INSTRUMENTATION GUIDELINES FOR THE ADVANCED NATIONAL SEISMIC SYSTEM

Prepared for

U.S. Geological Survey and

ANSS National Implementation Committee

Prepared by

Working Group D of the

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Preface

This document is a result of the efforts of Working Group D of the ANSS Technical Implementation Committee to rewrite Chapter 3 of the 2002 ANSS Technical Implementation Guideline document. Beginning in 2004 through 2006, Working Group D went through many revisions of the original Chapter 3. This effort included outside review by a broad spectrum of scientists and seismic instrumentation vendors.

We have taken the results of the Chapter 3 revision and created this stand-alone document to address ANSS' need for guidance in their planning and procurement of new instrumentation.

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A copy of this document and supporting files may be found at:
http://earthquake.usgs.gov/research/monitoring/anss/documents.php

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1 Introduction

This document provides guidelines for the seismic-monitoring instrumentation for long-term earthquake-monitoring station deployments that will sense ground motion, digitize and store the resulting signals in a local data acquisition unit, and optionally transmit these digital data. These guidelines are derived from specifications and requirements for data needed to address the nation's emergency response, engineering, and scientific needs as identified in *USGS Circular 1188*. Data needs are discussed in terms of national, regional, and urban scales of monitoring in Section 2. Functional performance specifications for instrumentation are introduced in Section 3.3 and discussed in detail in Section 5, using instrument classes and definitions from Section 4. System aspects and testing recommendations are discussed in Sections 6 and 7, respectively.

Although *USGS Circular 1188* recommends that the ANSS include portable instrumentation, performance specifications to this element are not specifically addressed in this document. Nevertheless, these guidelines are largely applicable to portable instrumentation. Volcano monitoring instrumentation is also beyond the scope of this document. Guidance for ANSS structural-response monitoring is discussed briefly herein but details are deferred to the ANSS document *Guideline for ANSS Seismic Monitoring of Engineered Civil Systems – Version 1.0, USGS Open-file Report 2005-1039*. Aspects of station planning, siting, and installation other than instrumentation are beyond the scope of this document.

2 Data Needs and Types of Seismic Monitoring Stations

2.1 Data Needs

Guidance for ANSS earthquake monitoring stations includes planning, siting, and installation of suitable instrumentation, all collectively intended to yield the data required to address the goals of ANSS. Thus the guidance for different types of stations flows directly from ANSS goals, hence from requisite data characteristics. Per ANSS Performance Standards, ANSS data needs include measurements to provide:

- National monitoring adequate to locate M3.0 and larger earthquakes and to quantify their salient properties including focal depth, magnitude, and source characteristics.
- Regional monitoring adequate to provide detailed information on scientifically or societally important earthquake source regions and zones, including active faults. Events with magnitudes as small as the M2.0–2.5 magnitude completeness level should be observed sufficiently well for location and magnitude determination. Of particular importance is detailed on-scale recording of large earthquakes within the distance range of less than 20 km for both scientific and engineering purposes. ShakeMap, earthquake catalogs, and early warning are examples of important ANSS products that depend upon regional monitoring data.
- Ground shaking from felt or damaging earthquakes for scientific and engineering uses, preparation of ShakeMap, rapid response or early warning, public information, and other purposes. ANSS has prioritized 26 urban areas for ground shaking monitoring.
- Detailed response characteristics of engineered civil systems including buildings, geosystems (such as embankments and earthen dams), and infrastructure (such as bridges and other transportation and utility system components), for use in improving understanding and predictive modeling of the response of structures and in aiding post-earthquake response and recovery.

2.2 Types of ANSS Seismic Monitoring Stations

The monitoring systems in ANSS, as defined in *USGS Circular 1188*, are characterized in terms of the National backbone network, Regional networks, and Urban monitoring networks. The concepts of National-, Regional-, and Urban-scale monitoring are readily understandable by federal and State funding agencies and officials and by the general public. However, based on the experience of the initial five years of implementation of ANSS, some refinement within these categories is needed to provide an up-to-date framework for selecting and instrumenting sites as ANSS stations. The traditional distinctions between National, Regional, and Urban stations, described respectively as having broadband, high-gain short-period, and strong-motion instruments, have blurred. In particular, the various networks have evolved to more effectively monitor and record the continuum of earthquake-caused motions at all frequencies and amplitudes. Another practical consideration relates to budgetary constraints on the full funding of ANSS, which now require an evolutionary approach to achieve the modernization and other goals of ANSS. Thus these revised instrumentation guidelines provide for the inclusion of some legacy seismic instrumentation, consistent with a longer development time and lower rate of capital investment for ANSS.

In this section, four categories of ANSS seismic-monitoring stations are identified: National, Regional, and Urban monitoring stations, along with a separate category for specialized instrumentation of structures. The first three categories involve monitoring vibratory ground motions; the fourth, monitoring of structural response to these ground motions. As detailed below, while these categories do not represent any fundamental change from *Circular 1188*, their refined description provides an improved framework to guide the planning and design of ANSS seismic monitoring stations and the performance of their instrumentation.

National monitoring stations are elements of a broad grid or network deployed on a national-to-global scale (station spacing of hundreds of kilometers) intended to provide uniform seismographic surveillance of the United States and its territories as well as supporting the detection of nuclear tests and tsunamigenic earthquakes outside U.S. boundaries. Within the ANSS framework, these stations generally are elements of the ANSS/EarthScope national backbone array, the legacy U.S. National Seismic Network (USNSN), or the Global Seismic Network (GSN). Operational responsibilities for these stations currently fall to the USGS in partnership with the National Science Foundation through its IRIS-managed programs. National-scale monitoring emphasizes the recording of longer-period data at very-low-noise sites with sensitive, low-noise seismographs; accelerometers are included to assure on-scale records of strong shaking, but the placement of the sensors may not meet the requirements of engineering users of strong-motion data.

Regional monitoring stations are elements of regional-to-local-scale grids or networks (station spacing of ~100 km to ~10 km) deployed for (a) the systematic seismic surveillance of all or part of a regional seismic belt, ANSS region, or State jurisdiction and/or (b) high-resolution monitoring of active faults and other seismic source zones within those domains. Within the ANSS framework, such stations generally have been elements of traditional regional seismic networks. Regional monitoring stations require diverse instrumentation and variable station spacing to meet different requirements such as the assured on-scale recording of moderate-to-large local earthquakes, high-quality broadband waveforms for moment-tensor inversions, the detection and fine spatial resolution of microseismicity associated with active faults, and near-fault recording of strong earthquake ground shaking on both rock and soils needed for earthquake-engineering purposes. These strong-motion records are also an important component of ShakeMap and early warning ANSS products.

Some local-scale monitoring within ANSS regions may be carried out by entities in coordination with ANSS, such as seismo-volcanic monitoring by the USGS volcano observatories, or in some cases independent of ANSS, such as localized monitoring by public- or private-sector groups of seismicity associated with impounded reservoirs, geothermal fields, nuclear and other critical facilities, and mining operations. Regional- and local-scale monitoring are invariably complementary in space and time, and real-time monitoring and response should be coordinated to the greatest extent possible. In the case of volcano monitoring, regional monitoring stations not only provide information about the surrounding tectonic setting (relevant to the interaction between volcanic and tectonic processes), but they also provide backup on-scale recording in the event of large eruptions that can cause the volcano-monitoring stations to go off scale or even to be destroyed.

Urban monitoring stations are designed for on-scale high-fidelity recording of seismic ground motions in the built environment, especially in areas of moderate to high seismic hazard and high seismic risk. In near-real-time after an earthquake, Urban monitoring stations provide vital information on the severity and extent of actual ground shaking for impact assessment and emergency response. They also inform earthquake engineers about ground motions that were input to Structural-response monitoring stations, and their data enable predictive modeling of ground shaking in future earthquakes for improved seismic design and for post-earthquake damage assessment of structures. In some areas, feasibility studies are under way aimed at using Urban monitoring stations (combined with Regional stations) for early warning of a destructive earthquake that is in progress. Urban monitoring stations will have high clipping levels. Where active faults are close, the instrumentation can provide good on-scale *P*- and *S*-wave waveforms for locating microearthquakes (depending on the urban noise levels).

Dense arrays of Urban monitoring stations are arrays with small inter-station spacing. Currently, the typical density of Urban monitoring stations is station spacing of as close as 3 to 4 km. The variability of ground motions recorded by nearby stations is high and not easily estimated unless the station spacing is reduced to about 1 km or less[1]. Such dense arrays of Urban monitoring stations are thus needed to confidently interpolate ground motions for use in detailed post-earthquake urban damage assessments and for other purposes. The dense arrays may be formed as "nested arrays"[2], anchored with state-of-the-art Class A (see Section 4) instrumentation and augmented by Class B or other instrumentation to provide high spatial resolution, in high priority areas likely to experience moderate to major earthquakes in coming decades and that have one or more of the following characteristics: (1) urban centers with dense populations and dense infrastructure; (2) near-source regions, giving preference to those in and near urban and suburban areas; (3) urban and suburban regions thought likely to suffer from localized effects, such as basin-edge or strong site effects, causing neighborhood-scale "hot spots" of high shaking strength; or

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[1] See, for example, Boore, D. M., J. F. Gibbs, W. B. Joyner, and J. C. Tinsley, Estimated ground motion from the 1994 Northridge, California, earthquake at the site of the Interstate 10 and La Cienega Boulevard bridge collapse, West Los Angeles, California, *Bull. Seis. Soc. Am.*, **93**, no. 6, 2737–2751, 2003.
[2] Evans, J. R., R. H. Hamstra, Jr., C. Kündig, P. Camina, and J. A. Rogers, TREMOR: A wireless MEMS accelerograph for dense arrays, *Earthquake Spectra*, **21**, no. 1, 91–124, 2005.

(4) NEHRP site-class E soils (and the adjacent area) for which few data currently exist but upon which is significant urban and infrastructure development in some regions.

Structural-response monitoring stations are arrays of sensors installed in and on structures including buildings, geosystems (geotechnically engineered structures such as landfills and dams), and infrastructure (principally utilities and transportation systems) to measure the earthquake response of such engineered civil systems. Dense geotechnical arrays may augment this class of ANSS stations.

Structure monitoring requires engineering design of the sensor layout and specifications of sensors and data acquisition systems to properly address the application of these data to improving understanding and predictive modeling of engineered civil systems, which lead to advances in seismic design codes and practices and in damage assessment and other immediate post-earthquake activities. Details are beyond the scope of this document, and can be found in the ANSS document entitled *Guideline for ANSS Seismic Monitoring of Engineered Civil Systems — Version 1.0, USGS Open-file Report 2005-1039.*

3 General Instrumentation Considerations

3.1 System Performance

The data needs stated in the previous section naturally lead to overall system performance requirements for seismic instrumentation. Generically, the monitoring station instrumentation system (sensors through data communications) should have the following performance:

- Accurate waveforms from first *P*-wave through surface waves;
- On-scale waveforms for all potential earthquakes;
- Accurate absolute timing of every sample throughout the record;
- Minimum loss of data due to instrumentation and data communication malfunctions;
- Timely transmission of continuous or segmented data for the required analysis applications, including ShakeMap and early warning;
- Minimum internal and external non-seismic noise contamination; and
- Consistent performance under field conditions.

Detailed instrumentation performance specifications are provided in Section 5 for each of the categories of ANSS monitoring stations. These follow from the system performance goals above.

3.2 General Design Concepts

Seismic station and network design are evolving practices, driven by both changing data needs and technological advances. A recent snapshot of the state-of-practice is found in the *IASPEI New Manual on Seismic Observatory Practice* (www.iaspei.org, 2002). The design and implementation of ANSS instrumentation is part of this evolution, with this document an attempt to provide guidance and organization.

Within this context, many basic decisions about the desired performance of ANSS stations either have been or can be made *a priori* based on experience, technological trends, and the stated goals of the ANSS. These include:

- The need for wide bandwidths and linear high dynamic range generally dictate feedback sensor designs.
- The need for high resolution dictates on-site digital recording and digital telemetry.
- Seismological research and engineering practice and research require a minimum of three-component linear-motion data. Nevertheless, there is still a useful role in active fault monitoring for single-component, high-gain, short-period sensors in Regional or Urban monitoring stations to complement three-component translational accelerometers.
- (The matter of the three rotational components of motion is a rapidly evolving field of uncertain outcome which may affect the minimum appropriate number of inertial sensors in an ANSS station.)
- Technological trends suggest standardizing on Internet protocols (IP) for data communication, though use of current and future transmission media options should not be limited.
- Strong-motion data should have continuous access to telemetry whenever possible and practical. However, if cost or technical issues render continuous telemetry impractical, dial-up telephone or other intermittent connections are satisfactory if engineered for latency of not more than a few minutes.
- Stations with limited continuous telemetry bandwidth can be accommodated by triggered full-sample-rate event recording, compressing all data, and adopting the highest sample rates consistent with requirements for continuous data transfer.
- The need for complete data implies substantial (days or longer) on-site buffering or backup storage for all types of stations.
- Reliable communications require error correction and packet retransmission, which implies bi-directional communication. Variable communications latency requires either on-site timing or network-based timing with adequate accuracy.
- Maintenance and reliability concerns similarly imply bi-directional communication and regular (at least daily) State-Of-Health (SOH) messaging from the instrument.

- Small data-delivery latency, a significant requirement for early warning, requires short packets and reasonably fast communication speeds with minimal routing/buffering delays (<1 second transit time).
- Instrumentation systems should be warranted for a period of at least one year, with three years desirable, and vendors should provide spare parts and service for their systems for a period of at least 10 years after purchase.

3.3 General Expectations

Robustness

Data delivery must be reliable and suitable for a variety of communication technologies. Equipment must operate reliably over long periods of time (at least 10 years) in hostile field environments (extreme temperatures, moisture, "dirty" power, other hazards).

Bandwidth

The station instrumentation's bandwidth is the range of ground motion frequencies that can be accurately reproduced by the resulting digital data. The overall system bandwidth is a product of the sensor, cabling, and digitizer bandwidths in the field environment of a station. Bandwidth goals for National stations are based on USNSN functional specifications and are nominally 0.01 – 50 Hz. The low-frequency specification is based on research needs while the high frequency specification is limited by attenuation over distances comparable with the inter-station spacing as well as interoperability with Regional and Urban networks. Bandwidths for Regional and Urban stations are based on experience and identified scientific and engineering needs and are nominally 0.02 – 50 Hz.

Dynamic Range

The instrumentation system's dynamic range is the range of amplitudes that can be accurately measured, bounded below by system and site noise or digital resolution and bounded above by the sensor or digitizer clip level. Formally, specified clipping levels are true maximum (peak) ground motions that are to be recorded within specifications. However, we define dynamic range as a ratio of rms values — that of a maximum unclipped sine wave to that of the noise floor. (So defined, dynamic range is also called signal-to-noise ratio (SNR) or when specified over a particular band the Bandwidth SNR (BWSNR).) Dynamic range specifications vary by station type; Sections 4 and 5 provide further details.

Furthermore, ANSS formally defines and recognizes only PSD and rms spectra generated as follows: From a long, unweighted time series take the Walsh-method PSD using multiple 50-%-overlapping Hanning subsegments, ideally at least 10 such subsegments, with the total trace length trimmed at the end so that these subsegments are an integer number of seconds in duration.

This algorithm is embodied in the MatLab™ script "ANSS noise rms rev4.m", available on-line at http://earthquake.usgs.gov/research/monitoring/anss/documents.php. This script also manages the trimming process.

Resolution

The amplitude resolution of a network of instruments is limited by the system noise, bandwidth, self noise and ambient site noise, and dynamic range of the instruments. Spatial resolution is limited primarily by the spacing between instruments compared not so often to horizontal wave numbers of the data but to the spatial covariance of observational phenomena.

Data Latency

Short latencies (a few seconds) for the data at various types of stations are needed to support ShakeMap generation and early warning applications. The combination of on-site storage and short latencies requires that transmission of old data be caught up while current data continue to flow uninterrupted. That is, after a communications outage, older data should be transmitted in time-sequential order in parallel with the near-real-time data but at a lower priority. This requirement also implies that both vendor-supplied and ANSS-supplied receiving software will tolerate and properly manage and re-sequence such out-of-sequence catch-up data.

Siting

While siting is the province of another portion of ANSS guidance, we note that **all** sensors, broadband, short period, and acceleration, require some degree of temperature stability to yield viable records; thus, they require thermal insulation. It has not always been the practice to insulate accelerometers and short period sensors, but we note significant temperature sensitivity in both types of sensor and a particular need for very good baseline stability in acceleration records (which are commonly doubly integrated). Thus, accelerometers and accelerographs require a significantly greater degree of thermal insulation than previously applied while copper-coil geophones should also be insulated at least moderately from diurnal cycling and rapid changes due to local conditions such as sunlight and shadow. Most modern broadband sensors, of course, require heavy thermal insulation.

4 Instrumentation Classes

4.1 *Purpose*

This section defines classes of instrumentation based upon data type and quality. These classes, coupled with the types of ANSS monitoring stations defined in Section 2.2, provide the framework for organizing performance specifications in Section 5.

4.2 *ANSS Instrumentation Definitions*

Accelerometer: A sensor that measures acceleration, commonly used as a strong-motion sensor in Urban and Structural-response networks as well as in National and Regional systems to guarantee on-scale recording of moderate and large nearby earthquakes.

BB: Broadband sensor or DAS; measures seismic motions with wide frequency and amplitude limits generally reaching down to or below site ambient noise. Frequency response includes the long periods/low frequencies needed for global and national seismology purposes.

Class A: Class A instruments (and "A–", "A+", etc., finer distinctions) are sensors and DAUs at or near the state-of-the-art, currently about 20 to 26 bits resolution over the dynamic range of the corresponding sensor types.

Class B: Class B instruments (and "B–", "B+", etc., finer distinctions) are sensors and DAUs the next significant step down in resolution from Class A, currently about 16 to 19 bits resolution across the dynamic range of the corresponding sensor types.

Class C: Class C instruments (and "C–", "C+", etc., finer distinctions) are sensors and DAUs lower still in resolution, currently about 12 to 15 bits resolution across the dynamic range of the corresponding sensor types, but remaining superior to the performance of legacy analog film instruments.

Class D: Class D instruments are sensors and DAUs with performance comparable to legacy analog instruments, about 8 to 11 bits digital resolution and/or using analog recording.

DAS: Data Acquisition System, a complete seismic monitoring system consisting of sensor(s), DAU(s), and communications hardware. Note that DAS = DAU + Sensors.

DAU: Data Acquisition Unit, a subsystem that acquires, stores, and transmits digital data from one or more sensors. Note that DAU = Amplifiers + ADC + storage + telemetry + timing source (GPS, NTP, or other).

Sensor: In the ANSS context, a sensor is a device that converts motion to an analog voltage or a digital signal. Ground motion sensors typically sense translational acceleration or velocity, but can also sense displacement, strain, force, or rotation.

Seismometer: A sensor that measures velocity or acceleration. In common use, indicates a BB or SP sensor as distinct from a SM sensor.

ShakeMap: A map generated by USGS and its partners of the shaking strength observed or predicted for the region of strong shaking[3].

SP: Short Period sensor or DAS, has limited bandwidth in the low frequencies/long periods; typically limited to frequencies above ~1 Hz.

SM: Strong-Motion sensor or DAS, measures large amplitude motions, to date without the low-amplitude resolution of BB.

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[3] Wald, D. J., V. Quitoriano, T. H. Heaton, H. Kanamori, C. W. Scrivner, and C. B. Worden, TriNet "ShakeMaps": Rapid Generation of Instrumental Ground Motion and Intensity Maps for Earthquakes in Southern California, *Earthquake Spectra*, **15**, no. 3, 537–555, 1999.

Strong-Motion Sensor: A seismometer or accelerometer that measures large amplitude earthquake motions, up to about 3.5 g acceleration and 3.5 m/s velocity.

4.3 *Application-Based Classification*

There are several types and classes of instrumentation (including both sensors and DAUs) with capabilities spanning the different ANSS monitoring needs described in Section 2 above. Table 1 indicates which instrument type and class are appropriate for each ANSS station type and monitoring application. See the previous section for definitions of the various instrument types and classes.

A table entry of "Primary" indicates that this is the instrument type and class generally recommended for the application. A table entry of "Option" indicates an acceptable instrumentation option or a preferred system in the case of atypical siting conditions or economic and operational limitations.

(Note that "interstation spacing" in Table 1 and elsewhere is an approximate average. It is often more realistic to aim for roughly constant interstation spacing but constraining more closely the equivalent area (km^2) covered be a given station. The conversion, assuming 2D hexagonal symmetry for the array design, is $A = \frac{\sqrt{3}}{4}\xi^2 \approx 0.433\xi^2$, where A is area per station (km^2) and ξ is the interstation spacing (km) from Table 1. A can be estimated by dividing the total area of the array by the number of stations in the array, with margins around the array loose by about $\xi/2$, to compute the area.)

Table 1: Selection of Instrumentation Type and Class by ANSS Application

ANSS Station Type and Application		Instrument Type/Class						
		BB/A+	BB/A	BB/A–	SP/A	SM/A	SM/B	Other
National Monitoring	***Teleseisms and some regional events:*** **Global (GSN) monitoring**	**Primary**	Option — Noisy sites			**Primary**		
National Monitoring	***Regional events; some teleseisms; some locals:*** **National monitoring (Interstation Spacing >70 km; ANSS backbone ~300 km)**	Option — quiet sites	**Primary**	Option — Noisy sites		**Primary**		
Regional Monitoring	***Local and regional events; some teleseisms:*** **Broadband (Interstation Spacing 50 – 70 km) [Option R.1]**		Option — quiet sites	**Primary**		**Primary**		
Regional Monitoring	***Primarily local and regional events:*** **Short period triaxial (Interstation Spacing 10 – 30 km) [Option R.2]**				**Primary**	**Primary**	Option	
Regional Monitoring	***Primarily local and regional events:*** **Short period vertical (Interstation Spacing 10 – 30 km) [Option R.3]**				Option	**Primary**	Option	Class C or D Option
Regional Monitoring	***Strong-Motion Regional Coverage*:** **Strong-motion sensor only (Interstation Spacing 3 – 30 km) [Option R.4]**					**Primary**	Option	Class C or D Option
Urban Monitoring	***Strong-motion and Regional:*** **Inclusive of broadband (Interstation Spacing 50 – 70 km) [Option U.1]**		Option — quiet sites	**Primary**		**Primary**		
Urban Monitoring	***Strong-motion and Active-Fault:*** **Includes short period triaxial (Interstation Spacing ≤4 km) [Option U.2]**				**Primary**	**Primary**		
Urban Monitoring	***Strong-motion and Active-Fault:*** **Includes short period vertical (Interstation Spacing ≤4 km) [Option U.3]**				Option	**Primary**	Option	
Urban Monitoring	***Strong-motion only:*** **Strong-motion sensor only (Interstation Spacing ≤4 km) [Option U.4]**					**Primary**	Option — Noisy sites	Class C Option
Urban Monitoring	***Strong-motion only:*** **Infill for Dense strong-motion array (Interstation Spacing ≤2 km) [Option U.5]**						**Primary**	Class C or D Option
Structural Monitoring	**Reference station(s) (configuration designed for each structure and corresponding, specified data requirements)**					**Primary**	Option	**GPS Sensors**
Structural Monitoring	**Structural array (instrumentation and configuration designed for each structure and corresponding, specified data requirements)**					Option	**Primary**	**Displacement, Strain, and GPS Sensors**

4.4 *Strong-Motion Monitoring System Classification*

Although strong-motion monitoring is included in the scope of the application-based classification in the previous section, it is distinct enough to warrant additional discussion.

In addition to the current and planned ANSS Urban monitoring stations, there are plans for development of a higher density of stations in some urban areas using lower-cost and lower-resolution instruments. "Urban Dense" stations may be operated by private industry, amateurs, schools, and sometimes by the ANSS. While of lower amplitude resolution than the primary ANSS Urban instruments, these stations will yield valuable results for ANSS engineering and research. They will add spatial resolution to ANSS networks and are useful also in situations where budgets are limited or sites are noisy.

Table 2 defines classes A–D of strong-motion systems in terms of resolution and estimated cost.

Resolution is defined as the system self noise or the least significant bit over the specified full system bandwidth. A clip level of 2.5 g rms (that is, the rms of a sine wave having ±3.5 g amplitude) is used to calculate dynamic range in dB or digital counts (bits). The units "dBa" in Table 3 are decibels referred to an acceleration of 1 m/s^2.

Cost is an estimate of the current retail cost (quantity 1) for a complete SM DAS from sensors through DAU through communications hardware.

Table 2: Strong-Motion System Classification

Strong-Motion DAS Class	DAS Resolution (mg)	DAS Dynamic Range (broadband) dB	Bits	Approx. 2007 Cost (DAS, Qty 1)
A	<7	>111	≥20	$10,000
B	7-107	87-111	≥16 to <20	$5,000
C	107-1709	63-87	≥12 to <16	$3,000
D	≥1709	<63	<12	$1,000

5 Functional Performance Specifications

5.1 *Scope*

"Functional Performance Specifications" are defined herein as detailed criteria or metrics for the desired levels of performance from numerous elements of ANSS instrumentation. These specifications were developed from the ANSS data needs summarized in Section 2.1.

The specifications in this section are not intended to be directly used as procurement specifications but are a resource for procurement of ANSS and ANSS-compatible seismic instrumentation. Vendors should adhere to procurement requirements.

The following sections present station performance goals, specifications for sensors, specifications for DAUs, and commentary for each ANSS monitoring station type.

5.2 *Monitoring Station Performance*

Overall functional performance goals for each type of ANSS monitoring station are provided below.

National Monitoring Stations

National stations must meet the diverse needs of national/global source monitoring, the needs of national/global earthquake research, and must capture strong ground motion for nearby events. They should also be interoperable with Regional stations, at least matching their performance. Specific performance requirements are:

- High resolution in the band 0.01 to 15 Hz (0.00278 Hz to 15 Hz for global stations), on-scale recording, and latencies less than about 30 s.
- Resolution below ambient noise in the band 0.04 Hz to 10 Hz (0.00278 Hz to 10 Hz for global stations), on-scale recording, high fidelity, and complete continuous data.

- Upper band limit of 50 Hz, thus 100–200 sps, where interoperable with and supporting Regional stations sampling at those rates.
- For the strong ground motion component, sensitivity in the band 0.02 to 50 Hz, a clip level of 3.5 g, constant absolute sensitivity, low hysteresis, and ≥200 sample-per-second recording.

Regional Monitoring Stations

Regional stations must meet the needs of regional seismicity monitoring of both small and infrequent events and the needs of national and regional seismological research, and must capture strong ground motions. Specific performance requirements are:

- High resolution in the band 0.02 to 35 Hz, on-scale recording, sampling at least at 100 sps and preferably 200 sps (to provide oversampling for better time resolution and/or to allow for the transition band of analog anti-alias filters), and latencies less than about 10 s.
- Resolutions below ambient noise in the band 0.04 to 10 Hz, on-scale recording, high fidelity, and complete, continuous data.
- For the strong ground motion component, sensitivity in the band 0.02 to 50 Hz, a minimum clip level of 3.5 g peak, constant absolute sensitivity, low hysteresis, and at least 200 sps recording.

Urban Monitoring Stations

Urban monitoring stations must: (a) Provide information about the strong-motion wave field and local site effects with little ("reference") or no ("free field") contamination from man-made structures; (b) provide data quickly enough to produce ShakeMaps and other information products within five minutes for emergency response, public media, and rapid recovery purposes; and (c) at sites where active-fault or regional planning considerations indicate the need, include broadband or short-period sensors. Specific performance requirements are:

- Resolutions below 100 μg over the band 0.02 to 50 Hz;
- On-scale recording to a minimum clip level of 3.5 g peak;
- Locally triggered data storage with optional continuous data streaming;
- Latency of a few minutes after detrigger
- Sensitivity in the band 0.02 to 50 Hz, constant absolute sensitivity, low hysteresis, and recording to at least 200 sps.

Structural-Response Monitoring Stations

Specifications for this class of ANSS station are largely the same as those for Urban monitoring stations. There can be unique sensors or subsystems for structural monitoring that are not used elsewhere within ANSS, such as strain, displacement, shock, or load sensors. Further performance requirements are found in *Guideline for ANSS Seismic Monitoring of Engineered Civil Systems – Version 1.0, USGS Open-file Report 2005-1039*.

5.3 Sensor Specifications

Table 3 contains specifications for various performance metrics relating to sensors, including BB, SP, and SM.

5.4 DAU Specifications

Table 4 contains specifications for performance metrics related to data acquisition units for all station types.

5.5 Power and Packaging

Power requirements are a critical parameter for seismic station design. Also, packaging of the system components is important for long-term reliability. Performance specifications for power and for several quantifiable aspects of packaging are provided in Table 5.

Table 3: Sensor performance specifications

Performance Metric	Broadband			Short Period	Accelerometer		Strong-Motion Velocity
	Class A+	Class A	Class A-	Class A	Class A	Class B	
Number of components/axes	3			3/1	3		
Clip-level (Peak)	≥±0.013 m/s for a sensitivity of 1500 Vs/m			≥±1.5 mm displ. or ≥±0.01 m/s at 1 Hz	≥±3.5 g	≥±3.5 g (at ANSS option, ≥±2 g)	≥±3.5 m/s and ≥±3.5 g
Sensor Dynamic Range (ratio of rms of largest sine to rms self noise — root of PSD *via* Walsh method)	155 dB, 0.01 – 0.05 Hz	143 dB, 0.01 – 0.05 Hz	131 dB, 0.01 – 0.05 Hz	138 dB, 1 – 10 Hz	145 dB, 0.02 – 2 Hz	87.3 dB, 0.1 – 35 Hz	140 dB, 0.02 – 50 Hz; or 87.3 dB, 0.1 - 35 Hz
	150 dB, 1 – 10 Hz	138 dB, 1 – 10 Hz	126 dB, 1 – 10 Hz	128 dB, 10 – 15 Hz	130 dB, 2 – 50 Hz		
	140 dB, 10 – 15 Hz	128 dB, 10 – 15 Hz	116 dB, 10 – 15 Hz				
Corner Frequency (force feedback) or Natural Frequency (open loop)	≤0.0033 Hz	≤0.01 Hz	≤0.033 Hz	0.5 – 2.0 Hz	≥100 Hz	≥100 Hz	≥100 Hz
Flat Response (–3 dB Points) Bandwidth required	Velocity 0.01 – 35 Hz	Velocity 0.01 – 50 Hz	Velocity 0.033 – 50 Hz	Velocity 1.0 – 35 Hz	Acceleration 0.02 – 50 Hz	Acceleration 0.1 – 35 Hz	Velocity 0.1 – 35 Hz
Bandwidth desired	Velocity 0.00278 – 50 Hz	Velocity 0.0083 – 50 Hz	Velocity 0.01 – 50 Hz	Velocity 0.2 – 50 Hz	Acceleration 0 – 100+ Hz	Acceleration 0.02 – 100+ Hz	Velocity 0.02 – 100+ Hz
Generator Constant at Output	1000 – 2400 Vs/m at 1 Hz			100 - 2000 Vs/m at 1 Hz	0.583 or 0.291 Vs^2/m at 1 Hz		5 or 2.5 V/(m/s)
Max. non-coherent noise: Bandwidth required	3 dBa below NLNM 0.01 – 35 Hz	13 dBa above NLNM 0.01 – 50 Hz	21.6 dBa above NLNM 0.033 – 50 Hz	13 dBa above NLNM 1 – 35 Hz	Average –95 dBa, over 0.02 – 50 Hz	Average –52 dBa, over 0.1 – 35 Hz	As either, dependent on Class
Bandwidth desired	3 dBa below NLNM 0.00278 – 50 Hz	13 dBa above NLNM 0.0083 – 50 Hz	21.6 dBa above NLNM 0.01 – 50 Hz	13 dBa above NLNM 0.2 – 50 Hz	Average –101 dBa, over 0 – 100+ Hz	Average –58 dBa, over 0.02 – 100+ Hz	
Sensitivity Accuracy (relative to vendor-specified)	1 % <1 Hz; 1.5 % <10 Hz; 5 % <50 Hz			1 % at 20 °C and <10 Hz	1 % and <10 Hz		
Total Harmonic Distortion	≤–70 dB in on-axis sinusoidal excitation (THD = ratio of power in the fundamental to the sum of power in observed harmonics)						
Cross axis coupling	≤–70 dB for inherent cross-axis; ≤–40 dB for cross-axis due to misallignment of active axis relative to case reference						
Linearity	≤–70 dB of ANSS full-scale guidance (deviation from best fit in static tilt calibration)						
Hysteresis	≤–70 dB of ANSS full-scale guidance (rapid-flip test between ±1 g on dead-level surface or equivalent)						
Temperature-Induced Output Offsets and Sensitivity Errors	Stays on scale over ±10 °C without mass recentering			Offset <2 %FS over –20 to +40 °C. Offset <1 %FS over 0 to +40 °C. Sensitivity stable and accurate to 0.5% over 0 to 40 °C,			As for Broadband
Operational Temperature Range	–30 to +45 °C						
RFI Susceptibility	RFI performance of the sensor shall be tested per IEC61326:2002, including EN55022 for emissions, EN61000-4-3 for immunity, and Annexes A, C, E, and F, which detail equipment types and usage circumstances.						
Clip recovery	<5 minutes			<10 s			<5 minutes
Expected Lifetimes	Five Years					Ten Years	Ten years
Output Seismic Signal	±20 V, differential			See Generator Constant; differential	±20 V (±10 V allowed), differential		
Retrievable sensor parameters	Upon request, sensor provides manufacturer name, model number, serial number, and factory calibration parameters including sensitivity and nominal transfer function.						
Calibration Input	Calibration enable: Either active high (+5V) or active low (ground). Calibrator input sensitivity: sufficient to drive the seismometer output to at least 1/2 of full scale at 0.1 Hz with a current of 0.4 mA at 5 V or less						
Sensor Compensation	All sensor compensation, whether in sensor hardware, sensor firmware, DAU firmware, or laboratory software, shall be seamless and transparent with uncompensated data inaccessible to casual users. Compensation process shall be ANSS auditable.						

Table 4: DAU performance specifications

Performance Metric	Broadband			Short Period	Strong Motion	
	Class A+	Class A	Class A-	Class A	Class A	Class B
Input sensor channels	6			6/4	6/4/3	3
Sampling rates	0.1, 1, 20, 50, 100, and 200 sps (200 sps preferred default)			1, 20, 50, 100, and 200 sps (200 sps preferred default)		
DAU Amplitude Resolution (signal-to-noise ratios) at 200 sps [resolved bits, PTP; and ANSS-method rms dB]	≥24 bits (135.5 dB) 23 bits (129.4 dB), 0.01 – 15 Hz 22 bits (123.4 dB), 15 – 30 Hz	≥22 bits (123.4 dB) 21 bits (117.4 dB), 0.01 – 15 Hz 20 bits (111.4 dB), 15 – 30 Hz	≥20 bits (111.4 dB), all frequencies	≥22 bits (123.4 dB) 21 bits (117.4 dB), 0.01 – 15 Hz 20 bits (111.4 dB), 15 – 30 Hz	≥22 bits (123.4 dB) 21 bits (117.4 dB), 0.01 – 15 Hz 20 bits (111.4 dB), 15 – 30 Hz	≥16 bits (87.3 dB), 0.1 – 35 Hz
Preamplifier Gains	1			1, 3.2, 10, 32, 100 (10 dB steps)	1	
Total Harmonic Distortion	≤–70 dB in sinusoidal excitation at ADC-system input (THD = ratio of power in the fundamental to the sum of power in observed harmonics, using ANSS-method PSD)					
Gainand Offset Stability and Accuracy over Temperature	Gain stable and accurate to 0.5% over 0 to 40 °C, to 1% over full operating temperature range, and to 0.25% at DC, 20 °C. Offset less then 0.5%FS from 0 to 40 °C.					Same except gain accurate to 0.5% at DC, 20 °C
Ground currents, supply- and reference-voltage stability	No part of the analog system, including amplifiers and ADC, shall suffer disturbance greater than the system's quiescent noise floor at any time due to disk spin up, GPS or telemetry power up, or any other system activity. An external connector to primary-ground, seperate and apart from the power pins, shall be supplied.					
Worst Timekeeping Error with Regular GPS Locks	<1 ms					<2 ms
Internal time reference accuracy (free running)	0.1 ppm/°C and 0.1 ppm/day (at ANSS option, WebSync and/or NTP capability)					The same, but with 0.2 ppm/°C and 0.2 ppm/day.
DAU Recording	Complete and continuous; storage buffer ≥12 hours, with compression enabled					**Required:** buffer ≥1 hour; **Desired:** As Class-A
Trigger Store-and-Forward	**Required:** ≥60-s pre- and ≥90-s post-event; save largest; storage buffer ≥8 Mbytes **Desired:** ≥120-s pre- and ≥180-s post-event; save largest; storage buffer ≥32 Mbytes					
Trigger Algorithms for High-Rate Store-and-Forward	STA/LTA or equivalent, threshold (≤0.0008 to ≥1.0 g), and timed triggers, as well as any more sophisticated algorithms vendors may wish to supply. All triggers shall include minimum and maximum event-duration criteria.					Required: Threshold plus minimum duration Desired: as Class A
Telemetry Latency	≤30 s					ShakeMap parameters within 120 s of trigger
Telemetry	Format: IP required (TCP preferred); Carriers: Vsat, CDMA, ISM, ISPs, Frame Relay, ...					
Expected Lifetime	Ten Years (manufacturer to justify)					
DAU sensor input	±20 V			±20 V	±20 V or ±10 V (matching sensors)	
Temperature Range for Meeting **All** Guidelines not otherwise indicated	–20 to +40 °C					
Operational Temperature Range	–40 to +60 °C					
Control signals	Lock/unlock and mass center (broadband only), self-test enable, ring-down or free period test, damping test, produce sine, step and random binary calibration signals, all to provide sensor output of 5 and 50 %FS.					**Desired:** Same as Class-A Accelerometers
Acquiring Sensor Parameters	Capable of acquiring parameters from seismometers and accelerometers (e.g., transfer functions).					

Table 5: Performance specifications for power and packaging

Performance Metric		Broadband			Short Period	Accelerometer	
		Class A+	Class A	Class A-	Class A	Class A	Class B
Power	Average Power Consumption	All sensors plus the DAU together shall draw a total of <2 W, worst-case 24-hour average (10.8 – 16.0 VDC single-sided at battery, negative ground)					
	General	Accommodate 10.8 – 16.0 VDC single sided power to DAU, with polarity and transient protection. Any internal backup batteries shall operate for at least seven days at 2-W average draw with surge power sufficient for DAS worst case, including telemetry and mass-storage cycling. Provide for automatic, controlled DAU and sensor shutdown below 10.8 VDC net available. Provide surge suppression and noise filtering from AC ("mains") power, static discharges from users, and proximal lightning strikes. Tolerate 90 – 130 VAC 60-Hz mains power. Offer solar-panel option.					
	DAU to Sensor	DAU shall supply 10.8 to 16.0 VDC single sided power to sensor, with not more than 1 mV ripple. Sensor shall be able to operate at full capability using this power.					
Packaging	Connector Standardization	ANSS, in consultation with vendors, will create standards for the interconnection between the DAU and sensors, the DAU and its ~12 VDC power supply, the ~12 VDC system and solar panels, the ~12 VDC system and AC "mains" power, and the DAU and GPS signals.					
	Environmental Considerations	All DAU, sensor, GPS and power supply systems shall meet IP67 requirements and be capable of operating permanently in 100% relative humidity, excepting that power supplies need withstand only heavy spray, not immersion, though it must safely shut down upon immersion.					
		Neither the sensors nor the DAU shall suffer disturbance above its self-noise floor in response to barometric variations of ±0.025 bar about ambient.					
		RFI performance of the DAU shall conform to IEC61326:2002 (EN55022 for emissions, EN61000-4-3 for immunity, and Annexes A, C, E, and F, for equipment types and usage circumstances).					
		Both sensors and DAU shall survive 30 cycles of 100-g 1-ms half-sines over an interval of 10 s, alternating polarity, and 30-s of 5-g rms Gaussian white noise, these paired intervals repeating in round-robin among the axes.					
	Leveling	All sensors shall be supplied with leveling devices. All strong-motion components shall be supplied with tie-down devices and internal bracing to prevent movement of the sensor, DAU, and other external units as well as shifting of internal parts up to ±3.5 g.					
	Mass	DAS (less power supply): <20 kg			DAS (less power supply): <15 kg	DAS (less power supply): <15 kg	
Orientations	Sensor Orientations	Standard orientations (in order of channel numbers) shall be positive Up, North, and East or Up and two horizontals in the same left-handed sense.					
	Orientation Indicators	A North-axis (1st horizontal) shall be proveded on the *top* of the sensor (or DAS) and shall be a scribed line at least 10 cm long or the width of the case, whichever is smaller, and with "N" or an arrowhead toward the positive ground-motion direction.					
	Level Indicators	If a leveling bubble is provided, it shall be on *top* of the sensor (or DAS).					

5.6 *Commentary by Station Type*

National Station

From Table 1, broadband (BB) weak-motion seismometers are suitable for National stations, ideally supplemented by strong-motion sensors and a 200 sps data stream. Stations meeting the specifications of the Global Seismographic Network (GSN) would require Class BB/A+ instrumentation, with emphasis on low noise at long periods. National monitoring stations (interstation spacing about 70 to 280 km) need to resolve higher frequency bands, with less emphasis on the long period band. The best of these stations (at low noise sites) would require Class BB/A instrumentation, whereas the noisiest of these stations would use Class BB/A– instrumentation. The bandwidth and dynamic range specifications listed in Table 1 reflect these varying requirements. The maximum non-coherent sensor noise specifications were derived from contour plots across the U.S. of seismic noise in various bands, as observed by the U.S. National Seismic Network (USNSN).

The DAU digitizer resolution requirements are matched to the dynamic range of the seismometers. Note that all DAUs should be capable of sampling at a rate of at least 200 sps, which is also the preferred sample rate where practical. Less resolution is needed to resolve signals at higher frequencies (e.g., up to 15 Hz *versus* 15–30 Hz) because of typically higher noise levels in these bands. Also, it is well known that digitizers running at higher sampling rates are not capable of the high resolutions possible at lower sample rates, though that advantage can be recovered by properly downsampling a higher-rate data stream.

The power system should meet the specifications listed in Table 5. State-of-health (SOH) monitoring functions for the power system should reside entirely within the DAU and should be comprised of the following:

- The DAU should sample at least once per second (and at least five times faster than the interval at which the SOH is transmitted, whichever is faster) the ~10.8 to 16 VDC voltage input to the DAU by the power system, as referenced to the master ground. This sampling should be at a resolution of 0.01 VDC or finer.

- For the interval between SOH messages, the DAU should calculate the mean, minimum, maximum, and RMS of this power voltage to a precision of 0.01 VDC or finer.
- The DAU should report these four values in each of its SOH messages to an accuracy of 0.01 VDC or finer.
- To facilitate diagnosis of AC power failures and other disruptions to power systems, DAU SOH messages should be reported at least four times per day, preferably twelve or more times per day. The DAU should, if feasible, also send an emergency SOH message containing the same information just prior to when the DAU shuts down for loss of power or other fault condition.

Regional Station

The seismometer may be the same as for a National station. However, the noise requirements are less stringent and there is a need for response to higher frequencies due to the interstation spacing of about 50–70 km, implying the possible use of a different seismometer meeting these specific requirements.

A single vertical or three components of short-period seismometer may be appropriate for some active fault monitoring applications. These should be in addition to three-component strong-motion sensors.

The DAU for a Regional station needs somewhat less resolution than a DAU for a National station. Note that zero-phase FIR filters used in modern digitizers are known to create acausal artifacts that can cause problems for automatic phase arrival time picks from stations near an event. Despite this drawback, it is recommended that zero-phase filters should be used for Regional stations because of the enhanced value for later research. It is suggested that acausal artifacts can be reduced to acceptable levels for near-real-time processing by attenuating high frequency energy using minimum phase filters. Alternatively and preferably, it is possible to correct for the effects of minimum phase filters through the use of a filter designed specifically for the purpose.

Urban Monitoring Station

As indicated by Tables 3 and 4, the ANSS is interested in 3-, 4-, and 6-channel systems. Further, the sensors, the DAU, and the power system may be delivered as an integrated system or as physically separate modular units connected together with cables.

In the latter case, the ANSS may collaborate with manufacturers to standardize connectors and modularization schemes. Tentatively, the sensor cable should be included with the sensor, the GPS cables with the GPS receiver, the power cables with the DAU, external data-storage unit cables with that unit, and any telemetry cables with the telemetry transmitter.

With 21-bits of resolution and a Class A strong-motion sensor, a magnitude 2.5 event at 10 km epicentral distance should be well recorded for use of the entire waveform, while a magnitude 1.8 event at more than 35 km can be recorded well enough to determine the peak accelerations. Ambient seismic noise is likely to be the limiting factor in station performance, not resolution.

For Class B strong-motion systems, the expectation is that events of primary engineering and emergency response interest will be well recorded, including those that are likely to exhibit non-linear soil response. Additionally, studies of the causes of spatial variation in strong ground motions are a critical target, beginning with nearby events of M>3, which should be well recorded. Life-cycle cost is a critical issue for Class B systems, including purchase, installation, and maintenance costs, possibly even implying the ability to download system software upgrades from a remote server and reboot, with crash recovery.

While most ANSS data recording uses (and in the future will to an even greater extent use) continuous recording, local buffering, and telemetry, there remains a need to use at least basic triggering for: (1) assuring backup recording of the critically needed rare near-fault, NEHRP site-class E, and strong urban recordings; (2) temporarily boosting sample rates during large events, particularly at Regional and National stations; (3) maintaining the option of reducing telemetry costs by operating selected systems only in triggered mode; and (4) operating Class B monitoring systems principally or only in triggered mode to lower their life-cycle costs.

Table 4 specifies a minimum complement of trigger algorithms and specifics but leaves open the field of triggering to include the range of more sophisticated triggers implemented in many current instrumentation DAUs. It is also desirable for users to be able to supply their own trigger algorithms to DAUs with a minimum of (ideally no) manufacturer intervention and in a high-level language such as C.

Engineered Civil System Response Monitoring Stations

Specifications for this class of ANSS station are largely the same as those for Urban monitoring stations. There can be unique sensors or subsystems for structural monitoring that are not generally used elsewhere within ANSS, such as strain, displacement, or load sensors. Further commentary on this type of ANSS station is found in *Guideline for ANSS Seismic Monitoring of Engineered Civil Systems – Version 1.0, USGS Open-file Report 2005-1039.*

6 System Issues

In addition to the element-level functional performance specifications in the previous section, the design, specification, and installation of seismic systems must consider external environmental effects including:

- Moisture: humidity, rain, snow, temporary submersion due to flooding, and salt drift near coastlines;
- Temperature, both high and low;
- Wind, as it may affect physical integrity of the system components as well as seismic noise;
- Sun, as it affects short-term thermal changes and long-term material degradation;
- Pressure, as it affects sensor noise;
- Radio frequency interference (RFI), both from external and internal sources;
- Magnetic interference from external sources (EMI); and
- Rigorous anchoring of strong-motion sensors and other components at such sites to prevent resonance, banging, and other internal noise generation as well as intra-event shifting at ±3.5 g peak.

Some of the specifications in the previous section cover these environmental effects for components, but not necessarily for the overall installed systems. In addition to environmental effects, the design, specification, and installation of DASs for ANSS applications should address the following general system issues:

- Need for standardization between vendors of external connectors for power, sensors, communications, and timing;
- Provisions for field leveling of sensors (such as leveling legs) as well as periodic automatic leveling, principally for BB sensors;
- Robust anchoring of strong-motion systems and all other components at sites with strong-motion sensors,
- System and component weight (including power systems) where important, such as in remote field installations;
- Need for standardized control and data communications interfaces, including at least the ability to use a wide range of hardware/software computer platforms;

- Need for thorough documentation of components and as-installed systems to enable operation, maintenance, and confident use of the data; and
- Maximization of remote operation and maintenance functions (e.g., SOH messaging and remote adjustment of operating parameters, including at least gains, filter settings, sampling rates, and trigger settings).

System issues may be network-dependent and site-dependent; a thorough description is beyond the scope of this document.

7 Testing Guidelines

7.1 Overview

In addition to manufacturers' validation testing for their own purposes, verification testing of performance may be conducted as part of the procurement process. ANSS may test samples of all items in the specifications sections above that are applicable to that particular sensor, DAU, or DAS. Random and targeted acceptance tests of instruments (the deliverables) may be performed by ANSS to verify ongoing compliance with specifications, testing all or portions of applicable specifications as deemed appropriate by ANSS. Routine operational tests may be performed by ANSS to maintain data quality and monitor ongoing performance of instruments, testing all or portions of applicable specifications as deemed appropriate by ANSS. From time to time, ANSS may perform or contract out NIST-traceable calibrations of various instruments to test performance of its networks or the compliance of deliverables to contract requirements, and may during such calibrations test all or portions of applicable specifications, as deemed appropriate by ANSS.

The intention of vendor and ANSS testing described here is to reduce the lifecycle cost of these instruments and to verify their performance. Therefore, significant initial expense is tolerated where it is likely to reduce long-term expense, failures, and uncertainties in performance, reliability, or the validity of the data for their intended uses.

7.2 Validation Testing

Validation testing by the manufacturer checks that the product design satisfies or fits the intended usage. Such high-level testing is generally part of the design process and as such may be used by vendors to prepare for performance verification tests described in Section 7.3. Such validation testing may be part of the vendors' research and development, pre-qualification, and manufacturing-development processes leading to their confidence in their product.

7.3 Performance Verification Testing

Verification testing confirms that products meet specified performance requirements. In the ANSS context, this should be a formal step in which vendors complete formal performance verification testing (often under close ANSS observation) of final versions of two randomly-selected sensors, two randomly-selected DAUs, or two randomly-selected DASs (whichever item(s) are bid). In general, these tests should be done to a high level of quality assurance, with NIST-traceable measurement of performance metrics and within some kind of quality assurance environment such as ISO 9000. Test specifications should be prepared in advance of any procurements. All resulting data and analyses should be provided to ANSS in sufficiently complete form that ANSS can analyze the test data and confirm test results.

It is recommended that two or more test specimens be selected at random from a batch of eight or more final manufactured copies of final versions of the proposed sensor, DAU, or DAS. ANSS may require that tests be witnessed in person by ANSS staff or their representative(s) and possibly recorded in video and sound (by ANSS) for documentation and external review. ANSS may require that original test data be supplied to the witness for direct transfer to ANSS at the time of the testing.

7.4 Post-Award Testing

ANSS may perform three additional types of tests on instrumentation during procurement or operation as follows:

Acceptance Tests

Acceptance tests of randomly selected units may be performed upon delivery or shortly afterward to verify whether the components and systems meet ANSS contract specifications. If they do not: (i) the components/systems should be returned to the vendor for repair, (ii) additional units of similar manufacturing lots or serial numbers should be tested by ANSS, and (iii) if a pattern of vendor non-compliance emerges, that the vendor's history may be considered substantially unresponsive in subsequent requisitions.

Routine Operational Tests

ANSS will perform various routine *in-situ* and laboratory operational tests to verify the continuing performance of the DASs and supporting systems it operates. These routine operational tests may include automatic self-testing by the DAS, manual or automated sensor tests, manual or automatic voltage checks, and other field tests by maintenance personnel. These tests may be similar to Acceptance or Performance Verification testing but will generally be less extensive.

NIST-Traceable Calibrations

From time to time, ANSS may deem it appropriate to perform or to contract out NIST-traceable calibrations of all or portions of particular sensors, DAUs, or DASs to monitor the performance of vendors and of ANSS networks. Such tests will be generally similar to all or portions of performance-verification tests.

ANSS may (1) maintain a testing laboratory at the USGS Albuquerque Seismological Laboratory, (2) cooperate with Sandia National Laboratory and other ANSS and IRIS institutions in the use of their testing facilities, and/or (3) contract some tests to NIST-traceable testing facilities for acceptance tests, portions of routine tests, NIST-traceable calibrations, and authenticating portions of vendors' performance-verification testing, as deemed advisable prior to final award of contracts (using either vendor-donated or first-article examples of the instruments).