SECTION 6

Geotechnical Engineering—Field Investigation

Equipment to Take

1. Hand-held inclinometer.
2. Optical survey equipment.
3. Maps. Every effort should be made to acquire a reasonable topographic map of the affected area prior to departure. A 1:100,000 scale map is good for a regional overview. Maps of 1:25,000 or less are better for more focused and site-specific concentration. Geologic maps and hazard maps (if available) are quite useful. Aerial photos, including stereo pairs, can be especially helpful. If time is available, topographic maps can be obtained from a variety of library services. Aerial photos can be obtained from institutions such as USGS, USDA, NASA, and the Department of the Army. Refer to Appendix C, Information Sources.

Types of Data to Be Collected and Recorded

Determine the effects that earth deformations and strong ground shaking had on structures. Cracks, fault widths, uplift, subsidence, tilting, or warping should be measured and noted. Surface expressions of the causative fault should be examined and documented. Where appropriate, draw geologic cross-sections to indicate the nature of earth materials. Inspect and assess the performance of engineered structures with respect to strong ground motion and earth deformations such as settlement, liquefaction, ground cracking, landslides, and ground offset. Documentation is also needed of undamaged sites, sites near the threshold of failure, and good performance of structures, noting types of soils.

CHECKLIST

Geotechnical Engineering

General Site Evaluation

1. What is orientation of the site relative to magnetic north?
2. What is the topography around the site?
3. Note location of sand boils and identify any material ejected.
4. Is there evidence of soil deformation?
5. Are any parts of the site on cut or fill? Can an estimate be made of the depth of the cut or fill just by looking?
6. Obtain as much information as possible on thickness and composition of soils.
7. Estimate slopes with hand-held inclinometer or optical survey equipment.
8. Is the site on alluvium? Inquire as to its depth.
9. Determine type of soil: soft soil, loose sand, unconsolidated silt, loam, mud, dump fill, firm soil, gravel, consolidated sand, consolidated silt.
10. What is drainage of site? Above or below grade?
11. Obtain as much information as possible about depth of water table on both sides of causative fault and throughout affected area.

12. Obtain a Mercalli estimate for the site.
13. Evaluate the overall quality of construction and the use of good seismic practices.
14. Investigate areas where amplification of ground motion may have taken place, e.g., topographic ridges, structural basins, soft and sensitive clays, etc.
15. Contact local geotechnical professionals to obtain information on local subsurface conditions, applicable codes, design and construction procedures, etc.

Ground Deformation

1. Document length and width of rupture.
2. Describe original displacement or renewed displacement on old fault trace.
3. Did any additional displacements (mainshock or aftershock) occur on nearby or subsidiary faults?
4. What is relative offset? Does offset change (along fault) as distance from epicenter increases?
5. Plot on geologic map: seismic data (instrumental and other) and contours for possible attenuation pattern(s).
6. What was amount of fault separation (slip)? Describe horizontal, oblique, and vertical characteristics. Note location of measurement.
7. Describe uplift, subsidence.
8. Did regional and local tilting and ground warping occur?
9. Identify locations of soil liquefaction.
10. Describe soil liquefaction according to flow failure, lateral spread, subsidence, loss of foundation bearing, and buoyancy effects on buried structures.
11. Describe in-place soil parameters and ground failures such as relative density versus liquefaction.
12. Note slickensides, gouge, fault breccia, other.
13. What is relationship of fault scarp formation and height to local geology, bedrock structure, and geomorphology? Include location.
14. Describe any secondary permanent effects.
15. Document post-earthquake fault creep.
16. What is depth to water table on both sides of fault?
17. Describe geologic structure on each side of fault (map units, bedding and/or joint attitudes, other faulting).
18. If underwater, note depth and sea conditions (velocity, direction, wave height).
19. Sites where ground improvement procedures have been applied should be specifically located and investigated and good as well as poor performance documented.
20. Geotechnical engineering needs fully documented case histories for liquefaction and landslide sites, including subsurface drilling information on soil and rock stratigraphy and properties. Note need for bore holes and geotechnical testing as part of the recommendations for further research.
21. Document undamaged sites and sites near the threshold of failure.

Soil-Structure Interaction

1. What is relationship between ground failure displacement and damage to engineered structures?
2. Liquefaction:
   a. What is distribution and severity of liquefaction effects with respect to the source zones of the earthquake?
   b. Assess the consequences of liquefaction, e.g., vertical and lateral displacements.
   c. Assess the performance of structures supported on deep foundations compared to those supported on shallow foundations in liquefied areas.
3. Note cracks in the soil around the base of the structure.
4. Is there foundation or subsoil evidence that the building rocked?
5. Note in particular the performance of stiff, massive structures that rest on flexible soil.
6. Try to correlate superstructure damage with local soil conditions. Geologic maps and soil boring data may be needed.
7. Pay particular attention to damage at locations of soft, sensitive clay. Target the areas for soil borings and in-situ tests.
8. Investigate infilled basins where amplification of ground motions through soft sediments is most likely. Document observations.
9. Was there damage to engineered structures? If so, note type of structure and specify damage and cause. Examine buried as well as surface structures.
10. Document good performance: undamaged buildings, bridges, and other structures founded on soft ground; liquefaction areas; landslide areas; etc. Document lack of damage along with any observed ground disturbance.
11. Be alert for lateral spreading effects on structures supported by deep foundations. Did lateral spread damage piles?
12. Examine footings of bridge and pipeline crossings for evidence of lateral spreading. Describe any damage. Observe soil-structure interaction. Observe response of deep foundations to ground movements.
13. Note performance of reinforced earth and other mechanically stabilized walls.
14. Note performance of earth and rock anchor tied-back walls.
15. Note performance of both hazardous and municipal landfills.
16. Note performance of retaining structures, including open fully or partially supported excavations, bridge abutments, etc.
17. Describe any movement of basement contents.

Landslides, Lateral Spreading, and Submarine Slope Failure

1. Indicate failures on geologic/topographic map.
2. Note latitude, longitude, area involved (m2), quantity (m3).
3. What was cause of failure?

4. Describe failure, including direction and rate of movement, soil and rock types, and groundwater conditions.
5. What was original slope angle? Ridge orientation?
6. Was this a new slide or a reactivated old slide?
7. Was this a natural or manmade slope?
8. What was time of failure relative to start of ground motion?
9. Was slide composed of artificial fill? If so, note age, type of construction, materials, and degree of compactive effort.
10. Describe any pressure ridge or graben development, including width, length, and depth.
11. Note distribution and frequency of landslides as a function of distance from the epicenter.
12. Document damage to engineered structures.
13. Describe other damage caused by ground failure.

Settlement

1. Describe settlement, including cause, i.e., compaction, consolidation, liquefaction.
2. Describe earth materials involved: age, type, sorting, grain size, water content, depth to water table, thickness, artificial fill including age and type of consolidation.
3. What was amount and extent of settlement? Of differential settlement?
4. Look for settlements at bridge and overpass abutments. Correlate settlement with bridge damage and damage to pipelines that may cross beneath the bridge.
5. Did mud or sand boils occur? If so, note location. Note amount and type of any material ejected.
6. Describe type and extent of damage to engineered structures, e.g., surface and buried, artificial fill, other.
7. Describe other damage caused by settlement.

Ground Cracking

1. Take note of geometry, including overall dimensions and slope. Draw geologic cross-section (use back of form sheet).
2. Describe location, length, width, depth, spacing, and attitude of ground cracking.
3. What type of surface materials (age, thickness, etc.) are involved?
4. Describe any extension or compression features.
5. Describe any relationship of ground cracking to landslides.
6. What were topographic effects? Shattered ridge tops?
7. Describe type and extent of damage to engineered structures, e.g., surface and buried, artificial fill, other.

Dams and Reservoirs

Earth and Rock Fill Dams

1. Are there cracks parallel to axis, indicating sliding of part or all of either the upstream or downstream faces?

2. Are there earthquake-induced settlements in rockfill shells?
3. Look for cracks perpendicular to the axis, indicating settlement or distortion of the dam. Are there changes in preexisting cracks?
4. Was there settlement or lateral movements of crest? Resurvey crest lines.
5. Was there increase or decrease in seepage? Is there seepage now occurring where there was none previously?
6. Have there been changes in color of seepage water, indicating solids in water?
7. Did surface slumps or sand boils occur?
8. Did cracking offsets in rock or concrete parapet walls or training walls occur?
9. Was there increase or decrease in leakage past gates?
10. Did bulging occur in ground at toe of dam?
11. Where foundation or embankment piezometers are available, have there been any changes in water level or pressure?

Concrete Dams

1. Have any new cracks occurred?
2. Has there been increase or decrease in leakage past gates?
3. Have abutment rockfalls occurred?4. Have there been any changes in seepage and seepage into galleries and shafts?
5. What is condition of water seals?
6. Where foundation drains or piezometers are available, have there been any changes in water level or pressure?
7. Did settlement or horizontal movement of crest occur? Resurvey crest.

Spillway, Inlet, and Outlet Structures

1. Did damage occur?
2. Was there any damage to auxiliary structures such as gate hoists, gates, or valves?
3. Was operability subsequent to earthquake affected by binding that might indicate distortion?
4. Did joint displacements occur?
5. Did structure maintain ability to function? If not, why?

Waterfront Structures

1. Compare behavior of waterfront dock and pier structures relative to construction type—e.g., pile-supported piers, quay walls, or sheet pile bulkheads.
2. Note types of waterfront retaining walls investigated (gravity, anchored bulkhead, cantilever, reinforced, etc.). Document any damage.
3. Check for ground deformation—liquefaction, sand boils, settlements, or landslides. Note type of soil on which each occurred.
4. Determine influence of batter piles on damage. Compare similar facilities with and without batter piles.
5. Inspect material-handling equipment such as moving cranes and conveyor systems. Did moving equipment jump off rails?

River Crossings

1. Examine footings of bridge or pipeline crossings from evidence of lateral spreading.
2. Document any damage.

Hydrologic Effects

1. Note elevation change(s) in water wells.
2. Note elevation change(s) or pressure changes in artesian wells.
3. Determine whether or not there was any damage to pump stations. Could water elevation change be due to lack of pumping?
4. Did salt water intrusion occur?
5. Were there changes in stream or spring flow?
6. Did streams exhibit increased sediment transport?
7. Did sag ponds form?
8. Describe any dam failure and inundated areas.
9. Identify benchmarks for changes in water level.

Secondary Impacts

Seiches

1. Describe type of water body affected (lake, bay, harbor, etc.).
2. Describe dimension, depth, location.
3. Determine orientation of major and minor axis of water body.
4. Is a bathymetric map available?
5. What was direction of seiche motion in relationship to shape of water body?
6. Note run-up, location, height, and period (in seconds).
7. Note time (local and UTC) for start and stop of seiche.
8. What is distance (in kilometers) of seiche occurrence from causative fault? From epicenter?
9. Describe geology and geomorphology of area.
10. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).

Local Waves

1. Describe damage from local waves due to nearby submarine slope failure or the sliding of surface earth or ice into a body of water.
2. Describe type of water body (lake, bay, harbor, etc.).
3. What was arrival time?
4. Document number of waves, frequency (period in seconds), run-up, and height.
5. Describe geologic setting where slope failure occurred.
6. Describe geologic setting where wave damage occurred.
7. What is distance of wave damage from point of slope failure?
8. What is distance of local wave occurrence from slope failure?

9. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).
10. If applicable, note quay wall and structural retaining wall performance.

Tsunami

Refer to Section 15, Tsunami Impacts—Field Investigation, for checklist.

Field Investigation Form—Geotechnical

Name of Investigator:________________________ Date: ___________

Ground Deformation

Amount of fault separation (slip?):

Horizontal: (m) Oblique: (m)

Vertical: (m) Location of measurement:

Fault: Strike: Dip:

Width of fault trace (latest rupture):

Slickensides, gouge, fault breccia, other:

Relationship of fault scarp formation and height to local geology, bedrock structure, and geomorphology (include location):

Relative offset as a function of depth: ___________ Location: _________

Faulting (original displacement or renewed displacement on old fault trace):

Liquefaction:

Any additional displacements on nearby or subsidiary faults (mainshock or aftershock)?

Evidence of fault creep:

Location: Amount: (m)

Sense of movement:

Foreslip or afterslip?

Relation to aftershocks:

Width of old fault zone through which new faulting took place: ________

Change of offset (along fault) with increase of distance from epicenter: (m)____

Other Effects

Damage to engineered structures (type):

(Note lack of damage as well.)

Water table depth:

One side of fault: (m)   Other side: (m)

Secondary Impacts

Secondary effects include landslides, lateral spreading, and submarine slope failures; settlement; ground cracking; hydrologic effects (including dam failure); tsunamis; seiches; and local waves. See checklist for observation details.

Recommendations for Further Geotechnical Research

Name of Investigator:________________________ Date: ___________

Location:

Why needed:

Trenching and/or Boreholes

Where, how deep, how many:

Why:

Instrument Installation

Type and number:

Geodetic Surveys

Location:

Engineering importance:

Recommendations for study:

Strain maps (crustal):

Measurements of afterslip:

Local tilting:

Submarine Studies

Describe proposed studies:

Recommend SCUBA investigation?

For what purpose?