APPENDIX C
METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
1. Methods of Access for Sampling, Test, or Observation			
Pits, trenches, shafts, tunnels	Excavation made by hadn, large auger, or digging machinery.	Visual observation, photography, disturbed and undisturbed sampling, in situ testing of soil and rock.	Depth of unprotected excavations is limited by groundwater or safety considerations. May need dewatering.
Auger boring	Boring advanced by hand auger or power auger.	Recovery of remolded samples and determining groundwater levels. Access for undisturbed sampling of cohesive soils.	Will not penetrate bounders or most rock.
Hollow stem auger boring	Boring advanced by means of continuous-flight helix auger with hollow-center stem.	Access to undisturbed or representative sampling through hollow stem with thin-wall tube sampler, core barrel, or split-barrel sampler.	Should not be used with coarse-grained soils. Not suitable for undisturbed sampling in loose sand or silt. Not recommended below the groundwater table in cohesionless soils.
Wash boring	Boring advanced by chopping with light bit and by jetting with upward deflected jet.	Cleaning out and advancing hole in soil between sample intervals.	Suitable for use with sampling operations in soil only if done with low water velocities and with upward deflected jet.
Rotary drilling	Boring advanced by rotating drilling bit; cuttings removed by circulating drilling fluid.	Boring in soil or rock.	Drilling mud should be used in coarse-grained soils. Bottom discharge bits are not suitable for use with undisturbed sampling in soil unless combined with protruding core barrel, as in Denison sampler, or with upward deflected jets.
Percussion drilling	Boring advanced by air-operated impact hammer.	Detection of voids and zones of weakness in rock by changes in drill rate or resistance. Access for in situ testing or logging.	Not suitable for use in soils.
Cable drilling	Boring advanced by repeated dropping of heavy big; removal of cuttings by bailing.	Advancing hole in soil or rock. Access for sampling, in situ testing, or logging in rock. Penetration of hard layers, gravel, or boulders in auger borings.	Causes severe disturbance in soils; not suitable for use with undisturbed sampling methods.
Continuous sampling or displacement boring	Boring advanced by repeated pushing of sampler, or closed sampler is pushed to desired depth and sample is taken.	Recovery of representative samples of cohesive soils and undisturbed samples in some cohesive soils.	Effects of advance and withdrawal of sampler result in disturbed sections at top and bottom of sample. In some soils, entire sample may be disturbed. Best suited for use in cohesive soils. Continuous sampling in cohesionless soils may be made by successive reaming and clearing of hole between sampling.

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
2. Methods of Sampling Soil or Rock			
Hand cut or cylindrical sample	Sample is cut by hand from soil exposed in excavation.	Highest quality samples in all soils and in soft rock.	Requires accessible excavation and dewatering if below water table. Extreme care is required in sampling cohesionless soils.
Fixed-piston sampler	Thin-walled tube is pushed into soil with fixed piston in contact with top of sample during push.	Undisturbed samples in cohesive soils, silts, and sands above or below the water table.	Some types do not have a positive means to prevent piston movement.
Hydraulic piston sampler (Osterberg Sampler)	Thin-walled tube is pushed into soil by hydraulic pressure. Fixed piston in contact with top of sample during push.	Undisturbed samples in cohesive soils, silts, and sands above or below the water table.	Not possible to determine amount of sampler penetration during push. Does not have vacuum breaker in piston.
Free-piston sampler	Thin-walled tube is pushed into soil. Piston rests on top of soil sample during push.	Undisturbed samples in stiff, cohesive soils. Representative samples in soft to medium cohesive soils and silts.	May not be suitable for sampling in cohesionless soils. Free piston provides no control of specific recovery ratio.
Open drive sampler	Thin-walled open tube is pushed into soil.	Undisturbed samples in stiff, cohesive soils. Representative samples in soft to medium cohesive soils and silts.	Small diameter of tubes may not be suitable for sampling in cohesionless soils or for undisturbed sampling in uncased boreholes. No control of specific recovery ratio.
Swedish Foil Sampler	Sample tube is pushed into soil, while stainless steel strips unrolling from spools envelop sample. Piston, fixed by chain from surface, maintains contact with top of sample.	Continuous undisturbed samples up to 20 m (66 ft) long in very soft to soft clays.	Not suitable for soils containing gravels, sand layers, or shells, which may rupture foils and damage samples. Difficulty may be encountered in alternating hard and soft layers, with squeezing of soft layers and reduction in thickness. Requires experienced operator.
Pitcher sampler	Thin-walled tube is pushed into soil by spring above sampler, while outer core bit reams hole. Cuttings removed by circulating drilling fluid.	Undisturbed samples in stiff, hard, brittle, cohesive soils and sands with cementation, and in soft rock. Effective in sampling alternating hard and soft layers. Representative samples in soft-to-medium cohesive soils and silts. Disturbed samples may be obtained in cohesionless materials with variable success.	Frequently ineffective in cohesionless soils.
Split-barrel or split-spoon sampler	Split-barrel tube is driven into soil by blows of falling ram. Sampling is carried out in conjunction with Standard Penetration Test.	Representative samples in soils other than coarse-grained soils.	Samples are disturbed and not suitable for tests of physical properties.
Auger sampling	Auger drill used to advance hole is withdrawn at intervals for recovery of soil samples from auger flights.	Determine boundaries of soil layers and obtain samples of soil classification.	Samples not suitable for physical property or density tests. Large errors in locating strata boundaries may occur without close attention to details of procedure. In some soils, particle breakdown by auger or sorting effects may result in errors in determining gradation.

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2. Methods of Sampling Soil or Rock			
Rotary core barrel	Hole is advanced by core bit while core sample is retained within core barrel or within stationary inner tube. Cuttings removed by drilling fluid.	Core samples in competent rock and hard soils with single tube core barrel. Core samples in poor or broken rock may be obtainable with double tube core barrel with bottom discharge bit.	Because recovery is poorest in zones of weakness, samples generally fail to yield positive information on soft seams, joints, or other defects in rocks.
Denison sampler	Hole is advanced and reamed by core drill while sample is retained in non-rotating inner core barrel with corecatcher. Cuttings removed by circulating drilling fluid.	Undisturbed samples in stiff-to-hard cohesive soil, sand with cementation, and soft rocks. Disturbed sample may be obtained in cohesionless materials with variable success.	Not suitable for undisturbed sampling in loose, cohesionless soils or soft, cohesive soils. Difficulties may be experienced in sampling alternating hard and soft layers.
Shot core boring (Calyx)	Boring advanced by rotating single core barrel, which cuts by grinding with chilled steel shot fed with circulating wash water. Used shot and coarser cuttings are deposited in an annular cup, or calyx, above the core barrel	Large diameter cores and accessible boreholes in rock.	Cannot be used in drilling at large angles to the vertical. Often ineffective in securing small diameter cores.
Oriented integral sampling	Reinforcing rod is grouted into small diameter hole, then overcored to obtain an annular core sample.	Core samples in rock with preservation of joints and other zones of weakness.	Samples are not well suited to tests of physical properties.
Wash sampling or cuttings sampling	Cuttings are recovered from wash water or drilling fluid.	Samples useful in conjunction with other data for identification of major strata.	Sample quality is not adequate for site investigations for nuclear facilities.
Submersible vibra-tory (Vibracore) sampler	Core tube is driven into soil by vibrator.	Continuous representative samples in unconsolidated marine sediments.	Because of high area ratio and effects of vibration, samples may be disturbed.
Underwater piston corer	Core tube attached to drop weight is driven into soil by gravity after a free fall of controlled height.	Representative samples in unconsolidated marine sediments.	Samples may be seriously disturbed. Cable supported piston remains in contact with soil surface during drive.
Gravity corer	Open core tube attached to drop weight is driven into soil by gravity after free fall.	Representative samples at shallow depth in unconsolidated marine sediments.	No control of spedific recovery ratio. Samples are disturbed.

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock			
Standard Penetration Test (SPT)	Split-barrel sampler is driven into soil by blows of free-falling weight. Blow count for each 15 cm (6 in.) Of penetration is recorded.	Blow count may be used as an index of consistency or density of soil. May be used for detection of changes in consistency or density in clays or sands. May be used with empirical relationships to estimate relative density of clean sand.	Extremely unreliable in silts, silty sands, or soils containing gravel. In sands below water table, positive head must be maintained in borehole. Determination of relative density in sands requires site-specific correlation or highly conservative use of published correlations. Results are sensitive to details of appratus and procedure. The technique should not be applied to soils containing large amounts of cobbles.
Cone Penetration Test (CPT)	Instrument steel cone is pushed continuously into the ground and measures resistance to penetration, skin friction, and other properties depending on devices incorporated in the cone.	Detection of changes in consistency, strength, and density in soils ranging from clays to finer gravel. Used to estimate static undrained shear strength of clays, liquefaction potential of cohesionless soils, and, if so instrumented, changes in pore water pressure in saturated soils. May also house accelerometer for use as downhole seismic receiver. Experimental cone penetrometers are under development to detect various contaminants.	Does not acquire soil samples, although similar tools are available to do so. Penetration depth may be limited due to push rig capacity in stiff soils, and the technique should not be applied to soils containing large amounts of cobbles.
Field vane shear test	Four-bladed vane is pushed into undisturbed soil, then rotated to cause shear failure on cylindrical surface. Torsional resistance versus angular deflection is recorded.	Used to estimate in situ undrained shear strength and sensitivity of clays.	Not suitable for use in silts, sands, or soils containing appreciable amounts of gravel or shells. May yield unconservative estimates of shear strength in fissured clay soils or where strength is strain-rate dependent.
Drive point penetrometer	Expandable steel cone is driven into soil by falling weight. Blow count versus penetration is recorded.	Detection of gross changes in consistency or relative density. May be used in some coarse-grained soils.	Provides no quantitative information on soil properties.
Plate bearing test (soil)	Steel loading plate is placed on horizontal surface and is statically loaded, usually by hydraulic jack. Settlement versus time is recorded for each load increment.	Estimation of strength and moduli of soil. May be used at ground surface, in excavations, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing plate only if properties of soil are uniform laterally and with depth.
Plate bearing test or Plate jacking test (rock)	Bearing pad on rock surface is statically loaded by hydraulic jack. Deflection versus load is recorded.	Estimation of elastic moduli of rock masses. May be used at ground surface, in excavations, in tunnels, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing pad only if rock properties are uniform over volume of interest, and if diameter of bearing pad is larger than average spacing of joints or other discontinuities.
Pressure meter test (Dilatometer test)	Uniform radial pressure is applied hydraulically over a length of borehole several times its diameter. Change in diameter versus pressure is recorded.	Estimation of elastic moduli of rocks and estimation of shear strengths and compressibility of soils by empirical relationships.	Test results represent properties only of materials in vicinity of borehole. Results may be misleading in testing materials whose properties may be anisotropic.

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3. Methods of In Situ Testing of Soil and Rock			
Field pumping test	Water is pumped from or into an aquifer at constant rate through penetrating well. Change in piezometric level is measured at well and at one or more observation wells. Pumping pressures and flow rates are recorded. Packers may be used for pump-in pressure tests.	Estimation of in situ permeability of soils and rock mass.	Apparent permeability may be greatly influenced by local features. Effective permeability of rock is dependent primarily on frequency and distribution of joints. Test result in rock is representative only to the extent that the borehole intersects a sufficient number of joints to be representative of the joint system of the rock mass.
Borehole field permeability test	Water is added to an open-ended pipe casing sunk to desired depth. With constant head tests, constant rate of gravity flow into hole and casing pipe are measured. Variations include applied pressure tests and falling head tests.	Rough approximation of in situ permeability of soils and rock mass.	Pipe casing must be carefully cleaned out just to the bottom of the casing. Clear water must be used or tests may be grossly misleading. Measurement of local permeability only.
Direct shear test	Block of in situ rock is isolated to permit shearing along a preselected surface. Normal and shearing loads are applied by jacking. Loads and displacements are recorded.	Measurement of shearing resistance of rock mass in situ.	Tests are costly. Usually, variability of rock mass requires a sufficient number of tests to provide statistical control.
Pressure tunnel test	Hydraulic pressure is applied to sealed-off length of circular tunnel, and diametral deformations are measured.	Determination of elastic constants of the rock mass in situ.	Volume of rock tested is dependent on tunnel diameter. Cracking caused by tensile hoop stresses may affect apparent stiffness of rock.
Radial jacking test	Radial pressure is applied to a length of circular tunnel by flat jacks. Diametral deformations are measured.	Same as pressure tunnel test.	Same as pressure tunnel test.
Borehole jack test	Load is applied to wall of borehole by two diametrically opposed jacks. Deformations and pressures are recorded.	Determination of elastic modulus of rock in situ. Capable of applying greater pressure than dilatometers.	Apparent stiffness may be affected by development of tension cracks.

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3. Methods of In Situ Testing of Soil and Rock			
Borehole deformation meter	Device for measuring diameters is placed in borehole, and hole is overcored to relieve stresses on annular rock core with deformation meter. Diameters (usually 3) are measured before and after overcoring. Rock modulus is measured by laboratory tests on core; in situ stresses are computed by elastic theory.	Measurement of absolute stresses in situ.	Stress field is affected by borehole. Analysis subject to limitations of elastic theory. Two boreholes at different orientations are required for determination of complete stress field. Questionable results in rocks with strongly time-dependent properties.
Inclusion stressmeter	Rigid stress-indicating device (stressmeter) is placed in borehole, and hole is overcored to relieve stresses on annular core with stress meter. In situ stresses are computed by elastic theory.	Measurement of absolute stresses in situ. Does not require accurate knowledge of rock modulus.	Same as above.
Borehole strain gauge	Strain gauge is cemented to bottom of borehole, and gauge is overcored to relieve stresses on core containing strain gauge. Stresses are computed from resulting strains and from modulus obtained by laboratory tests on core.	Measurement of one component of normal stress in situ. Does not require knowledge of rock modulus.	Stress field affected by excavation or tunnel used. Interpretation of test results subject to assumption that loading and unloading moduli are equal. Questionable results in rock with strongly time-dependent properties.
Hydraulic fracturing test	Fluid is pumped into sealed-off portion of borehole with pressure increasing until fracture occurs.	Estimation of minor principal stress.	Affected by anisotropy of tensile strength in rock.
Crosshole seismic test	Seismic signal is transmitted from source in one borehole to receiver(s) in other borehole(s), and transit time is recorded.	In situ measurement of compression wave velocity and shear wave velocity in soils and rocks.	Requires deviation survey of boreholes to eliminate errors due to deviation of holes from vertical. Refraction of signal through adjacent high-velocity beds must be considered.
Uphole/downhole seismic test	Seismic signal is transmitted between borehole and ground surface, and transit time is recorded.	In situ measurement of compression wave velocity and shear wave velocity in soils and rocks.	Apparent velocity obtained is time-average for all strata between source and receiver.

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3. Methods of In Situ Testing of Soil and Rock			
Acoustic velocity log	Logging tool contains transmitting and two receiving transducers separated by fixed gauge length. Signal is transmitted through rock adjacent to borehole, and transit time over the gauge length is recorded as the difference in arrival times at the receivers.	Measurement of compression wave velocity used primarily in rocks to obtain estimate of porosity.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Use is limited to materials with P-wave velocity greater than that of the borehole fluid.
3-D velocity log	Logging tool contains transmitting and receiving transducer separated by fixed gauge length. Signal is transmitted through rock adjacent to borehole, and wave train at receiver is recorded.	Measurement of compression wave and shear wave velocities in rock. Detection of void spaces, open fractures, and zones of weakness.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Correction required for variation in hole size. Use is limited to materials with P-wave velocity greater than that of borehole fluid.
Electrical resistivity log	Apparent electrical resistivity of soil or rock in neighborhood of borehole is measured by in-hole logging tool containing one of a wide variety of electrode configurations.	Appropriate combination of resistivity logs can be used to estimate porosity and degree of water saturation in rocks. In soils, may be used as qualitative indication of changes in void ratio or water content for correlation of strata between boreholes and for location of strata boundaries.	Can be obtained only in uncased boreholes. Hole must be fluid filled, or electrodes must be pressed against borehole. Apparent resistivity values are strongly affected by changes in hole diameter, strata thickness, resistivity contrast between adjacent strata, resistivity of drilling fluid, etc.
Neutron log	Neutrons are emitted into rock or soil around borehole by a neutron source in the logging tool. A detector, isolated from the source, responds to either slow neutrons or secondary gamma rays. Response of detector is recorded.	Correlation of strata between boreholes and location of strata boundaries. Provides an approximation to water content and can be run in cased or uncased, fluid filled, or empty boreholes.	Because of very strong borehole effects, results are generally not of sufficient accuracy for quantitative engineering uses.
Gamma-gamma log (Density log)	Gamma rays are emitted into rock around the borehole by a source in the logging tool, and a detector isolated from the source responds to back-scattered gamma rays. Response of detector is recorded.	Estimation of bulk density in rock, qualitative indication of changes of density in soils. May be run in empty or fluid filled holes.	Effects of borehole size and density of drilling fluid must be accounted for. Presently not suitable for qualitative estimate of density in soils other than those of rock-like character. Cannot be used in cased boreholes.
Borehole cameras	Film-type or television camera in a suitable protective container is used for observation of walls of borehole.	Detection and mapping of joints, seams, cavities, or other visually observable features in rock. Can be used in empty uncased holes or in boreholes filled with clear water.	Results are affected by any condition that impairs visibility.
Borehole televiewer	A rotating acoustic signal illuminates the borehole wall, and reflected signals are recorded.	Detection and mapping of joints, seams, cavities, or other observable features in rock. Can be used in mud-filled boreholes.	Transparency of borehole fluid is not essential.