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STRUCTURAL MONITORING EQUIPMENT IN BUILDINGS DESIGNED WITH NONLINEAR RESPONSE HISTORY PROCEDURE

SCOPE

These special standards for the installation and servicing of structural monitoring equipment shall apply only to new buildings designed in accordance with the nonlinear response history procedure of Chapter 16 of ASCE 7, "Seismic Response History Procedures" and required structural monitoring instrumentation per Section 1613.10.2 of the Los Angeles Building Code (LABC). The instrumentation requirements in this bulletin shall be used with the requirements in Information Bulletin P/BC 2014-048 for conventional high-rise buildings.

OVERVIEW

The primary objective of structural monitoring is to improve safety and reliability of infrastructure systems by providing data to improve computer modeling and enable damage detection for post-event condition assessment. Given the spectrum of structural systems used and response quantities of interest (acceleration, displacement, strain, rotation, pressure), the purpose of this bulletin is to provide comprehensive and flexible installation requirements for instrumentation to facilitate achieving these broad objectives. The instruments should be selected to provide the most useful data for post-event condition assessment. Variations in the instrumentation scheme for a given building type (e.g., steel moment frame) may be warranted to provide a broader range of data given the required relatively sparse instrumentation. An advantage of proper instrumentation to the building owner is that post event assessment may be expedited thru utilization of the data from the instrumentation meeting that described herein.

PART I: REQUIREMENTS

A. Instrumentation Plan and Review

The proposed instrumentation plan shall be prepared by the structural engineer of record and approved by the Department and the independent design Peer Review Panel (PRP) during the peer review process described in LABC Section 1613.10.2 and ASCE 7 Section 16.2.5. Approved instrumentation plans shall be incorporated into structural drawings. This shall include, but not limited to the following:

1. Review of compliance of the proposed monitoring system to these specifications. If the building is intended to be included in the inventory of buildings monitored by the California Geologic Survey (CGS), then the recorders and accelerometers shall be of a type approved by the CGS. For additional information regarding CGS monitoring program and funding for instruments, see <http://www.conservation.ca.gov/cgs/smip/Pages/about.aspx>.

2. Review of usefulness of selected monitored response quantities.
3. Review of the appropriateness and functionality of any novel sensors, if applicable.
4. Delegation of responsibility for system maintenance and data collection.

B. Minimum Number of Channels

Every new building shall be provided with a minimum number of channels as specified in Table 1. The minimum number of required channels may be increased at the discretion of the PRP. Each channel corresponds to a single response quantity of interest (e.g., unidirectional floor acceleration, inter-story displacement, etc.)

Table 1. Minimum Number of Channels

Number of Stories Above Ground	Minimum Number of Channels
6 - 10	12
11 - 20	15
21 - 30	21
31 - 50	24
more than 50	30

C. Distribution

The distribution or layout of the proposed instrumentation shall be logically designed to monitor the most meaningful quantities. See COSMOS Instrumentation of Buildings Workshop Proceedings for example deployments, <http://www.cosmos-eq.org/>.

The channels shall be located at key measurement locations in the building as appropriate for the measurement objectives and sensor types. The sensors shall be connected by dedicated cabling to one or more central recorders, interconnected for common time and triggering, located in an accessible, protected location with provision for communication.

PART II: SPECIFICATIONS

Structural monitoring equipment must be complete, integrated systems, unobtrusive, easily serviced, and stable over long periods of time without attention. Sensing and data acquisition equipment shall be at least equal in quality to those as specified in these specifications.

Recorders and accelerometers must be of a type approved and in use by the CGS or United States Geologic Survey, described in the Information Bulletin P/BC 2014-048, "Specifications for Strong Motion Accelerographs & Requirements for Installation and Service." Only supplemental sensing equipment meeting the following criteria may be installed in a building to fulfill requirements of LABC Section 1613.10.2.

A. Displacement Sensors

Relative displacement sensors shall be of a type commonly used in long-term installations such as Linear Variable Differential Transformer (LVDT), Linear Potentiometer, String or Draw-Wire Potentiometers, and Laser and Acoustic Sensor technology.

1. Stroke range shall be selected to reasonably match the expected response quantity magnitude.
2. Accuracy: 0.5% full stroke.
3. Repeatability: $\pm 0.05\%$ full stroke.
4. Resolution: 0.01% of full stroke.
5. Operating temperature range: -20 to +60°C.

B. Strain Gages

1. **Materials:** All materials shall be appropriately selected for thermal expansion compatibility with specimen material.
2. **Compensation Temperature Range:** -20 to +60°C.
3. **Strain limit:** 4% when yielding is expected, 0.5% otherwise (at room temperature).
4. **Fatigue limit:** 1 million cycles (at room temperature).
5. When using embedded gages (e.g., rebar strain gage), a minimum of 3 sensors shall be initially installed for redundancy to account for potential failures during and after concrete placement.

C. Other Sensors

This section refers to the use of commercially available sensors that measure response quantities other than acceleration, displacement, and strain, such as: rotation, inclination, velocity, force, pressure, etc. The instrument specifications will be dependent on the given technology, but must satisfy requirements as those previously listed.

D. Novel Sensors

Unavailability or shortcomings in existing transducers or advances in sensor technology may lead to the development of novel sensing systems that are not commercially available. The City of Los Angeles encourages the use of novel sensing systems as needed to capture essential data provided:

1. Data are provided to demonstrate proper sensor function for the response quantity of interest over the response range of interest.
2. The design and maintenance requirements are well documented and meet industrial standards.
3. Calibration factors and range of linearity shall be provided.
4. The sensors' expected life shall be similar to that of conventional sensors (15 - 20 years or more) or the sensor shall be easily replaceable upon failure.

E. Communication

In the event that more than one central recorder is used, the following shall be provided:

1. A continuous 4-pair inter-connection cable (plenum-rated RS-485 cable similar to Belden 9844 or approved equal) is required between the recorders. (A Conduit is only required where the cable is likely to be damaged.)
2. A continuous 4-pair communications cable (plenum-rated Category 5 such as Belden 1624P or approved equal) is required between the recorders.
3. A four-port AC-powered phone switch (such as a ComSwitch 7500 or an approved equal) shall be installed to allow communication with all recorders via one phone line. The ports of the telephone switch are to be connected to the recorders via the communication cable.
4. Alternate inter-connection and communication cabling methods between the instruments may be approved after review.

PART III: INSTALLATION AND SERVICING

A. Equipment Installation

Installation details will vary considerably for each structural monitoring installation; however, the following are general requirements that shall be followed:

1. **General:** Instrumentation shall be installed with normal standards of professional care. The need for long-term reliability shall be foremost in the installation work plan and details.
2. **Reference Location Accuracy:** A reference location on the structure or nearby ground shall have documented accuracy of one ten-thousandth of a degree in latitude and longitude.
3. **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.
4. **Sensor Gage Length:** Where applicable, as-built sensor gage length shall be measured and recorded to ensure data reliability. Photographic documentation of the sensor as installed, with a scale (ruler) included in the photo, shall be provided to the building owner, and used as a reference for maintenance.
5. **Sensor Orientation:** Sensors within a structure should be oriented in a logical manner in line with the structure's primary axes or as needed to measure the response quantity of interest. Sensors should be mounted within 0.5 degrees of the desired orientation within the structure. Sensor orientation is critical to data interpretation and shall be well documented and controlled.
6. **Anchoring and Hardening:** All sensors, recorder and auxiliary components shall 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. Photographic evidence (and/or sketch if necessary) of the anchoring shall be provided.

B. Maintenance

Required structural monitoring instrumentation shall be serviced and maintained in proper working condition to provide measurements during seismic and wind events of interest. The installation, servicing or removal of the instrumentation shall be done by an authorized maintenance agency.

1. **Service Period:** The maximum service interval is one year. If the instrumentation is inoperative at consecutive service inspections because of recurring similar problems, then a re-inspection and servicing shall be required at least semi-annually until the problem is corrected. The authorized maintenance agency shall determine the shorter period so the instrumentation is continually operative.

2. **Refurbishing:** Where the instrumentation maintenance agency finds that the instrument must be removed from the building for repair, the instrument shall be returned and made operative as soon as possible but in not more than 60 days from the removal date.
3. On request of the building owner, and acceptance of the installation of a recording system that meets the CGS System Requirements for structural systems (<http://www.consrv.ca.gov/cgs/smip/Documents/SystemRqmts-CentralRecordingAccelerograph.pdf>), California Strong Motion instrumentation Program (CSMIP) shall agree to provide long term monitoring of the recording system to help assure its correct operation. CSMIP will perform periodic state-of-health checks and functions tests remotely via the provided phone line and notify the building contact person and the city of Los Angeles Department of Building and Safety Inspector when any repairs are needed. Needed repairs shall be the responsibility of the building owner.
4. For instrumentation systems monitored by CSMIP, CSMIP will monitor and report on the apparent health of the recorder, accelerometers and displacement sensors. Other sensors will also be monitored and their apparent health reported if the building owner or representative provides information on the characteristics of the signal produced by the sensors in their operational and failed states.

PART IV: DATA MANAGEMENT

A long term goal is to have near-real time controlled access to the building response data via a website or some other html-based application. To this end, structural monitoring systems shall be extensively and formally documented, with narrative and digital photographic descriptions of each component, and shall comply with the following criteria to allow for future coordination.

A. Format

Recorded data shall be provided in (or easily converted to) a format consistent with that currently required to be published in the Consortium of Organizations for Strong Motion Observation Systems (COSMOS) database (COSMOS 2001). These requirements can be found at the COSMOS website (<http://www.cosmos-eq.org/>) under the publications menu. Data files names shall be in a form identifying the building, channel and date/time, for example: Building_name.sensor_id.date.start_time.txt.

B. Metadata

The following building specific information shall be provided in a single or multiple file as needed:

1. Building/station.
2. Building/station location (address & coordinates).
3. Structure/system type.

4. Description and detailed sketch of monitoring system including sensor layout.
5. Monitoring system history (installation data, modifications, etc.).
6. Other descriptive information (e.g., construction documents, material properties, detailed mathematical analysis results).
7. In correspondence to each sensor (or group of sensors), the following information shall be included in either the data files as a delimited header or in a separate metadata file.
8. Sensor type (acceleration, displacement, etc.).
9. Sensor manufacturer, model, serial number.
10. Output units (including time units) with calibration factors.
11. Sensor location (coordinates to reference location).
12. Sensor orientation (label appropriate columns).

C. Storage

1. Triggered systems should be provided with sufficient capacity to store the recordings of 30 or more earthquakes each of which are a minimum of 2 minutes in length.
2. Continuously recording systems, if used, shall be provided with sufficient local storage to record 200 sps per channel for a minimum period of 7 days.
3. Reliable on-site storage capacity such as flash memory or raid array shall be provided in each central recorder.
4. There shall be one or more central recorders with all sensors communicating by wire.
5. The central recorders shall be physically accessible and capable of enabling future internet access (e.g., ftp).

D. Collection

1. The data shall be collected by an approved agency and stored in a secure off-site location.
2. For recording systems monitored by CSMIP, the data will be recovered and processed and the results will be provided to the building owner and to DBS with the approval of DBS placed at the CSMIP web site and with only the location generically identified.