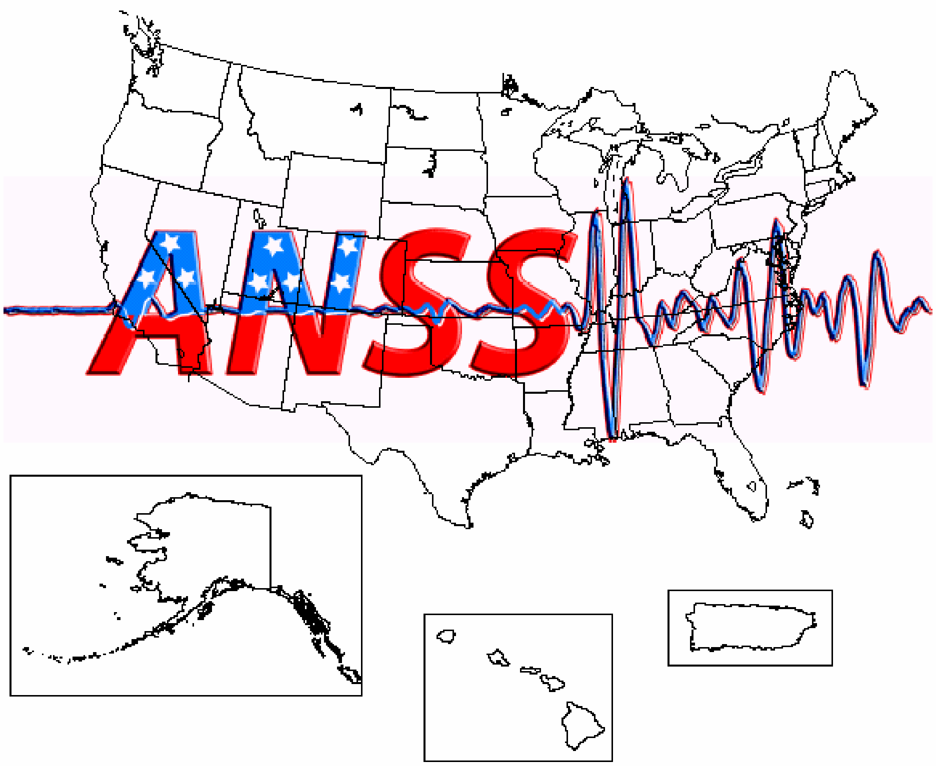
GUIDELINE FOR ANSS SEISMIC MONITORING OF ENGINEERED CIVIL SYSTEMS

Prepared by the ANSS Structural Instrumentation Guideline Committee

Open-File Report 05-xx



U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Guideline for ANSS Seismic Monitoring of Engineered Civil Systems

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[1]Members listed in Appendix A

EXECUTIVE SUMMARY

U.S. Geological Survey Circular 1188 *Requirement for an Advanced National Seismic System* (ANSS), published in 1998, states that "another 3000 strong-motion instruments should be installed in buildings and structures to resolve outstanding issues in engineering design practice " and that "…approximately 1/3 ($56m) of the $171m ANSS capital cost should go toward structural monitoring."

The ANSS Guideline for monitoring the earthquake response of civil engineered systems was developed by a team of practicing and academic geotechnical and structural engineers over a five month period in 2004. Formed by the ANSS National Steering Committee, the Structural Instrumentation Guideline Committee was composed of two geotechnical engineers and ten structural engineers. The purpose of the Guideline is to provide ANSS management with specific technical requirements for earthquake response monitoring of civil engineered systems (buildings, geosystems, and infrastructure) and a process for selecting candidate systems for future instrumentation and monitoring. The scope of response monitoring was expanded beyond building structures by the ANSS National Steering Committee to include geosystems and infrastructure.

The mission of response monitoring within the ANSS program is to provide data and information products that will (1) contribute to earthquake safety through improved understanding and predictive modeling of the earthquake response of engineered civil systems and (2) aid in post-earthquake response and recovery. The targeted end-users of ANSS response data and products are structural and geotechnical design professionals and academicians and emergency planners and responders. This Guideline was written to ensure that the ANSS response monitoring program provides raw data and metadata in near real-time following an earthquake and processed data in a timely manner after the earthquake to the targeted end-users.

The Guideline identifies instrumentation needs for buildings, geosystems, and infrastructure, based on a review of previously published documents and surveys of the design professional community. Technical requirements for monitoring-system hardware and information technology are presented in the Guideline. Specific requirements for data, metadata, and information related to structural response monitoring are identified. The development of relevant and useful metadata is needed to speed the transfer of results of post-earthquake analysis of engineered-system response into design practice and the research community. An open-data policy ensures that the targeted end-users of the data can benefit in near real-time following an earthquake.

The formal national-level selection process ensures that the ANSS funds for response monitoring are spent in a cost-effective manner and that the ANSS products are of the highest value to the targeted end-users. A two-step proposal process is described.

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 ADVANCED NATIONAL SEISMIC SYSTEM

The Advanced National Seismic System (ANSS) is a major national initiative led by the U.S. Geological Survey (USGS) that serves the needs of the earthquake monitoring, engineering, and research communities as well as national, state, and local governments, emergency response organizations, and the general public. Congressional legislation authorizing the ANSS was passed in 2000, and funding for new seismic instrumentation and infrastructure development has been appropriated beginning in FY2000. When fully operational, ANSS will be an advanced monitoring system distributed across the United States that operates with high performance standards, gathers critical technical data, and effectively provides timely and reliable earthquake products, information, and services to meet the Nation's needs. The ANSS will automatically disseminate timely and authoritative products describing the occurrence of earthquakes, earthquake source properties, the distribution of ground shaking, and the response of buildings and other engineered civil systems. Most importantly, the ANSS will provide earthquake data, derived products, and information to the public, emergency responders, officials, engineers, educators, researchers, and other ANSS partners rapidly and in forms that are useful for their needs.

In the guiding document An Assessment of Seismic Monitoring in the United States: Requirements for an Advanced National Seismic System (USGS 1998, p 20), four fundamental goals of ANSS are specified as follows:

1. *Establish and maintain an advanced infrastructure for seismic monitoring throughout the United States that operates with high performance standards, gathers critical technical data, and effectively provides information products and services to meet the Nation's needs. An Advanced National Seismic System should consist of modern seismographs, communication networks, data processing centers, and well-trained personnel; such an integrated system would constantly*

record and analyze seismic data and provide timely and reliable information on earthquakes and other seismic disturbances.

2. *Continuously monitor earthquakes and other seismic disturbances throughout the United States, including earthquakes that may cause a tsunami or precede a volcanic eruption, with special focus on regions of moderate to high hazard and risk.*

3. *Thoroughly measure strong earthquake shaking at ground sites and in buildings and critical structures. Focus should be in urban areas and near major active fault zones to gather greatly needed data and information for reducing earthquake impacts on buildings and structures.*

4. *Automatically broadcast information when a significant earthquake occurs, for immediate assessment of its impact. Where feasible, for sites at distance from the epicenter, broadcast an early warning seconds before strong shaking arrives. Provide similar capabilities for automated warning and alert for tsunamis and volcanic eruptions, equipment modernization, new monitoring concepts, and rapid dissemination of information.*

The third goal addresses the need to monitor earthquake shaking in buildings and critical structures. The 1998 USGS document further details the requirements for structural monitoring as follows:

> *Another 3,000 strong-motion instruments should be installed in buildings and structures to resolve outstanding issues in engineering design practice. The strong-motion instruments described here are intended to provide data on critical structures, facilities, and buildings for emergency response applications and for engineering research and applications.*

The ANSS requirement to obtain data from buildings, geosystems and infrastructure (referred to herein as "Engineered Civil Systems") is the focus of this document. This is a major component of ANSS, with approximately 1/3 ($56m) of the total proposed capital budget of $171m allocated to structural response monitoring equipment.

1.2 VOCABULARY

For the purposes of this document the following meanings for commonly used terms are followed. Some of these terms have a different emphasis or specific meaning than some current uses.

ANSS user - Anyone interested in acquiring ANSS waveforms, products, or information (also referred to as end-users or customers)

ANSS System Response Monitoring Coordinator – The ANSS staff member given overall responsibility for the ANSS Structural Monitoring Program.

ANSS National Steering Committee – A volunteer committee charged with setting priorities and goals for ANSS and with oversight of operations.

ANSS Regional Advisory Committee - A volunteer committee charged with assisting one of the seven ANSS regions with setting priorities and goals.

ANSS System Response Monitoring Advisory Committee – The SRMAC is a volunteer committee recommended herein that will set priorities and goals for the ANSS structural monitoring program.

building – A walled and roofed structure intended to permanently shelter people , goods and/or facilities

data - Any or all of waveforms and metadata.

geosystem – A geotechnically engineered structure such as a landfill, dam, etc.

FEMA – The Federal Emergency Management Agency of the Department of Homeland Security.

Infrastructure – Permanent installations supporting human activities, principally utilities and transportation systems and related facilities (e.g. roads, bridges, pipelines).

metadata - Information needed to process or interpret input and response waveform data (including instrument location, instrument calibration, site geology, site velocity structure, construction drawings, design and construction data, mathematical models, and earthquake damage data).

NEES – NSF's Network for Earthquake Engineering Simulation

NSF – National Science Foundation.

payload project - A portion of a response monitoring project with primary goal(s) other than those identified in this Guideline.

products - Routinely produced earthquake parameters or other results of automatic and manual processing (hypocenters, peak accelerations, responses, shake maps, etc.).

response – Dynamic motion of a system or component thereof due to ground shaking input.

waveforms – Raw, unprocessed, but possibly reformatted ground motion or response time series.

1.3 RESPONSE MONITORING OF STRUCTURES AND GEOSYSTEMS

In the United States, seismic response monitoring is carried out by many government agencies and private organizations. Applications range from the collection of data for research, design issues, and building code development to safety-related monitoring of dams, bridges, nuclear power plants, and private buildings. Celebi (2004) summarizes the history and current status of structural response monitoring with a focus on the two largest programs, the California Strong Motion Instrumentation Program (CSMIP) and the U.S. Geological Survey's National Strong Motion Program (NSMP). CSMIP monitors close to 200 structures, while NSMP monitors 51 buildings, 13 bridges, and 48 infrastructure facilities.

CSMIP developed and is using formal priorities and criteria for the selection of buildings and the configuration of instrumentation systems within those buildings. These criteria are presented in CSMIP (1985).There is a predefined matrix of building types and configurations, with the general goal of covering a wide range of structural systems representative of the California building inventory. Huang and Shakal (2001) updated the CSMIP structural response monitoring criteria and priorities in 2001. NSMP structural response monitoring has in the past focused on building code-related applications in addition to managing structural response monitoring for partner agencies and organizations, but recent applications include more extensive building arrays and real-time applications for emergency response and structural health monitoring purposes (Celebi 2004).

General technical guidance for ANSS system response monitoring is provided in the Technical Guidelines for ANSS (USGS 2002). Section 3.5.4 of that document provides basic instrumentation specifications for “Strong Motion Stations (Structural)”, and Section 4.5.6 provides a list of data products, siting criteria, and recommended station design for “Structural Monitoring Stations.” While this guidance is useful, it has an overall emphasis on ground motion monitoring and lacks needed detail for specifying and designing structural monitoring installations.

COSMOS organized a November 2001 “Invited Workshop on Strong-Motion Monitoring of Buildings” (Stepp and Nigbor, ed 2001). This workshop was funded by both NSF and USGS. Funding by the USGS was specifically targeted toward the development of recommendations useful to ANSS. The proceedings of this workshop contain papers on 1) current building instrumentation programs and guidelines, 2) future needs and priorities for building instrumentation, and 3) instrumentation technologies. Working groups discussed various aspects of strategies for building selection. Specific recommendations are provided in the following areas:

- Building types and measurement priorities
- National priorities
- Regional priorities
- Use of new technologies

- Encouraging private participation

Since the 2001 COSMOS workshop and the publication of the 2002 ANSS Technical Guidelines there have been and continue to be important changes in technology, especially in the area of structural health monitoring, which should be considered by ANSS. Celebi (2004) describes several of these new technologies as applied to seismic structural response monitoring. There are also important developments in earthquake engineering research, and new areas for ANSS coordination and collaboration including the National Science Foundation's Network for Earthquake Engineering Simulation (NEES: www.nees.org) and the Federal Emergency Management Agency's (FEMA) program on Performance Based Earthquake Engineering, that were considered in the development of this document.

The number of instrumented engineered systems is quite small compared to the at-risk inventory in the United States. The proceedings of a 1998 NSF-sponsored workshop "Vision 2005: An Action Plan for Strong Motion Programs to Mitigate Earthquake Losses in Urbanized Areas" (Stepp 1998) review the then-current state of structural response monitoring and conclude that approximately 10,000 additional instruments should be deployed in structures to assist in a significant earthquake loss reduction effort. USGS Circular 1188 includes a 3000-instrument subset of these recommended structural response instruments in the plan for ANSS. To date three buildings have been instrumented by USGS under the ANSS program. Figure 1 presents a schematic of one of these, the Atwood Building in Anchorage, Alaska. This building has been instrumented to measure structural response; a vertical ground motion array in close proximity to the site provides site response data, allowing analysis of seismic response of the entire soil-structure system.

Measurement of the response of buildings, geosystems and infrastructure to earthquake ground shaking has, for decades, been an important component of earthquake engineering study and research in many parts of the world. Design codes and earthquake-resistant design methods are based in part upon such quantitative measurements. Greater and more immediate impact on codes, design practice and methods of construction would have been realized if a larger number of sensors had been available for deployment in a greater number of engineered civil systems. The ANSS response monitoring program provides a unique and high-value opportunity to achieve such an impact and to improve the resilience of our Nation's engineered civil systems against catastrophic loss from earthquake shaking through careful deployment of dense arrays of instruments in engineered civil systems.

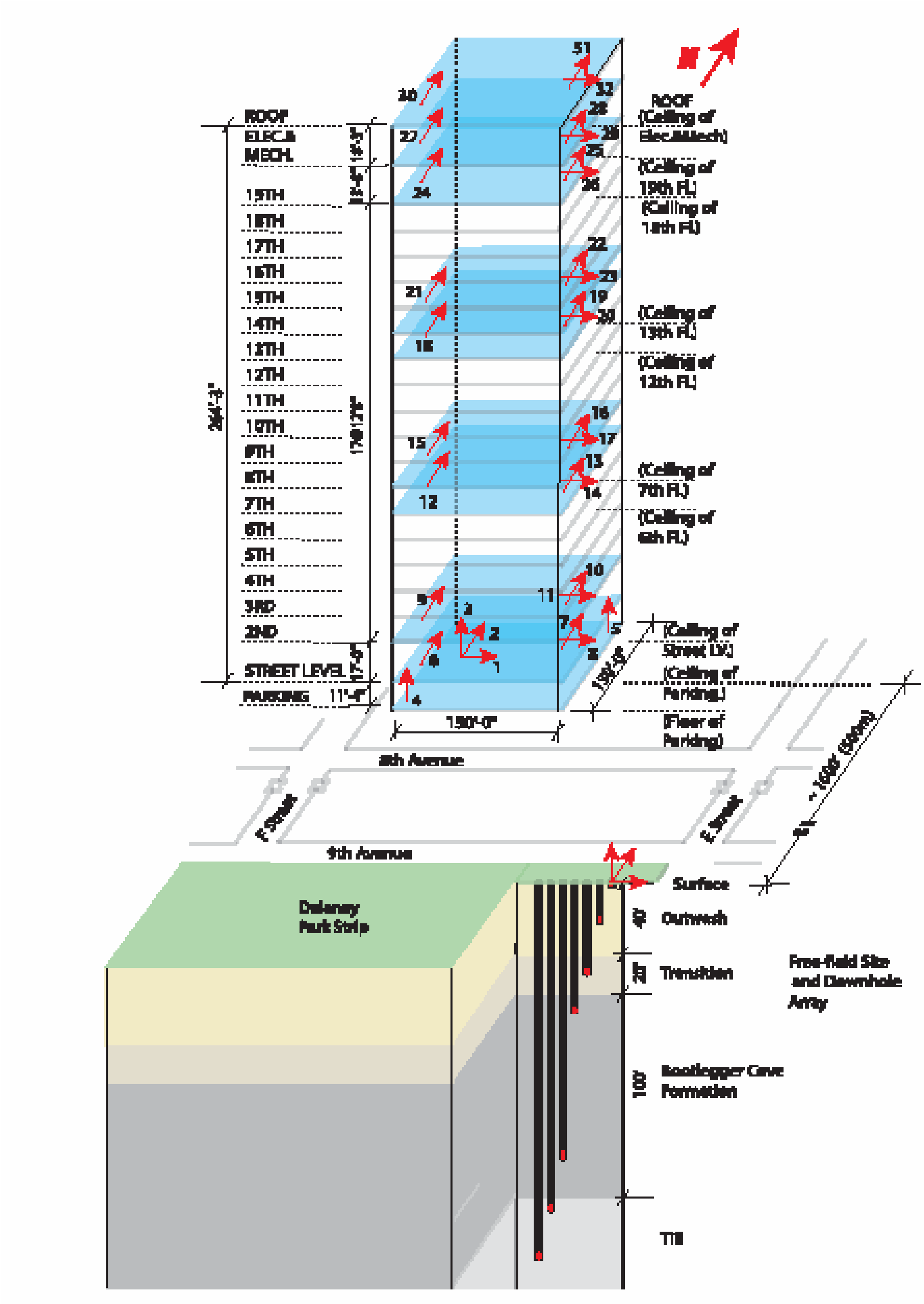

Figure 1: ANSS Structural Response Monitoring Plan for the Atwood Building in Anchorage

1.4 MISSION FOR ANSS RESPONSE MONITORING OF ENGINEERED CIVIL SYSTEMS

From U.S. Geological Survey Circular 1188 (USGS, 1998) the mission of ANSS is as follows:

> ***The mission of the Advanced National Seismic System is to provide accurate and timely data and information on seismic events and their effects on buildings and structures, employing modern monitoring methods and technologies.***

Response monitoring within ANSS will directly address the "effects on buildings and structures" portion of the ANSS mission and facilitate, in the longer term, the near real-time collection of response and damage data to aid in post-earthquake emergency response and recovery. Importantly, ANSS response monitoring will provide data critical to improvement of seismic-resistant design and assessment of engineered civil systems and will support the on-going development of tools and guidelines for performance-based seismic design: important work being funded at the time of this writing by two other NEHRP agencies: the National Science Foundation (NSF) and the Federal Emergency Management Agency (FEMA). Further, data collected from ANSS instruments on the response of full-scale engineered civil systems will complement those collected from tests of *models* of components and elements of such systems conducted by previous research studies and under the NSF NEESR program. ANSS has the full support of the broad earthquake engineering community (EERI 2003) and is considered key to a successful and robust national earthquake engineering research program in the next two decades.

Predictive modeling is at the core of modern earthquake engineering. It is central to everything earthquake engineers do, from post-earthquake investigations to assessment and design of new and retrofit construction. It is also the cornerstone of performance-based design, which is the new paradigm for earthquake engineering research and practice. System response data are needed to improve, calibrate and validate predictive modeling and therefore to improve the earthquake-resistant design of engineered civil systems.

To serve these purposes, the mission for ANSS Response Monitoring is:

The mission of response monitoring within ANSS is to provide data and information products that will (1) contribute to earthquake safety through improved understanding and predictive modeling of the earthquake response of engineered civil systems and (2) aid in post-earthquake response and recovery.

1.5 GUIDELINE DEVELOPMENT

The charge to the ANSS Structural Instrumentation Guideline Committee was to prepare an ANSS guideline for the USGS that will (a) identify and prioritize the needs of the structural and geotechnical engineering community that can be addressed by earthquake-related data collected from ANSS-monitored engineered civil systems, (b) provide procedures to identify and prioritize candidate engineered systems for ANSS monitoring projects, and (c) provide recommendations on procedures and practices for instrument installation and operation, data access and distribution, and data utilization.

The Committee was organized in April and May, 2004 at the direction of the National Steering Committee and the ANSS Coordinator within USGS. Appendix A contains the names of the Committee members. Andrew Whittaker of the University at Buffalo chaired the Committee and Robert Nigbor served as a member of the Committee and helped draft and edit this document under contract to USGS. The committee was composed of eleven practicing and academic structural and geotechnical engineers.

The Committee met in person on June 7, 2004, in Menlo Park, and via teleconference on July 8, 2004 and October 11, 2004.

A final draft of the document was delivered to the ANSS National Steering Committee on October 31, 2004. This draft was circulated for review and comment within the ANSS and earthquake engineering communities. After review and revision, Version 1.0 was finalized and disseminated on February 1, 2005.

As ANSS evolves, along with the users it serves, so too should this document. The Structural Instrumentation Guideline Committee recommends the formal review and revision of this guideline every three years to ensure that improvements in instrumentation and information technology and changes in the needs of the design professional community are incorporated into the document.

1.6 GUIDELINE ORGANIZATION

Chapter 2 presents the Committee's consensus regarding engineering needs for buildings, geosystems and infrastructure. Chapter 2 then discusses national priorities and recommendations for management of these priorities by ANSS. Chapter 3 covers technical requirements, including monitoring approach, system issues, hardware issues, and information technology issues. Chapter 4 presents consensus requirements for data and metadata. Chapter 5 includes a recommended selection process for engineered civil systems to be monitored and administered by ANSS.

Appendix A lists the authors of this document and their affiliations. A list of cited references is presented in Appendix B. The interim ANSS data policy is reproduced in Appendix C. Appendices D, E, and F contain selection criteria for buildings, geosystems and infrastructure, respectively. Appendix G provides technical specifications for ANSS response monitoring instrumentation.

2 PRIORITIES FOR MONITORING CIVIL SYSTEMS

The two goals for ANSS response monitoring are stated in Section 1.4, namely, 1) provide response data to improve understanding and predictive modeling of engineered civil systems, and 2) provide data to aid in post-earthquake damage assessment and recovery. At this time, the primary focus for ANSS response monitoring should be to provide data for improved understanding and development of predictive modeling tools. Once the improved understanding and predictive tools are available, they can be applied to damage assessment and other immediate post-earthquake activities.

With this overall prioritization in mind, this chapter describes needs, recommendations for national priorities, opportunities for regional participation and collaboration with other organizations, and recommendations for management of priorities within ANSS.

2.1 NATIONAL RESPONSE MONITORING NEEDS

Within the context of this Guideline, the broad category of “Engineered Civil Systems” includes all constructed structures and systems at risk from earthquake shaking. Buildings, dams, and bridges are obvious major components of this category. Nonstructural systems, tanks, landfills, and pipelines are equally important components for earthquake loss reduction. It is intended that this Guideline, and the ANSS Structural Response Monitoring program, consider all engineered civil systems that contribute to societal seismic risk.

Within this context, the key need for all engineered civil systems is the collection of both input and response data that will improve our ability to predict response, damage, and loss. Data collected from sparse arrays of instruments are unlikely to lead to fundamental advances in predictive modeling and damage assessment. As such, the use of dense arrays of instruments, deployed to provide maximum benefit to predictive modelers and damage assessors, is needed. Such data and information, if carefully analyzed and studied, will lead to improved design practice and building codes, facilitate the development of robust tools for performance-based seismic design, and lead to reduced losses in future earthquakes.

ANSS should consider all types of engineered civil systems as potential candidates for monitoring. However, given the limited annual budget for monitoring engineered civil systems, instruments should be deployed to best meet national engineering needs in civil systems that are located in sites most likely to be subjected to moderate-to-severe earthquake shaking[1]. The Committee deliberated this optimization issue and developed a list of needs and an associated scoring system for each of the following three subcategories of engineered civil systems: 1) Buildings; 2) Geosystems; and 3) Infrastructure Systems. The needs, scoring categories, and weightings are based upon the Committee's collective earthquake-engineering experience and were developed by the Committee for the selection process detailed in Chapter 5 of this Guideline. The ANSS National Steering Committee considers buildings to be the most important engineered civil system and the primary, but not sole, recipient of instrumentation in the ANSS program at the time of this writing when funding for instrumentation is limited. The consensus of the 2001 COSMOS workshop (Stepp and Nigbor, ed 2001) support this emphasis as follows:

> *As an initial tradeoff, it is recommended that instrumentation of buildings should be given high priority. Other structures, such as bridges, other lifeline structures, dams and other critical facility structures, typically have independent requirements for strong-motion measurements.*

The writers of this Guideline concur with the National Steering Committee and the consensus findings of the COSMOS workshop, but also believe that the other classes of engineered systems also warrant response monitoring under the ANSS program. Needs for buildings, geosystems, and infrastructure systems are detailed in the following three sections. Appendices D, E, and F contain the draft scoring systems for each category. The Committee expects the lists to be revised on a regular (three-year) basis following

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[1] ANSS should invest in response monitoring infrastructure in locations with the highest probability of collecting data: Recommendation #9 of the 2001 COSMOS workshop (Stepp and Nigbor 2001)

consultation with the end-users of the ANSS data, namely, the academic and design professional communities and emergency planners and responders.

An important overall need for all types of engineered civil systems is the need to correlate earthquake damage with measured ground shaking and response data. This need suggests that an important criterion for an ANSS-instrumented structure is the ability to document and disseminate detailed information on damage, or lack of damage, following earthquake shaking.

2.1.1 Engineering Needs for Building Instrumentation

Buildings are the largest single category of engineered civil systems, and have a very large contribution to seismic risk. As defined herein, the term "buildings" encompasses all structures intended to enclose people and/or their activities. Structures in this category range from single-family houses to apartments to office buildings to industrial buildings. Within this broad range there is an enormous number of building types and construction; a fact that makes the specification of needs and priorities difficult.

Celebi (2004), the ANSS Technical Guidelines (USGS 2002), and the COSMOS workshop proceedings (Stepp and Nigbor, ed 2001) all provide information on priority needs for building instrumentation. The Committee reviewed these documents and discussed prioritization of needs for buildings, considering the current state-of-practice in earthquake engineering and the needs of the earthquake-engineering research community. Based upon these deliberations, response data should be collected, processed and curated to address high-priority needs that include:

- Performance of buildings undergoing inelastic response and damage to the point of incipient collapse to support the development of tools and methods for performance-based seismic design
- Global response of buildings subjected to near source shaking
- Higher-mode response of mid-rise and high-rise buildings
- Modification of free-field earthquake shaking by building foundations

- Soil-structure interaction effects on building response including the rocking response of shear wall and braced frame buildings
- Behavior of nonductile concrete frame buildings
- Behavior of tuck-under apartment buildings
- Behavior of unreinforced masonry (URM) components and buildings
- Behavior of tilt-up buildings with flexible diaphragms
- Response of buildings incorporating advanced technologies such as isolation and damping systems
- Performance of retrofitted buildings.

Additional information on high-priority needs is incorporated in the scorecard specific to buildings presented in Appendix D.

2.1.2 Engineering Needs for Geosystem Instrumentation

Geosystems are facilities comprised in whole or in part of soil or rock materials. Examples include earth and rockfill dams, solid waste landfills, dikes, levees, tunnels, and retaining walls. Foundations are covered under building and bridge structural systems, and are not considered a geosystem. The subject of ground response in the absence of a structure/geosystem is covered under the ground motion instrumentation program of ANSS, and is not covered here.

Based upon Committee deliberations, response data should be collected, processed, and curated to address the following high-priority needs of the geotechnical engineering community:

- Wave propagation and site response within geosystems undergoing inelastic behavior
- Ground motions in geosystems experiencing significant softening or liquefaction
- Response of geosystems to near-source effects, especially directivity pulses

- Response of geosystems to incoherent ground motion inputs, such as might arise from variable ground conditions underlying a large size facility.

Additional information on high-priority needs is incorporated in the scorecard specific to geosystems presented in Appendix E.

2.1.3 Engineering Needs for Infrastructure System Instrumentation

Recent earthquakes in Japan (1995), Taiwan (1999) and Turkey (1999) have resulted in huge economic losses due to failures of infrastructure, including bridges, port and harbor structures and petrochemical structures. The following needs are among those with a high priority in advancing the understanding of how to best improve the resilience of and reduce losses to infrastructure during strong ground shaking.

- Performance of bridges and infrastructure undergoing inelastic response and damage to the point of incipient collapse to support the development of tools and methods for performance-based seismic design
- Global response of bridges subjected to near source shaking
- Global response of distributed systems subjected to differential support excitation
- Soil-structure interaction effects on bridge and infrastructure response including rocking response and liquefaction
- Response of bridges and infrastructure incorporating advanced technologies such as isolation and damping systems
- Performance of retrofitted bridges.

Additional information on high-priority needs is incorporated in the scorecard specific to infrastructure is presented in Appendix F.

2.2 COLLABORATIVE OPPORTUNITIES

ANSS should adopt national priorities for response monitoring of civil engineered systems and make annual resource allocation decisions based upon these priorities. However, ANSS should also consider opportunities for collaboration with other government programs or private industry that would provide substantial leverage for an ANSS investment.

The USGS National Strong Motion Program (NSMP) already benefits from collaborations with other government agencies and programs. Celebi (2004) notes that 17 of 51 extensive building instrumentation arrays operated by USGS are collaborative efforts with other agencies, including the Department of Veterans Affairs, General Services Administration, Los Angeles County, and NASA.

There is currently a strong opportunity for collaboration with NSF's Network for Earthquake Engineering Simulation (NEES). There is a continuing opportunity for collaboration with the three NSF-funded earthquake engineering research centers. Other opportunities may exist for collaboration between ANSS and government-funded earthquake engineering research projects or programs. There may also be international opportunities for collaboration in earthquake engineering research, and perhaps opportunities for collaboration in other areas such as structural health monitoring or homeland security.

Both the USGS NSMP and ANSS have already benefited from collaborations with private building owners. A key recommendation of the 2001 COSMOS workshop (Stepp and Nigbor, ed. 2001) regarding private partnership is stated as follows:

> *Demonstration projects, with co-funding or cooperative research and development agreement (CRADA) relationships, are seen as a way of expanding private sector participation and getting new organizations involved in building instrumentation projects. To bridge the education gap between owners and strong-motion data providers, guidelines focused on the practical application of strong-motion data should be prepared that specifically target building owners. The ANSS should consider providing technical support for private owner participation in building monitoring by serving as recorder and distributor of any data collected. The building owner's needs for the data may be as limited as providing data obtained*

from free-field station that can be incorporated into ShakeMap[1]. If instrumentation of a building meets the national and regional priorities of ANSS and the owner agrees to the use of the data for the public good, then the project would clearly contribute to ANSS goals. There is a range of possible building owner relationships with the ANSS that would have to be developed on a case-by-case basis. Building owner/operators engaged on any level in getting and applying earthquake data become advocates for the overall ANSS program.

ANSS should seek and encourage all of the above collaboration possibilities, as long as they fit within the mission of ANSS response monitoring and within the ANSS priorities. Openly available data, metadata, and post-earthquake damage survey data should be required for all collaborative projects. All such opportunities can enhance the ANSS program and can provide significant leverage to the limited funds available to ANSS.

2.3 SETTING NATIONAL PRIORITIES

ANSS management should decide annually how to allocate the available financial resources for response monitoring of engineered civil systems. Chapter 5 provides a framework for this decision-making process in which candidate systems are ranked according to national priorities. Final decisions regarding funding will be made by the System Response Monitoring Advisory Committee (SRMAC).

All other factors being equal, buildings should be given highest priority at this time, followed by geosystems and infrastructure systems. However, instrumentation of all three classes of engineered systems is considered essential to the ultimate success of ANSS. The scorecards of Appendices D, E, and F provide a framework for assessing the relative merits of candidate buildings, geosystems and infrastructure, respectively..

[1] ShakeMap is a map of earthquake shaking intensity, and is a main product of ANSS ground motion monitoring. See www.anss.org for further details.

ANSS management should consider national needs to be primary and regional needs to be secondary when setting priorities and ranking annual candidate systems for ANSS response monitoring. Possibilities for collaboration with other agencies or companies, work that would significantly leverage the limited ANSS resources, should be considered carefully.

2.4 DATA DISSEMINATION AND COLLECTION

For ANSS response monitoring to meet the needs of the targeted end-users, data should be made available in a complete and timely manner. Metadata (see Chapter 3) for each monitored system should be made available to the public at large via an ANSS website dedicated to instrumented and monitored engineered civil systems. Uncorrected earthquake response data (time series) should be made available at the ANSS website in near real time following earthquake shaking at the site of the monitored system. Earthquake damage data for monitored systems, which is vital to the improvement of understanding and the development of predictive modeling tools, should be collected immediately following an earthquake and made available in a timely manner either at the ANSS website of via a link at the ANSS website.

The ANSS mission does not include earthquake damage reconnaissance. Collection and rapid publication of earthquake damage data is vital to the success of the ANSS response monitoring program and ANSS management is strongly encouraged to formally coordinate future data collection and reporting with those organizations tasked with collecting earthquake damage data.

3 TECHNICAL REQUIREMENTS

This chapter presents detailed technical requirements for ANSS response monitoring. These are largely based upon the 2001 COSMOS workshop (Stepp and Nigbor, ed. 2001) recommendations and the 2002 ANSS Technical Guidelines (USGS 2002). The major topics of this chapter are Monitoring Approach, System Issues, Hardware, and Information Technology.

3.1 MONITORING APPROACH

It is the nature of engineered civil systems that every system is unique, unlike aerospace, automotive, or mechanical systems. Even buildings of the same basic type (e.g. low-rise masonry) are typically different. This greatly complicates any attempt to standardize ANSS response monitoring.

Provided herein is a common monitoring approach that can be applied to all ANSS-instrumented systems. All ANSS-instrumented systems should have common goals and basic design concepts. The approach allows for Payload Projects with other goals or design concepts to accompany, but not replace, the basic ANSS response monitoring goal described in the next section.

3.1.1 BASIC GOAL

In keeping with the mission of ANSS response monitoring, the basic goal of any ANSS structural monitoring project is to provide data and information that will contribute to future earthquake safety of life and property through improved understanding and predictive modeling of the earthquake response of engineered civil systems.

3.1.2 PURPOSE

Section 5 of this Guideline presents a two-step proposal process to select candidate engineered civil systems for ANSS instrumentation and monitoring. The first (pre-proposal) step will involve the completion and submission of a standard form. Appendices D, E and F provide the forms for buildings, geosystems and infrastructure, respectively. The proposer must complete the relevant form and scorecard, identify the purpose (engineering rationale) for instrumenting the building, and present a list of objectives of the measurement system,

3.1.3 BASIC DESIGN REQUIREMENTS

Every engineered civil system is unique, and therefore every response monitoring system will be different. However, the following basic design concepts should be present in every ANSS-monitored engineered civil system:

1. Measurement of both input and response. Every structure should have an appropriately justified number of reference ground motion sensors in addition to the in-structure sensors to measure the response of the engineered civil system.
2. Measurement of base motion. Every system should have a sufficient number of sensors installed at its base or foundation. Where relevant to the proposed instrumentation system, sensors should be installed to measure soil-structure interaction effects.
3. A sufficient number of sensors to meet the purpose of the proposed instrumentation system.
4. Sufficient measurement resolution (both dynamic range and frequency response of sensor and data acquisition channels) to meet the system-specific measurement objectives.
5. Detailed metadata to enable speedy or real-time evaluation and interpretation of instrument data, consistent with the purpose of the proposed instrumentation scheme.
6. Compatibility of data, metadata, and data transmission with ANSS standards.
7. Immediate post-earthquake access to the engineered civil system for collection of perishable earthquake damage data.

Every proposal (see Section 5.3) for ANSS response monitoring support should clearly directly address these seven basic design requirements. Some of these design requirements must be addressed in the pre-proposal (see Section 5.3).

3.1.4 PAYLOAD MONITORING PROJECTS

The design of the instrumentation system for every candidate system should meet the basic goal of Section 3.1.1 above. Additional goals or capabilities are defined as "Payload Monitoring." Payload monitoring is encouraged to broaden the scope and utility of ANSS response monitoring.

Collaborative monitoring with other government agencies might have operational or research goals distinct from the ANSS goals. Examples include, 1) information from the monitoring of a dam or bridge might be used by a partner agency for agency-internal actions following earthquake shaking, and 2) an owner of a steel-framed building might seek specific response data to justify not inspecting welds after moderate earthquake shaking. Additional monitoring capabilities should be considered as Payload Monitoring and should be in addition to but not in place of those needed to address the goal and purpose of the ANSS monitoring.

3.2 SYSTEM DESIGN REQUIREMENTS

3.2.1 FUNCTIONAL SPECIFICATIONS

An ANSS response monitoring system should be designed, installed, and operated to provide appropriate data for meeting both its Purpose (Section 3.1.2) and Basic Design Requirements (Section 3.1.3). General guidance for installation is provided below.

- *Measurement types:* Acceleration, displacement, deformation, and strain should be the main quantities measured. (The use of advanced or innovative sensors is encouraged to improve the state of practice.) Recording should be digital.
- *Dynamic range:* Dynamic range is defined herein as the combined clip level (sensor, signal conditioning and digitizer) compared to the combined RMS noise level.

Recommended system dynamic range for each measurement channel is 19 bits (114dB). Minimum system resolution for every channel should be 16 bits (96dB).

- *Frequency response:* Minimum frequency response of acceleration channels should be 0.02 – 50 Hz. Frequency response of displacement or other measured quantities may be less than this, but should be justified if less. Minimum channel sample rate should be 200 samples per second.
- *Channel skew/phase delay:* The digitizer skew or delay time between any two channels should be less than 1 millisecond. Any sensor or filter phase delays should be constant, correctable to less than 1 millisecond, and included in the metadata.
- *Triggering:* For triggered recording systems, trigger thresholds should be appropriate for the minimum earthquake and response motions of interest. Pre-event times should be sufficient to capture the P-wave upon S-wave triggering; 30 seconds is a recommended minimum. Post-event times should be adequate to capture significant free response of the structure after ground shaking has stopped. Eighty seconds is a recommended minimum, but more time will be required for low frequency structures such as high-rise buildings or long-span bridges.
- *Real-time systems:* Systems providing real-time data transmission should also have on-site triggered recording and data storage.

3.2.2 PROCUREMENT PROCESS

All hardware and software used in a monitoring project should be formally approved by the ANSS Response Monitoring Coordinator prior to procurement.

If new hardware or software is proposed as part of the ANSS monitoring system, detailed information should be provided as part of the proposal, and detailed evaluation and acceptance testing should be provided as a condition of procurement.

3.2.3 PACKAGING AND INFRASTRUCTURE

Component and instrumentation system packaging should meet all applicable ANSS standards and should be appropriate for the expected environment in or on the structure.

Instrumentation system design should consider the availability and reliability of power and communications infrastructure. Appropriate backup power and communication systems should be supplied as necessary to ensure data survivability.

3.2.4 INSTALLATION

Installation details will vary considerably for each structural monitoring project. Following are general requirements that should be followed for each project:

- *General*: Instrumentation should be installed with normal standards of professional care. The need for long-term reliability should be foremost in the installation work plan and details.
- *Reference location accuracy*: A reference location on the structure or nearby ground should have documented accuracy of one ten-thousandth of a degree in latitude and longitude.
- *Sensor location accuracy*: Within the structure, sensor location accuracy should be 10 mm or better in all three axes relative to a designated reference sensor.
- *Sensor orientation*: Sensors within a structure should be oriented in a logical manner in line with the structure's primary axes. Sensors should be mounted within 0.5 degrees of the desired orientation within the structure. Sensor orientation is critical to data interpretation and should be well documented and controlled.
- *Anchoring and hardening*: All sensors, recorder and auxiliary components should be anchored securely to the structure to prevent relative motion and hardened to prevent damage in the event of failure of the engineered civil system.
- *Maintenance program:* A post-installation maintenance program is essential to the success of a structural monitoring project. The maintenance program should be

documented as part of the proposal for ANSS monitoring. Special tools or materials required for maintenance should be provided to ANSS operations at the time of instrumentation system installation. ANSS management will be responsible for assuring that the maintenance program is carried out.

3.2.5 DOCUMENTATION AND METADATA

An installation should be extensively and formally documented, with narrative and digital photographic descriptions of each component of the instrumentation system.

Detailed metadata should be compiled as part of the ANSS monitoring system. USGS and ANSS funds should be used to develop the metadata. Metadata should include sufficient site condition data for evaluation of local site effects and soil-structure interaction, detailed mathematical models of the engineered civil system being monitored, results of the analyses performed to support the type and location of all transducers in the monitoring system, construction documents (including structural and architectural drawings) for the building, sample results from the analysis of the mathematical model of the civil system, and post-earthquake damage data and information[1]). Section 4.3 lists additional metadata requirements.

3.3 HARDWARE REQUIREMENTS

3.3.1 SENSORS

Appendix G.1 provides current specifications for strong-motion accelerometers suitable for deployment in engineered civil systems.

Appendix G.2 provides current specifications for cable extension relative displacement sensors suitable for long-term deployment in engineered civil systems.

Appendix G.3 provides current specifications for weldable metal foil strain gauge systems suitable for long-term deployment in engineered civil systems.

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[1] No guidance is provided for collection and publication of earthquake damage data because such work falls outside the scope of ANSS.

Technical requirements for other sensor types are not provided herein; specifications for other sensors should be included as part of a proposal for an ANSS monitoring system. Such specifications should meet the Basic Design Requirements (3.1.3) and Functional Specifications (3.2.1) presented above.

3.3.2 DATA ACQUISITION SYSTEMS

Appendix G.4 presents technical requirements for data acquisition systems that will form part of an ANSS response monitoring system. These requirements make substantial use of the specifications set forth in the 2002 ANSS Technical Guidelines.

3.3.3 DATA TRANSMISSION

Data transmission within the monitoring system hardware and software should be compatible with existing ANSS systems. See Section 3.4 below.

3.3.4 NEW TECHNOLOGIES

If possible and where appropriate, an ANSS response monitoring system should use hardware and software currently in use within the ANSS environment to ensure compatibility. However, the use of new technologies and instruments is strongly encouraged when it broadens, improves, or lowers the cost of current instruments or systems.

The development and deployment of instrumentation systems capable of real-time, continuous monitoring of response of civil engineered systems is considered a high priority. Collaboration with other organizations focused on real-time health monitoring of engineered systems for non-earthquake-induced movement or damage would represent an appropriate leverage of ANSS resources for this purpose.

3.4 INFORMATION TECHNOLOGY REQUIREMENTS

3.4.1 DATA FORMATS

The instrumentation used in a specific ANSS response monitoring project should output digital data that meets, at a minimum, the data specifications set forth in the most current ANSS Technical Guidelines.

Data should also be capable of translation to the latest COSMOS data format to facilitate further use by the earthquake engineering community.

3.4.2 METADATA FORMATS

A specific ANSS response monitoring project should be capable of providing metadata that meets, at a minimum, the metadata specifications set forth in the most current ANSS Technical Guidelines. All metadata (see Section 4.2) should be available online at all times for automatic download by the public.

3.4.3 DATA COMMUNICATION

A specific ANSS response monitoring project should be capable of data communications with the designated ANSS Engineering Data Center. If a proposed ANSS response monitoring project has real-time data transmission capability, it should be compatible with existing ANSS real-time data systems in use in the ANSS region where the engineered system is located. The system should also have parallel triggered local recording capability.

If the project does not include real-time capabilities, then it should be compatible with existing offline automated data retrieval systems in use within ANSS. Data retrieved offline should be automatically available to users.

4 DATA AND METADATA

4.1 OPEN DATA POLICY AND DATA REQUIREMENTS

The basic intent of ANSS, including its response monitoring program, is to openly provide data, metadata, and information from monitoring projects of civil engineered systems in a timely manner. Data will be managed and distributed through an ANSS Engineering Data Center.

Appendix C contains a draft of the ANSS open data policy, which states that:

> *All data collected, and data products generated by the ANSS and its constituent networks shall be freely and easily available to the user community for earthquake monitoring and notification, emergency response, scientific research, volcano monitoring and notification, general education, and all other appropriate purposes*.

Currently, all existing USGS cooperative agreements for seismic monitoring include a statement requiring that data should be made available to USGS as soon as it is accessible. This requirement needs to apply to all ANSS structural monitoring data as well. Therefore, any collaborative or payload projects should follow this open data policy as well.

The Committee strongly agrees with the ANSS open data policy. That policy should be expanded for response monitoring projects to include all site and engineered system data and metadata. These data should be made available online at all times for use by the public. Raw (unedited) response data should be made available to the user community immediately following an earthquake event that triggers the ANSS monitoring system at that site.

The following data should be openly disseminated in a coordinated package by ANSS in a timely manner, via a dedicated ANSS website for monitored engineered systems, following triggering of an ANSS monitoring system:

- Raw, unedited digital waveform data from all channels including reference and base motion channels;
- Zero-corrected and scaled waveform data from all error-free sensor channels; and
- Processed strong-motion data, both input and response, from all error-free sensor channels. COSMOS-standard processing or equivalent should be used.

Earthquake damage data from monitored engineered systems should be made available online at the dedicated ANSS response monitoring website or via a hyperlink to the website of the data-collection organization.

4.2 METADATA REQUIREMENTS

Listed below is the minimum metadata for an ANSS monitored engineered civil system that should be available online at the dedicated ANSS response monitoring website.

Basic Station Data and Auxiliary 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 mapped values, S_s and S_1
- ASCE-7 site class
- Vs30 (average shear wave velocity in the upper 30m) if available
- Station instrumentation details
- Station calibration data
- Station history (installation date, modification descriptions/dates, etc.)

- Ambient noise spectra (national and regional broadband sites only)
- 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
- Other descriptive information about the site

Sensors

- Sensor type
- Sensor manufacturer, model, serial number
- Output units
- Sensitivity
- Frequency response parameters or curve
- Location in the system
- Orientation in the system
- Photograph of installed sensor

Engineered Civil System

- Structure/system type
- Year of construction
- Design codes
- Occupancy/use description
- Sketch of building and sensor layout (similar to Figure 1)

- Detailed design drawings (CAD if available)
- Material properties
- Detailed mathematical models of the engineered civil system being monitored
- Results of the analyses performed to support the type and location of all transducers in the monitoring system
- Construction documents,
- Sample results from the analysis of the mathematical model of the civil system

5 ANSS INSTRUMENTATION SELECTION PROCESS

5.1 INTRODUCTION

A formal, national-level process is needed to rank and select individual engineered civil systems for ANSS response monitoring. This chapter presents a selection process that will address national priorities using the resources of the ANSS Regional Advisory Committees.

5.2 ORGANIZATION

The Structural Instrumentation Guideline Committee that drafted this Guideline was dissolved upon the delivery of the Guideline to the ANSS National Steering Committee (NSC). Because of the distinct and important end-user function of the ANSS Response Monitoring Program, a new System Response Monitoring Advisory Committee (SRMAC) should be formed immediately to provide the oversight and guidance needed to implement this Guideline.

The SRMAC should have the following charges:

1. Advise the ANSS NSC during the formation of the ANSS Structural Response Monitoring Program;
2. Advise the ANSS NSC on the implementation of this Guideline;
3. Review and rank candidate civil engineered systems on an annual basis for the ANSS NSC; and
4. Review the priorities and ranking criteria contained in this Guideline on an annual basis for the ANSS NSC.

The SRMAC should consist of fifteen (15) members. The membership of SRMAC should reflect the targeted end-users of ANSS response monitoring data, namely, a mix of practicing and academic structural, geotechnical, and instrumentation engineers. The makeup of the SRMAC should be established by the ANSS National Steering Committee.

The SRMAC should be funded by and report to the ANSS National Steering Committee and should coordinate its activities with the ANSS Response Monitoring Coordinator.

5.3 SELECTION PROCESS FOR ENGINEERED CIVIL SYSTEMS

A formal, annual solicitation and two-step proposal and review process is recommended to form a robust pool of candidate engineered civil systems for ANSS response monitoring.

The USGS ANSS response monitoring solicitation should seek pre-proposals from the ANSS Regional Advisory Committees and also from individuals, organizations and companies not part of the Regional Advisory Committees. Such individuals, organizations and companies are, however, encouraged to respond to the solicitation through their Regional Advisory Committee[1]. The scope of the pre-proposal is presented in Section 3.1.2. Additional criteria may be added by the SRMAC. The SRMAC will review and rank all nominations and select nominations for development into detailed proposals. Pre-proposals will be ranked on the basis of the statement of purpose, the objectives of the measurement system and the scorecard.

The authors of the selected pre-proposals should then be asked to develop detailed proposals within four months of the solicitation-response date for submittal to the SRMAC. ANSS should consider providing financial and staff support at this stage to assist in the proposal developments. The detailed proposal should include, as a minimum, the following information:

1. Location of the engineered system, including latitude and longitude
2. Site geology,
3. NEHRP mapped values, S_s and S_1
4. Site class per ASCE-7
5. Monitoring history (i.e., are instruments already deployed at the station or in the engineered system),

[1] If an organization or company is not associated with a specific ANSS region, contact should be made with the ANSS Response Monitoring Coordinator to aid in the development of a pre-proposal.

6. A photograph of the engineered system,
7. Site map,
8. Description of the engineered system,
9. Year of construction,
10. Design codes used for construction,
11. Occupancy/use description,
12. Sketch of engineered system and proposed distribution of sensors,
13. Detailed rationale for instrumenting the system,
14. Point score per Appendix D, E or F,
15. A letter from the system owner noting support for the deployment of instruments in the system, development and publication of all metadata, etc.,
16. Sufficient information to justify the type and location of sensors in the monitoring system,
17. A detailed plan to develop and archive metadata using the ANSS infrastructure, and
18. A budget for the proposed monitoring system (to include the cost of developing all the proposed metadata).

ANSS technical staff will assist the proposer to develop instrumentation schemes and budgets for the proposed monitoring system. Detailed proposals will be submitted to the SRMAC for formal review and ranking. Rankings will be submitted to the ANSS National Steering Committee for approval and funding up to the level appropriated for that fiscal year. The selection process presented above has three goals, namely, 1) to limit the effort required to assemble detailed proposals that have a reasonable probability of funding, 2) to eliminate at the pre-proposal stage those proposals with little to no chance of funding, saving those proposers the time and expense involved in drafting a competitive full proposal, and 3) to ensure high-caliber detailed proposals worthy of ANSS funding.

APPENDIX A: ANSS Structural Instrumentation Committee

Dr. Andrew S. Whittaker, S.E. (Chair)
Department of Civil Engineering
University at Buffalo
230 Ketter Hall
Buffalo, NY 14260
Ph: 716-645-2114, ext. 2418
Email: awhittak@acsu.buffalo.edu

Dr. John L. Aho, P.E.
Principal Engineer/Vice President
CH2M Hill
301 W. Northern Lights Blvd., Suite 601
Anchorage, AK 99503-2662
Ph: 907-278-2551
Email: jaho@ch2m.com

Dr. C. B. Crouse, P.E.
Principal Engineer/Vice President
URS Corporation
1501 Fourth Avenue, Suite 1400
Seattle, WA 98101-1616
Ph: 206-438-2700
Email: cb_crouse@urscorp.com

Dr. Robert Frosch
School of Civil Engineering
Purdue University
550 Stadium Mall Drive
West Lafayette, IN 47907-2051
Ph: 765-494-5904
Email: frosch@purdue.edu

Mr. Dominic J. Kelly, S.E.
Simpson Gumpertz & Heger Inc.
41 Seyon Street, Bldg. 1, Suite 500
Waltham, MA 02453
Ph: 781-907-9000
Email: djkelly@sgh.com

Mr. Bret Lizundia, S.E.
Principal
Rutherford & Chekene
427 Thirteenth Street
Oakland, CA 94612
Ph: 510-740-3200
Email: blizundia@ruthchek.com

Dr. Laura N. Lowes
Department of Civil & Environmental Eng.
233C More Hall, Box 352700
University of Washington
Seattle, WA 98195-2700
Ph: 206-685-2563
Email: lowes@u.washington.edu

Dr. Eduardo Miranda
Dept. of Civil & Environmental. Eng.
Terman Room 293
Stanford University
Stanford, CA 94305-3707
Ph: 650-723-4164
Email: emiranda@stanford.edu

Dr. Robert L. Nigbor, P.E.
Department of Civil Engineering
University of Southern California KAP210
Los Angeles, CA 90089-2531
Ph: 213-740-9165
Email: nigbor@usc.edu

Dr. David H. Sanders
Department of Civil Engineering
University of Nevada Reno, MS 258
Reno, NV 89557-0152
Ph: 775-784-4288
Email: sanders@unr.edu

Dr. Jonathan Stewart, P.E.
Dept. of Civil & Environmental Eng.
University of California Los Angeles
5731-H Boelter Hall
Los Angeles, CA 90095-1593
Ph: 310-206-2990
Email: jstewart@seas.ucla.edu

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APPENDIX C: ANSS Interim Data Policy

Advanced National Seismic System Interim Data Policy

Adopted by ANSS national Implementation Committee, Dec. 2003

Elements of Data Policy

This documents sets down the principal points of a Data Policy for the Advanced National Seismic System (ANSS).

All data collected, and data products generated by the ANSS and its constituent networks shall be freely and easily available to the user community for earthquake monitoring and notification, emergency response, scientific research, volcano monitoring and notification, general education, and all other appropriate purposes.

All data collected by the ANSS shall have sufficient metadata giving the location, instrumentation type and response, and other information on the conditions of data recording needed for the application of the data. These metadata shall be associated with the recorded (or raw) data in a manner that will ensure that the recorded data and metadata can be easily matched.

To the extent possible and practical, recorded data and associated metadata should be deposited at and distributed through existing data management centers and facilities. Data so deposited and distributed must be clearly attributed to the ANSS.

All ANSS data products and derivative information created by the ANSS should be deposited at and distributed through an ANSS Data Product Management Center.

The ANSS Technical Integration Committee shall develop specifications for ANSS data, metadata, and data products, for approval by the ANSS National Implementation and Steering Committees.

All ANSS-funded participants, including cooperative network operators, must follow these elements and the developed and approved specifications.

APPENDIX D: Selection Criteria for Buildings

Submission Form for Candidate Buildings

Fill in the information as completely as possible. Where the information is unknown, indicate "unknown".

General Information	
Proposer:	
Name:	
Address:	
Email:	
Building location:	
Address:	
City:	
State:	
Latitude/Longitude:	
Building information:	
Stories above grade:	
Stories below grade:	
Square footage:	
Date constructed:	
Building code used:	
ASCE 31-02 structure type(s):	
Foundation type:	
Seismically rehabilitated: Yes/No.	
Year of rehabilitation:	
Criteria for rehabilitation:	
Already instrumented: Yes/No.	

Photograph attached: Yes/No.	
Original structural drawings are available[1]: Yes/No	
Seismicity (2003 NEHRP map values): S_s:	
S_1:	
ASCE-7 Site Class (Soil type): A, B, C, D, E, F	
A geotechnical report is available: Yes/No:	
Owner:	
Name:	
Address:	
Public or private:	
Access[2]:	
The owner has been contacted and agreed to allow ANSS instrumentation and post-earthquake access: Yes/No.	
The owner has been contacted and may allow ANSS instrumentation and post-earthquake access: Yes/No.	
Shared Funding: The owner or another entity will provide partial funding for instrumentation: Yes/No/Unknown.	

[1]At a minimum, drawings depicting the original existing structural conditions of the buildings are required. These can be from the bid set or they can be drawings that have been created by field measurements. Do not submit the building as a candidate for ANSS instrumentation without this minimum level of documentation.

[2] If the owner has been contacted and will not agree to instrumentation, do not submit the building as a candidate for ANSS instrumentation. For buildings that are short-listed, a letter from the owner will be required agreeing to all ANSS instrumentation and usage of the data.

WEIGHTED SCORING	
Seismicity (up to 30 points): Seismicity shall be defined by NEHRP map values, using the high, medium and low seismicity categories in ASCE 31-03. Use ASCE-7 Site Class D when the site class is not known.	
High *($S_{DS} \geq 0.5g$ and $S_{D1} \geq 0.2g$)* (30)	
Medium *(Not High or Low)* (5)	
Low *($S_{DS} \leq 0.167g$ and $S_{D1} \leq 0.067g$)* (1)	
Reference Instrument Availability (up to 20 points)	
Free-field station(s) already installed (20)	
Free-field location(s) available (16)	
SMRS-OG (see COSMOS(2001)) Urban reference station(s) already installed (10)	
SMRS-OG Urban reference location(s) available (8)	
No reference locations available (0)	
Unknown (0)	
Existing Instrumentation (up to 10 points):	
Over 10 sensors (10)	
3-10 sensors (8)	
1-3 sensors (6)	
No sensors (0)	
Unknown (0)	
Current Metadata Availability (up to 13 points):	
Computer models (5):	
Nonlinear 3-D computer model available (5)	
Linear 3-D computer model available (3)	

2-D computer model(s) available (2)	
Record Drawings[1] (3):	
Architectural and structural record drawings (3)	
Structural record drawings only (2)	
Architectural record drawings only (1)	
No record drawings available (0)	
Previous instrumentation information (5):	
Studies using instrumentation records (5)	
Records only (3)	
No previous records (0)	
Unknown (0)	
Building Simplicity (up to 10 points):	
No 2003 IBC irregularities (10)	
Either 2003 IBC plan (Table 1616.5.1.1) or vertical (Table 1616.5.1.2) irregularities present but not both (5)	
Both 2003 UBC plan and vertical irregularities present (0)	
Unknown (0)	
Building Types With Large Portfolios and High Life Safety Risk (up to 20 points)	
Unrehabilitated woodframe apartment over open parking on at least one side (tuck-under apartment) (20)	
Rehabilitated tuckunder apartments with moment frame on open front (20)	
Unrehabilitated URM bearing wall with flexible diaphragm (20)	

[1] As noted previously, original bid drawings or their equivalent are required. Record drawings define the final "as-built" conditions and incorporate changes made to the bid documents during construction. To qualify for additional points here, the record drawings must also cover modifications made to the building since the original construction period.

URM bearing wall rehabilitated to the equivalent of the UCBC or more stringent (20)	
URM bearing wall rehabilitated to the less stringent criteria than the UCBC (15)	
Unrehabilitated tilt-up with flexible diaphragm (15)	
Unrehabilitated nonductile concrete frame without URM infill (15)	
Unrehabilitated nonductile concrete frame with URM infill (10)	
Building Types With Large Portfolios and Uncertain Life Safety Risk (up to 15 points)	
Ordinary concentric steel braced frame (15)	
Pre-Northridge moment frame (15)	
Other Building Types with Large Portfolios (up to 10 points)	
Post-Northridge special moment-resisting frames (10)	
Special concentrically-braced frame (10)	
Midrise (3-6 stories) concrete shear wall (5)	
Building Types With Small Portfolios but of Important Engineering Interest (up to 10 points)	
Buckling-restrained (unbonded) braced frame (10)	
Seismically-isolated (10)	
Passively-damped (10)	
Concrete special moment-resisting frame (5)	
Coupled shear wall (5)	
Precast moment frames (5)	
Issues (up to 20 points)	
Founded on piles (5)	
Underground structure (5)	
Very large structure with potential ground motion coherency issues (5)	

Rocking response anticipated (5)	
Total Score from Categories with Listed Point Values:	

Statement of Purpose (Engineering Rationale) for Instrumenting and Monitoring System:

Objectives of the Measurement System:

Other Issues: Other building types besides those identified above will be considered. List any other issues of interest for instrumenting and monitoring this building that the ANSS SRMAC should consider as part of their review.

APPENDIX E: Selection Criteria for Geosystems

Submission Form for Candidate Geosystems

Circle or fill in the information as completely as possible. Where the information is unknown, indicate "unknown".

General Information	
Proposer:	
Name:	
Address:	
Email:	
Geosystem location:	
Address:	
City:	
State:	
Geosystem information:	
Type of geosystem	
Materials used in construction	
Approximate footprint area and height	
Date constructed:	
Seismically rehabilitated: Yes/No.	
Year of rehabilitation:	
Criteria for rehabilitation:	
Already instrumented: Yes/No.	
Photograph attached: Yes/No.	
Original geosystems drawings are available[1]: Yes/No	

[1]At a minimum, drawings depicting the original existing construction conditions are required. These can be from the bid set or they can be drawings that have been created

Seismicity (2003 NEHRP map values): S_s:	
S_1:	
ASCE-7 Site Class (Soil type): A, B, C, D, E, F	
A geotechnical report is available: Yes/No:	
Owner:	
Name:	
Address:	
Public or private:	
Access[1]**:**	
The owner has been contacted and agreed to allow ANSS instrumentation and post-earthquake access: Yes/No.	
The owner has been contacted and may allow ANSS instrumentation and post-earthquake access: Yes/No.	
Shared Funding: The owner or another entity will provide partial funding for instrumentation: Yes/No/Unknown.	

by field measurements. Do not submit the geosystem as a candidate for ANSS instrumentation without this minimum level of documentation.

[1] If the owner has been contacted and will not agree to instrumentation, do not submit the geosystem as a candidate for ANSS instrumentation. For geosystems that are short-listed, a letter from the owner will be required agreeing to all ANSS instrumentation and usage of the data.

WEIGHTED SCORING	
Seismicity (20 points): Seismicity shall be defined by NEHRP map values, using the high, medium and low seismicity categories in ASCE 31-03. Use ASCE-7 Site Class D when the site class is not known.	
High *($S_{DS} \geq 0.5g$ and $S_{D1} \geq 0.2g$)* (20)	
Medium *(Not High or Low)* (10)	
Low *($S_{DS} \leq 0.167g$ and $S_{D1} \leq 0.067g$)* (3)	
Reference Instrument Availability (up to 20 points)	
Free-field station(s) or COSMOS SMRS-OG stations already installed or available (20)	
No reference locations available (0)	
Unknown (0)	
Existing Instrumentation and availability of Previous Records (10 points):	
Existing array with > 10 sensors and previous recordings (10)	
Existing array with 3-10 sensors and previous recordings (8)	
Existing array with 1-3 sensors and previous recordings (6)	
Existing array but no previous recordings (3)	
No sensors (0)	
Unknown (0)	
Metadata Availability (20 points):	
Drawings (10):	
Plan and profile views of geosystem (10)	
No information (0)	
Material properties (10)	

Properties known well enough to allow detailed modeling of seismic performance (e.g., soil types, index properties, shear wave velocity, shear strength) (10)	
Properties only known well enough to allow simplified modeling of seismic performance (e.g., soil types and index properties, but no shear wave velocity or strength data) (5)	
Insufficient information to enable an engineering assessment of seismic performance (0)	
Is the Geosystem Common? (10 points):	
No unusual 3D geometries or irregular ground conditions (10)	
Ordinary soil types but highly 3D shape (5)	
Non-representative geosystem (2)	
Unknown (0)	
Likelihood of Significant Response of Engineering Interest (30 points)	
Significant geosystem for which there is currently a lack of instrumented sites (e.g., tunnels, retaining walls). (30)	
Geosystem for which the existing state-of-knowledge provides relatively low confidence in the prediction of both the seismic response (i.e., ground motion variations across the geosystem) and performance (i.e., accrual of permanent displacements within the geosystem). Moreover, the regional seismicity may be expected to trigger site performance of engineering interest. (30)	
Geosystem for which the existing state-of-knowledge provides relatively high confidence in the prediction of seismic response (e.g., systems with a nearly 1D geometry) but lower confidence in the prediction of performance. The regional seismicity may be expected to trigger site performance of engineering interest. (20)	
Either of the above two cases, but regional seismicity is unlikely to produce site performance of engineering interest (i.e., expected motions are unlikely to induce permanent deformations). (10)	
Total Score from Categories with Listed Point Values:	

Statement of Purpose (Engineering Rationale) for Instrumenting and Monitoring System:
Objectives of the Measurement System:
Other Issues: Displacement and pore water pressure instrumentation should be considered in addition to accelerometers for many geosystems. List any other issues of interest in instrumenting this geosystem that the ANSS SRMAC should consider as part of their review.

APPENDIX F: Selection Criteria for Infrastructure

Submission Form for Candidate Infrastructure System (including bridges)

Fill in the information as completely as possible. Where the information is unknown, indicate "unknown".

General Information	
Proposer:	
Name:	
Address:	
Email:	
Infrastructure system location:	
Address:	
City:	
State:	
Latitude/Longitude:	
Infrastructure system information:	
Type of infrastructure system	
Materials used in construction	
Approximate footprint area and height	
Date constructed:	
Seismically rehabilitated: Yes/No.	
Year of rehabilitation:	
Criteria for rehabilitation:	
Already instrumented: Yes/No.	
Photograph attached: Yes/No.	
Original construction drawings are available[1]: Yes/No	

[1]At a minimum, drawings depicting the original existing construction conditions are required. These can be from the bid set or they can be drawings that have been created

Seismicity (2003 NEHRP map values): S_s:	
S_1:	
ASCE-7 Site Class (Soil type): A, B, C, D, E, F	
A geotechnical report is available: Yes/No:	
Owner:	
Name:	
Address:	
Public or private:	
Access[1]:	
The owner has been contacted and agreed to allow ANSS instrumentation and post-earthquake access: Yes/No.	
The owner has been contacted and may allow ANSS instrumentation and post-earthquake access: Yes/No.	
Shared Funding: The owner or another entity will provide partial funding for instrumentation: Yes/No/Unknown.	

by field measurements. Do not submit the infrastructure as a candidate for ANSS instrumentation without this minimum level of documentation.

[1] If the owner has been contacted and will not agree to instrumentation, do not submit the infrastructure as a candidate for ANSS instrumentation. For infrastructure that are short-listed, a letter from the owner will be required agreeing to all ANSS instrumentation and usage of the data.

WEIGHTED SCORING	
Seismicity (up to 30 points): Seismicity shall be defined by NEHRP map values, using the high, medium and low seismicity categories in ASCE 31-03. Use ASCE-7 Site Class D when the site class is not known. .	
High *($S_{DS} \geq 0.5g$ and $S_{D1} \geq 0.2g$)* (30)	
Medium *(Not High or Low)* (5)	
Low *($S_{DS} \leq 0.167g$ and $S_{D1} \leq 0.067g$)* (1)	
Reference Instrument Availability (up to 20 points)	
Free-field station(s) already installed (20)	
Free-field location(s) available (16)	
SMRS-OG (see COSMOS(2001)) Urban reference station(s) already installed (10)	
SMRS-OG Urban reference location(s) available (8)	
No reference locations available (0)	
Unknown (0)	
Existing Instrumentation (up to 10 points):	
Over 10 sensors (10)	
3-10 sensors (8)	
1-3 sensors (6)	
No sensors (0)	
Unknown (0)	
Current Metadata Availability (up to 15 points):	
Computer models (5):	
Nonlinear 3-D computer model available (5)	
Linear 3-D computer model available (3)	
2-D computer model(s) available (2)	
Drawings (5):	

Architectural and structural (5)	
Structural only (4)	
Architectural only (2)	
None available (0)	
Previous instrumentation information (5):	
Studies using instrumentation records (5)	
Records only (3)	
No previous records (0)	
Unknown (0)	
For remaining issues provide points on a sliding scale based on judgment of reviewer.	
Structure Material (10 + 5 points)	
Complete Drawings (10 points)	
Material Properties (5 points)	
Structure Type (15 points)	
Site Conditions (15 points) .	
Special Issues (10 points)	
Total Score from Categories with Listed Point Values:	

Statement of Purpose (Engineering Rationale) for Instrumenting and Monitoring System:
Objectives of the Measurement System:
Other Issues: List any other issues of interest in instrumenting this infrastructure system that the ANSS SRMAC should consider as part of their review.

APPENDIX G: Technical Specifications for Instrumentation

G.1. Acceleration Sensors

Accelerometers have been the primary sensors used for response monitoring in the past. Below are basic specifications for accelerometers. These specifications are compatible with the specifications for ANSS ground motion monitoring accelerometers.

- +/-4g full-scale is sufficient for both reference stations and building response accelerometers;
- >4g full-scale should be considered for special measurements (e.g., impact/pounding, special buildings, equipment);
- <4g full-scale may be sufficient for downhole measurements;
- Frequency response should be 0.02 – 50 Hz minimum. The high frequency response should be appropriately increased when high accelerations are anticipated in specific installations (e.g., building pounding, brittle fracture);
- Dynamic range (clip level/rms noise level) of at least 120 dB in the range .02 to 2 Hz and at least 100 dB in the range 2 to 50 Hz.
- Nominal distortion less than -60 dB and
- Nominal cross axis coupling less than -40 dB.
- Operating temperature range of -20 to +60 degrees C. Instrument sensitivity and output offset should remain within 1% of nominal value over a temperature range of 0 to 40 degrees C and within 2% over entire temperature range. Gain stable to 1 % under all conditions.
- Transfer functions should be supplied with each instrument and should be accurate to within 1% in amplitude and 4 degrees in phase over the pass band of the instrument.

- Hysteresis in acceleration offset should be less than –100 dB referenced to full scale under all conditions.
- Calibration input, remote calibration enable function, and manual offset adjustment, if present, should be lockable to prevent non-linear effects.
- Instrument output should be unaffected by reasonable changes in magnetic field and atmospheric pressure and reasonable levels of radio frequency interference.
- Instruments should be designed for a 10-year (minimum) life and should be demonstrated to have a 40,000 hour (minimum) mean time between failures (see Appendix C).
- Power consumption should not be greater than 1 watt in operational mode at 12 VDC.

G.2. Cable-Type Displacement Sensors

This section refers to cable-type displacement sensors also known as:

- cable actuacted position sensor
- cable extension transducer
- cable position transducer
- cable sensor
- cable-actuated sensor
- CET
- CPT
- stringpot
- string potentiometer
- draw wire encoder

- draw wire transducer

These names all refer to devices that measure displacement via a flexible displacement cable that extracts from and retracts to a spring-loaded drum. This drum is attached to a rotary sensor converting rotation to an electrical output.

For ANSS applications, basic specifications are:

- Full Stroke Ranges: 0-2 to 0-50 inches
- Accuracy: 0.5% full stroke
- Repeatability: ± 0.05% full stroke
- Resolution: 0.01% of full stroke
- Measuring Cable: nylon-coated stainless steel
- Enclosure Weather Resistance: NEMA 4 or better
- Input Power: 14.5–40VDC1, 0 mA max.
- Operating Temperature: 0_{o} to 200_{o}F
- Vibration: up to 10 G.s to 2000 Hz maximum

G.3. *Weldable Metal Foil Strain Sensors*

There are many types of strain sensors applicable to ANSS response monitoring. The following specifications refer to one type, a weldable metal-foil resistance strain gauge. This is suitable for long-term installation on steel structural members of steel reinforcing bars where steel yielding is not anticipated.

Nominal specifications are:

- Material: stainless steel or iconel
- Compensation temperature range: +10 to +100°C (for thermal expansion of 11ppm/°C)
- Strain limit : 0.5 (at room temperature

- Fatigue limit: 1×10^6 at room temperature

G.4. Digitizers

The general specifications for digitizers or data acquisition systems below are compatible with COSMOS (Stepp and Nigbor, ed 2001) and ANSS ground motion guidelines.

- Analog-to-digital converter (ADC) with input range matched to the sensors. Resolution should be at least 16 bits from 0.01 to 50 Hz. Higher resolutions (19 bits or above) are highly recommended..
- The sensitivity of each digitizer channel (counts per volt) should be accurate to 0.1 % or better at DC (0 Hz).
- External time reference accurate to 1 ms absolute.
- Data samples on all channels running at the same sample rate should be taken simultaneously to within 1% of the sample interval.
- Operating temperature range of -20 to +60 degrees C. Sensitivity stable to 1% over range 0 to 40 degrees C and to 2% over entire temperature range.
- Capable of generating control signals matched to sensors, such as lock/unlock, mass center, calibrate enable, initiate ring-down or free period test, damping test, etc. Capable of generating step, sine, and random binary telegraph calibration signals configurable to provide sensor outputs between 5% and 50% of full scale.
- All channels should be derived from raw digitizer sample rate using linear phase "brick-wall" filters with high frequency corner fc at least 80% of the Nyquist frequency and stop band amplitude (Nyquist to higher frequencies) at least 120 dB below the pass band. Pass band (DC to fc) ripple should be less than 5%.
- Capable of sampling of at least 200 samples per second per channel. Higher sample rates may be needed for some cases.

- Capable of detecting, and storing on local storage media, events on all channels of each sensor, flagging events in the continuous data from the primary sensor, and buffering triggered data for transmission from the secondary sensor.
- Capable of data compression at all sample rates. Packets will have a maximum length of 1000 samples to provide adequate latency.
- Data telemetry, if used, should be error corrected, should support standard IP communications protocol(s), should support a variety of communications technologies, and should be capable of transmitting backlogged and triggered data without interrupting realtime data delivery.
- Capable of buffering a minimum of 7 days of seismic data (in the event of a telemetry outage) in on-site storage media.
- Instrument output should be unaffected by reasonable changes in magnetic field and reasonable levels of radio frequency interference
- Instrument should be designed for a 10-year (minimum) life and should be demonstrated to have a 40,000 hour (minimum) mean time between failures.
- Power consumption: Not greater than 1 watts average, 2 watts peak at 12 VDC if non-grid power (e.g., solar) is used, not limited if mains power used with 30-minute minimum UPS backup.