4. Summary of Workshop Discussions and Workshop Recommendations

PEDRO DE ALBA
J. CARL STEPP
ROBERT L. NIGBOR
JAMISON H. STEIDL
COSMOS

After the individual presentations, it was originally planned to have three break-out discussion groups to address the following topics:

- Site characterization requirements
- International collaboration, data sharing, and data dissemination
- Need for geotechnical strong-motion measurements

In view of the lively discussions that took place during the individual presentations, the organizers proposed that the workshop as a whole address the three topics in succession.

SITE CHARACTERIZATION

Depth of Exploration

Soils exploration should be taken to at least the depth of the deepest instrument. Exploration should extend into "sound" rock or stiff soil, with $V_s \geq 600$ m/sec. While this is NEHRP Category C, it is now considered to be engineering rock for most applications. Whether directly or indirectly, the position of rock with $V_s \geq$ 1500 m/sec must be established.

Soil Characterization

In general, the level of effort in geotechnical site characterization should be related to the stiffness of the soils. More effort should be made in characterizing near-surface soft and weak soils (e.g., soft marine clays, liquefiable soils) than stiff soils. The softer layers may have a disproportionately greater influence on the instrumented site response; a thick deposit of soft to medium stiff clayey soil should warrant more detailed investigation than a deposit of dense sand.

As a minimum, a borehole with dense sampling using simple techniques should be carried out to the depth of the deepest instrument. This borehole would be parallel to the deepest instrument borehole. Index properties and densities of all soils should be obtained at frequent intervals. For this purpose, Standard Penetration Tests (SPT), with energy calibration at selected depths and recovery of disturbed samples, should be carried out in sands and thin-walled tube sampling in clays. Undrained shear strength of clays should be

obtained from field or laboratory tests, and friction angle of sands inferred from SPTs. The workshop also strongly recommended that geophysical logs using gamma-gamma and neutron methods be used to develop density/water content distribution with depth if deep borings make the collection of soil samples difficult.

It is also highly recommended that cone penetration tests (CPT) centered on the sampling boring be carried out to (a) explore lateral variability of the shallower deposits: and (b) obtain additional parameters for numerical modeling studies. As a minimum, shear-wave (V_s) and compression-wave (V_p) velocity measurements must be carried out to the depth of the deepest instrument. Deeper measurements are required if V_s at the deepest instrument location is still below 600 m/sec. If possible, more than one technique should used to check results.

Other Issues

It was suggested that at least one empty-cased borehole be left open at the array site for future site characterization research, such as the use of active measurements and property inversion techniques for measuring soil damping *in situ*. It would also be useful to develop a guideline for geotechnical site characterization. The guidelines followed should include protocols for drilling, sampling, and performance of *in situ* tests.

Discussion of site response predictions using computer models that incorporate multiparameter constitutive models of soils led to the suggestion that a group of informed users should come to some agreement as to the importance of precise measurements of different input parameters as used by state-of-the-art finite element and finite difference codes. A study of this type would greatly assist in defining minimum requirements for site characterization, and direct where efforts in laboratory and field testing should be focused.

INTERNATIONAL COLLABORATION, DATA SHARING, AND DISSEMINATION

Following a presentation on the ongoing development of the COSMOS Geotechnical Virtual Data Center (GVDC), https://geodata.cosmos-data.org, workshop participants advised the following:

Two new categories should be established: "deep array" and "surface array." These categories are needed where more than one sensor is associated with a strong-motion station. Selection of one of these new categories will allow users to choose a location and access the available metadata for all sensors. A pointer will then lead users to a representative surface record at the COSMOS strong-motion data center (SMVDC), http://www.db.cosmos-eq.org, where a flag will direct users to the array operator's database, from which other records may be obtained. This methodology may also be applicable for structural arrays. Given the importance of public recognition in assuring future operating funds, all users should be strongly encouraged to properly acknowledge the source of all records used.

International collaboration in developing common formats for metadata and records should be vigorously pursued; COSMOS is encouraged to take a leadership role in this area. Collaborative efforts in establishing geotechnical arrays in highly seismic areas outside the United States should also be pursued; the Pacific Rim of Latin America is a prime candidate for this type of cooperative effort. A full compilation of currently operating geotechnical strong-motion arrays should be made and kept current into the future.

THE NEED FOR GEOTECHNICAL STRONG-MOTION MEASUREMENTS

Density of Instrumentation

Participants agreed that careful consideration should be given to large impedance contrasts in the placement of instruments so that strain distribution through the soil profile may be correctly approximated from the measurements (for example, an instrument should always be placed in a soft layer between two hard layers). At least one (base) instrument should be placed at a depth where shear wave velocity $V_s \geq 600$ m/sec. Based on site-specific Vs profiles and the wavelengths of interest, the distribution of instruments may be optimized by site response analyses carried out after the initial exploration program is completed. Further, it was considered that a deep soil deposit (100 m, for example) should have several instruments distributed through the profile, even with uniform soil conditions, rather than just one at the surface and one at the base. An ideal spacing would be one that samples directly below, within, and directly above any layer where strongly nonlinear behavior is predicted.

Minimum Depth of Instrumentation

This depends to some degree on local geologic conditions and the principal purpose of the array. Ideally, the deepest instrument should be in rock with Vs $\geq$ 1500 m/sec. If not feasible, 100 m was suggested by some participants as a minimum recommended depth. For soil-structure interaction studies, some considered that a better use of limited resources might be a dense near-surface array. On the other hand, it was pointed out that for site response studies motions at frequencies down to 0.5 Hz or lower are of great engineering interest. Therefore, assuming average shear wave velocities in soils and shallower rock, a minimum depth of 300 m (1000 ft) to 400 m (1300 ft) would be needed to properly evaluate base/ surface transfer functions. It was noted in the discussion that the KiK-net array in Japan has 21 instruments installed at depths of 1000 m or more, with the deepest at 2300 m.

Surface Arrays

It was recommended that deep instrumentation arrays be combined with a surface array whenever possible to evaluate basin effects and identify azimuth and apparent propagation velocity of seismic waves. The use of surface motion measurements for incoherence studies for the seismic design of lifelines should also be considered in laying out such arrays. A strong plea was made for developing unified formats for array data and creating unified metadata descriptions. COSMOS was seen as playing an important role in establishing uniformity in this regard.

Piezometers

Arrays of piezometers capable of recording earthquake-induced pore pressures were considered indispensable at instrumented sites where the possibility of liquefaction is likely. These instruments must be designed for recording dynamic water pressure signals and should be installed so that their long-term performance can be verified. Pre-earthquake water levels must be recorded, and recording must continue through the post-earthquake pressure dissipation phase.

Installation

Concerns were expressed about developing agreed-upon standards for downhole accelerometer installation. Two specific problems were mentioned:

1. The effects of the stiffness of the grouted-in casing on measured instrument response (especially for shallow instruments). Further discussion of this problem, leading to standardization of casing properties and dimensions, as well as grout mix proportions, was considered a topic for discussion in the second phase of the Workshop.
2. Accurate orientation and repeatable positioning of downhole accelerometers is essential. Two systems for installing these instruments were discussed: locking the sensor in place using a specially designed casing section (such as the California Strong-Motion Instrumentation program (CSMIP) "bishop's hat,") versus confining the accelerometer in sand or glass beads. Strong views were expressed on both sides. No agreement was reached. This topic merits further discussion.

Candidate Sites

Several possible array locations to address gaps in the current body of knowledge were suggested:

1. Parallel arrays at improved and unimproved locations to study effects of soil improvement techniques.
2. Arrays in deep, non-plastic silts and in large landfills.
3. More arrays designed to study soil/structure interaction. Because the profession currently has little information on this subject, a special plea was made for instrumentation of complex structures in waterfront berthing and cargo handling areas. Such arrays would require very careful attention to deformation measurements, as well as surface/downhole accelerometer arrays and piezometers in potentially liquefiable materials.

DEVELOPMENT OF AN IMPLEMENTATION ACTION PLAN

The perspective gained from the workshop discussions and the recommendations of the workshop participants will significantly guide Phase II of this project, which will develop an action plan for coordination of geotechnical array installation and ongoing coordination of long-term operation. As part of Phase II, a second workshop will be held to review and reach consensus on coordinating an implementation action plan for geotechnical array installation and long-term operation that is consistent with the future needs developed as part of the first workshop. Sessions of the workshop will address:

- Guidelines for selection of sites for geotechnical monitoring: Selection criteria may include probability of recording nonlinear behavior, probability of liquefaction, probability of capturing lateral spreading, proximity to earthquake sources, probability of capturing basin effects, obtaining recordings on improved soil sites, soil-structure interaction, and, possibly, other criteria. No one site can possibly satisfy all these criteria;

instead, the workshop will focus on developing guidelines on how these criteria should be prioritized and applied for selection of sites.

- Site installation and long-term operation: This session will focus on how installation and operation should be institutionalized so that the long-term existence of a site does not depend on the interest of any particular individual. It also will address how ongoing monitoring should be coordinated taking into account established geotechnical array monitoring programs and specific experimental sites, for example, those operated under specific grants. The session will in addition address long-term oversight and issues of long-term funding.
- Archiving and dissemination of borehole array observations and associated metadata worldwide: This session will document current practices in archiving and dissemination of strong-motion recordings, geotechnical data, and metadata. This will include archiving and dissemination of strong-motion data and geotechnical data worldwide. It will include existing and developing geotechnical database archives and ongoing geotechnical virtual data center development activities, as well as relevant supporting research activities. Activities aimed at archiving and dissemination of metadata will be reviewed. The session will address whether existing and developing database archiving and dissemination infrastructure is sufficient and/or what additional development is needed to accommodate data from geotechnical borehole array monitoring and associated surface arrays. Finally, the session will address coordination of data dissemination and long-term funding requirements.