Appendix B
PROVISIONS FOR SITE CHARACTERIZATION

B.1 GENERAL

Site characterization shall be performed for each substructure element, as appropriate, to provide the necessary information for the design and construction of foundations. The type and extent of site characterization shall be based on subsurface conditions, structure type, and project requirements. The site characterization program shall be extensive enough to reveal the nature and types of soil deposits and/or rock formations encountered, the engineering properties of the soils and/or rocks, the potential for liquefaction, and the groundwater conditions.

Site characterization normally includes subsurface explorations and laboratory testing of samples of soil/rock recovered during the exploration work. Subsurface exploration can include drilling and sampling of the soil or rock, as well as in situ testing.

B.2 SUBSURFACE EXPLORATIONS

Subsurface explorations shall be made to competent material of suitable bearing capacity or to a depth where added stresses due to the estimated footing load is less than 10 percent of the existing effective soil overburden stress, whichever is the greater. If bedrock is encountered at shallow depths, the exploration shall advance a minimum of 3000 mm into the bedrock or to 1000 mm beyond the proposed foundation depth, whichever is greater.

C.B.2

As a minimum, the subsurface exploration and testing program should obtain information to analyze foundation stability and settlement with respect to:

- Geological formation(s);
- Location and thickness of soil and rock units;
- Engineering properties of soil and rock units, including density, shear strength and compressibility;
- Groundwater conditions;
- Ground surface topography
- Local considerations, such as expansive or dispersive soil deposits, collapse potential of soil in arid regions, underground voids from solution weathering or mining activity, or slope instability potential; and
- Behavior under seismic loading, including liquefaction, seismic-induced ground settlement, lateral flow and spreading (e.g., sloping ground underlain by very loose saturated soil and the presence of a free face), and ground motion amplification or attenuation.

Issues related to the constructibility of the foundation system should also be identified during the subsurface investigation process. These issues can include the drivability of piles, the excavatibility/stability of holes for drilled shafts and similar bored systems (e.g., Cast-in-Drill Hole (CIDH) piles), occurrence of boulders and rocks that could affect pile or retaining wall construction, need for and ability to de-water soils or control groundwater flow.

B.2.1 In Situ Tests

In situ tests may be performed to obtain deformation and strength parameters of foundation soils or rock for the purposes of design and/or analysis. The tests shall be performed in accordance with the appropriate standards recommended by ASTM or AASHTO and may include the following in-situ soil tests and in-situ rock tests:

In Situ Soil Tests

- Standard Penetration Test - AASHTO T 206 (ASTM D 1586)
- Static Cone Test - ASTM D 3441
- Field Vane Test - AASHTO T 223 (ASTM D 2573)
- Pressuremeter Test - ASTM D 4719
- Plate Bearing Test - AASHTO T 235 (ASTM D 1194)
- Well Test (Permeability) - ASTM D 4750

In Situ Rock Tests

- Deformability and Strength of Weak Rock by an In-Situ Uniaxial Compressive Test - ASTM D 4555
- Determination of Direct Shear Strength of Rock Discontinuities - ASTM D 4554
- Modulus of Deformation of Rock Mass Using the Flexible Plate Loading Method - ASTM D 4395
- Modulus of Deformation of Rock Mass Using a Radial Jacking Test - ASTM D 4506

C.B.2.1

The most suitable type of exploration method will depend on the type of soil/rock encountered, the type and size of the foundation, and the requirements of design. Often a combination of one or more methods is required. In nearly every situation at least one boring with soil/rock sampling should be planned. Results of other soil exploration methods, such as the cone penetrometer or field vane, should be compared to information recovered in the soil boring. Table B.1-1 provides a summary of the suitability and information that can be obtained from different in situ testing methods.

Parameters derived from field tests, such as standard penetration, cone penetrometer, dynamic penetrometer, and pressuremeter tests, can often be used directly in design calculations based on empirical relationships. These are sometimes found to be more reliable than analytical calculations, especially in familiar ground conditions for which the empirical relationships are well established.

- Modulus of Deformation of Rock Mass Using the Rigid Plate Loading Method - ASTM D 4394

- Stress and Modulus of Deformation Determination Using the Flatjack Method - ASTM D 4729

- Stress in Rock Using the Hydraulic Fracturing Method - ASTM D 4645

If so requested by the Owner or required by permitting agencies, boring and penetration test holes shall be plugged to prevent water contamination.

Table B.1-1 - In-Situ Tests

TYPE OF TEST	BEST SUITED TO	NOT APPLICABLE TO	PROPERTIES THAT CAN BE DETERMINED
Standard Penetration Test (SPT)	Sand	Coarse Gravel	Qualitative evaluation of compactness. Qualitative comparison of subsoil stratification.
Dynamic Cone Test	Sand and Gravel	Clay	Qualitative evaluation of compactness. Qualitative comparison of subsoil stratification.
Static Cone Test	Sand, Silt, and Clay	Coarse Gravel, Cemented Soil, Rock	Continuous evaluation of density and strength of sands. Continuous evaluation of undrained shear strength in clays.
Field Vane Test	Clay	All Other Soils	Undrained shear strength.
Pressuremeter Test	Soft Rock, Sand, Gravel, and Till	Soft Sensitive Clays	Bearing capacity and compressibility.
Plate Bearing Test and Screw Plate Test	Sand and Clay	-	Deformation modulus. Modulus of subgrade reaction. Bearing capacity.
Flat Plate Dilatometer Test	Sand and Clay	Gravel	Empirical correlation for soil type, K_e, overconsolidation ratio, undrained shear strength, and modulus.
Permeability Test	Sand and Gravel	-	Evaluation of coefficient of permeability.

B.2.2 Explorations for Seismic Studies

In areas of high seismic activity (e.g., Seismic Detailing Requirement (SDR) 3 and above), special consideration shall be given to the seismic response of the site during the planning of field explorations. The planning process shall consider the potential for liquefaction and the requirement to determine the Site Class Definition, as required for establishing the Seismic Hazard Level and SDR. Article 3.7 provides definitions Seismic Hazards Level (SHL), SDAP and SDR.

C.B.2.2

Subsurface exploration methods in areas of high seismicity are generally the same as those used for standard subsurface explorations. However, the empirical correlations used to estimate the potential for liquefaction or the shear wave velocity of the soil normally require use of equipment that have been calibrated according to certain standards. The geotechnical engineer or engineering geologist responsible for having the subsurface explorations carried out should become familiar with these methods and confirm during the exploration program that correct methods and calibrated equipment are being used. If incorrect methods or un-calibrated equipment are used, it is possible to predict overly conservative or unconservative ground response for a design seismic event.

B.2.2.1 Liquefaction Potential

Field explorations shall be performed to evaluate the potential for liquefaction in SDR 3, 4, 5, and 6 at those sites potentially susceptible to liquefaction. For sites that are potentially liquefiable, it is important to obtain an accurate determination of soil stratigraphy, the groundwater location, and the density of cohesionless soil. Of particular importance is the identification of thin layers that, if liquefied, could result in lateral flows or spreading of the soil above the liquefied layers.

C.B.2.2.1

A potential for liquefaction exists if the following conditions are present: (1) the peak horizontal acceleration at the ground surface is predicted to be greater than 0.15g (g = acceleration of gravity); (2) the soil consists of loose to medium dense non-plastic silts, sands, and in some cases gravels; and (3) the permanent groundwater location is near the ground surface. Appendix D provides specific guidance on the determination and evaluation of liquefaction.

Depth of Exploration

The potential depth of liquefaction is an important decision. Normally, liquefaction is assumed to be limited to the upper 15 to 20 m of soil profile. However, it appears that this limiting depth is based on the observed depth of liquefaction rather than the maximum depth of liquefaction that is physically possible. For this reason an exploration program should extend at least to 25 m or until a competent bearing layer (with no underlying loose layers) is encountered, whichever occurs first.

Methods of Exploration

Several different exploration methods can be used to identify soils that could be susceptible to liquefaction. These include the Standard Penetration Test (SPT), the cone penetration test (CPT), and certain types of shear wave velocity measurements (e.g., crosshole, downhole, and SASW methods). ASTM standards exist for conducting SPTs, CPTs, and certain types of shear wave velocity (see Article B.2.1). These methods should be followed. If standards are not available, then it is essential to have testing completed by experienced individuals, who understand the limitations of the test methods and who understand the level of accuracy needed by the engineer for Site Class Definition or liquefaction determination.

Standard Penetration Test (SPT) Method: The SPT is currently the most common field exploration method for liquefaction studies. It is critical that if SPTs are conducted to obtain information for liquefaction assessments, procedures follow those recommended by Youd and Idriss (1997). These procedures have strict requirements for hammer energy, sampler size, and drilling method. If these methods are not followed, the value of the blow count determined from the SPT can vary by 100 percent, resulting in great uncertainty in any liquefaction assessment based on the SPT results. Recommended SPT procedures are summarized in Table B.2.2-1.

An automatic trip hammer should be used wherever possible; hammer energy calibrations should be obtained for the hammer, whether it is a donut hammer or an automatic hammer. Records should also be available that indicate whether the SPT sampler used liners or not, and the type of drilling method that was used. It will usually be necessary to conduct the SPTs at close depth intervals, rather than the conventional 1.5-m interval, because thin liquefiable layers could be important to design.

Sites with gravel deposits require special consideration when performing SPTs. Because of the coarse size of gravel particles, relative to the size of the sampler, these deposits can result in misleadingly high blow counts. Three procedures can be considered for these sites:

- If a site has only a few gravel layers or if the gravel is not particularly abundant or large, it may be possible to obtain an equivalent SPT blow count if "incremental" blow counts are measured. To perform "incremental" blow count measurements, the number of blows for each 25 mm of penetration is recorded, rather than the blows for 150 mm. By plotting the blow counts per 25 mm versus depth, it is sometimes possible to distinguish between the blow count obtained in the matrix material and blow counts affected by large gravel particles. The equivalent blow count for 150 mm can then be estimated by summing and extrapolating the number of blows for the representative 25 mm penetrations that appear to be uninfluenced by coarse gravel particles. This procedure is described in Vallee and Skryness (1980).

Andrus and Youd (1987) describe an alternate procedure for determining blow counts in gravel deposits. They suggest that the penetration per blow be determined and the cumulative penetration versus blow count be plotted. With this procedure, changes in slope can be identified when gravel particles interfere with penetration. From the slope of the cumulative penetration, estimates of the penetration resistance can be made where the gravel particles did or did not influence the penetration resistance.

An alternative in gravel deposits is to obtain Becker Hammer blow counts, which have been correlated to the standard penetration test blow count (Youd and Idriss, 1997).

Cone Penetrometer Test (CPT) Method: For many locations the CPT is the preferred method of determining liquefaction potential. This method is preferred because it is able to provide an essentially continuous indication of soil consistency and type with depth. It is also less susceptible to operator-related differences in measurements. The CPT method may not be applicable at sites where cobbles and gravels overlie looser sandy soils. At these sites it may be impossible to push the CPT rod and sensor through the gravel. For these sites it is sometimes possible to auger through the gravel materials to provide access for the cone penetrometer rod and sensor.

Most CPT equipment are not capable of obtaining soil samples. Empirical correlations can, however, be used to estimate soil type and grain size. Although these correlations often provide very good indirect estimations of soil type and grain size, it is generally desirable to perform a limited number of SPTs at the site to obtain soil samples for laboratory determination of grain size, to confirm soil descriptions, and to provide a comparison to SPT blow counts.

Procedures for interpreting liquefaction resistance from the CPT measurement are given in Youd and Idriss (1997).

Shear Wave Velocity Methods: Shear wave velocity can also be used for both liquefaction evaluations and the determination of soil shear modulus, which is required when establishing spring constants for spread footing foundations. The shear wave velocity of the soil is also fundamental to the determination of Site Class Definition, as discussed in Article 3.4.2.1.

A variety of methods are available for making shear wave velocity measurements. They include downhole and crosshole methods which are performed in boreholes, seismic-cone methods which are conducted in conjunction with a CPT, and Spectral Analysis of Surface Wave (SASW) methods which are conducted from the ground surface without a borehole. Experienced individuals should perform these methods, as the collection and interpretation of results requires considerable skill. In the absence of this experience, it is possible to obtain misleading results. Surface wave refraction procedures should not be used, as they are generally not able to obtain information in low-velocity layers. Additional information about the shear wave velocity can be found in Kramer (1996).

Procedures for interpreting liquefaction resistance from shear wave velocity data are discussed in Youd and Idriss (1997).

Table B.2.2-1 - Recommended SPT Procedure

Borehole size	66 mm < Diameter < 115 mm
Borehole support	Casing for full length and/or drilling mud
Drilling	Wash boring; side discharge bit Rotary boring; side or upward discharge bit Clean bottom of borehole*
Drill rods	A or AW for depths of less than 15 m N or NW for greater depths
Sampler	Standard 51 mm O.D. +/- 1 mm 35 mm I.D. +/- 1 mm >457 mm length
Penetration resistance	Record number of blows for each 150 mm; N = number of blows from 150 to 450 mm penetration
Blow count rate	30 to 40 blows per minute

* Maximum soil heave within casing <70 mm

B.2.2.2 Site Response Determination

The field exploration shall provide sufficient information to determine the Site Class Definition (see Article 3.4.2.1), which is used to determine the Seismic Hazards Level.

C.B.2.2.2

The Site Class Definition is used to determine whether amplification or de-amplification of ground motions occurs as earthquake-induced motions propagate from depth to the ground surface. Five general site classes have been defined (Article 3.4.2.1) for seismic studies. These categories generally require determination of soil properties in the upper 30 m of soil profile. Procedures for establishing the soil properties include the SPT, the shear wave velocity, and the strength of the material. It is important when planning the field explorations to recognize that this information could be important to a site and make explorations plans accordingly.

B.3 LABORATORY TESTING

Laboratory tests shall be performed to determine the strength, deformation, and flow characteristics of soils and/or rocks and their suitability for the foundation selected. In areas of higher seismicity (e.g., SDR 3, 4, 5, and 6), it may be appropriate to conduct special dynamic or cyclic tests to establish the liquefaction potential or stiffness and material damping properties of the soil at some sites if unusual soils exist or if the foundation is supporting a critical bridge.

C.B.3

An understanding of the engineering properties of soils is essential to the use of current methods for the design of foundations and earth structures. The purpose of laboratory testing is to provide the basic data with which to classify soils and to measure their engineering properties. The design values selected from the laboratory tests should be appropriate to the particular limit state and its correspondent calculation model under consideration.

For the value of each parameter, relevant published data together with local and general experience should be considered. Published correlations between parameters should also be considered when relevant.

B.3.1 Standard Laboratory Tests

Laboratory soil tests may include:

- Water Content - ASTM D 4643
- Specific Gravity - AASHTO T 100 (ASTM D 854)
- Grain Size Distribution - AASHTO T 88 (ASTM D 422)
- Soil Compaction Testing – ASTM D 698 or D 1557
- Liquid Limit and Plastic Limit - AASHTO T 90 (ASTM D 4318)
- Direct Shear Test - AASHTO T 236 (ASTM D 3080)
- Unconfined Compression Test - AASHTO T 208 (ASTM D 2166)
- Unconsolidated-Undrained Triaxial Test - ASTM D 2850
- Consolidated-Undrained Triaxial Test - AASHTO T 297 (ASTM D 4767)
- Consolidation Test - AASHTO T 216 (ASTM D 2435 or D 4186)
- Permeability Test - AASHTO T 215 (ASTM D 2434)

CB.3.1

Standard laboratory tests of soils may be grouped broadly into two general classes:

- Classification tests: These can be performed on either disturbed or undisturbed samples.
- Quantitative tests for permeability, compressibility, and shear strength. These tests are generally performed on undisturbed samples, except for materials to be placed as controlled fill or materials that do not have an unstable soil-structure. In these cases, tests should be performed on specimens prepared in the laboratory.

A certain number of classification tests should be conducted at every bridge site; the number of quantitative tests will depend on the types of soils encountered. In many cases disturbance associated with the soil sampling process can limit the usefulness of quantitative test results. This is particularly the case for cohesionless soil. It can also occur for cohesive soil if high quality Shelby tube samples are not obtained. High quality sampling also requires careful sampling and careful soil setup once the sample is retrieved from the ground.

B.3.2 Special Testing for Seismic Studies

For some important projects it may be necessary or desirable to conduct special soil laboratory tests

C.B.3.2

For liquefaction assessments it is generally preferable to rely on in situ methods for determining to establish the liquefaction strength or stiffness and material damping properties of the soil. These tests can include resonant column, cyclic triaxial, and cyclic simple shear tests. Only a limited number of academic and consulting organizations are currently conducting these types of tests; therefore, special care is required when selecting a testing laboratory for these tests. Kramer (1996) provides a summary of the laboratory testing for determination of dynamic properties of soil.

the liquefaction strength of the soil, because of difficulties associated with sample disturbance. The exception to this general rule is for non-plastic silty soil, where the database for in situ-based correlations is not as well established. For these soils cyclic laboratory test may be necessary to estimate liquefaction strengths.

Empirical correlations have also been developed to define the effects of shearing strain amplitude and confining pressure on shear modulus and material damping of cohesionless and cohesive soils. Laboratory determination of these properties may be warranted where special soil conditions exist or where the stress state on the soil could change. Kramer (1996) provides a summary of the available methods for estimating shear modulus and material damping as a function of shearing strain amplitude and confining pressure.

B.3.3 Rock Testing

Laboratory rock tests may include:

- Determination of Elastic Moduli - ASTM D 3148
- Triaxial Compression Test - AASHTO T 266 (ASTM D 2664)
- Unconfined Compression Test - ASTM D 2938
- Splitting Tensile Strength Test - ASTM D 3967

C.B.3.3

Laboratory testing of rock has very limited applicability for measuring significant rock properties, such as:

- Compressive strength,
- Shear strength,
- Hardness,
- Compressibility, and
- Permeability.

Rock samples small enough to be tested in the laboratory are usually not representative of the entire rock mass. Laboratory testing of rock is used primarily for classification of intact rock samples, and, if performed properly, serves a useful function in this regard.

Laboratory tests on intact samples provide upper bounds on strength and lower bounds on compressibility. Frequently, laboratory tests can be used in conjunction with field tests to give reasonable estimates of rock mass behavioral characteristics.