Instrument Location:	
Keys Needed:	
Instrument History:	
Inspection Dates:	

-

Commissioning for
Strong-Motion Reference Station

Station Name:	
Location:	
Accelerograph S/N:	

Date:	
Performed By:	
Title:	

PURPOSE OF PROCEDURE

The purpose of this procedure is to insure proper installation of the system, including sensor mounting, interconnection, power supply, and setting of parameters.

PERFORMANCE PRACTICE AND LIMITATION

Any situation that is not covered in the body of this procedure will be explained under "Comments." Unless otherwise noted, limits will be based upon in-house acceptance test. If an item is found to be outside those limits and cannot be adjusted sufficiently to satisfy this procedure, the Field Engineer will recommend an appropriate course of action, but it will be the responsibility of the Supervisor to indicate the action to be followed.

Station Commissioning Checklist

ACTION	PERFORMED	COMMENTS
Upgrade station data		
Upgrade recorder info		
Upgrade sensor info		
Upgrade firmware		
Take general view picture		
Take instrument picture		
Take instrument location picture		
Take sensor picture(s)		
If the station is an upgrade then: Retrieve Events		
Copy events on two different media		
Run FT 'As Found"		
Install new instrument		
Run FT "As Left"		
Secure instrument		
Back-up data		

Station Commissioning Data

SYSTEM SPECIFIC INFORMATION				
Modem Connection (type and model)				
Modem Telephone No.				
GPS Timing System				
UPS / Internal Battery / External Battery / AC / Solar				
Other Auxiliary Rackmount Equipment				
Comments				
SYSTEM COMMISSIONING DATA				
Location	**S/N:**			
	Room			
	Floor			
Check all cables for continuity				
Using a compass note the +Long position				
Measure the battery voltage (no load) (13+/-1.0Vdc)				
Measure the battery voltage (with load) (13 +/-1.0Vdc)				
Measure the charge current				
Does unit have an external battery (Yes / No)				
Confirm that battery terminals are tight and clean				
Turn the unit ON and set the baud-rate				
Read the offset of the accelerometers	**L=**		**V=**	**T=**
Confirm the proper setting for the parameters				
Erase memory				
Run a functional test and retrieve the file	**Filename**			
Clear event and alarm LED				
Make sure the instrument is in acquisition mode				
If the unit has a modem set the baudrate to 19200				
If the unit has a modem disable auto-baudrate				
Check the external cables for proper connection				