GEOCONSULT - San Juan, P.R.

GUIDELINES FOR GEOTECHNICAL INVESTIGATIONS

SUGGESTED INVESTIGATION DENSITY

by Alan R. Crumley, May 17, 2004 Rev. Nov. 6, 2007

MEASUREMENTS IN FEET (IMPERIAL SYSTEM)

Note: All soundings, borings or surveys must be located with *x, y, z* coordinates.

For purposes of this table, SPT borings and CPT soundings are interchangeable. Use of continuous sampling is highly recommended.

General note:	It is relatively easy to set guidelines for the initial or preliminary stages of the investigation. The final stage of geotechnical design will require greater analysis; each site or case will have specific requirements.	The investigation density or effort will depend on the design stage, the size and type of structure and lot size, plus other site-specific factors such as geometry of the site and structures. Thus, these suggestions can only be called "guidelines" and are not standards or rules to be followed; the only standard than can be applied is that the investigation provide the necessary information as set forth by the scope of work in the geotechnical report. The investigation density will depend on the specific subsurface conditions and the type and location of structures.	The purpose of the investigation must be to obtain reliable subsurface information. The investigation is usually performed using borings with the Standard Penetration Test (SPT) or soundings with the Cone Penetrometer Test (CPT). In the case of SPT borings, the engineer should include subsurface characterization using undisturbed samples, consolidation tests and Atterberg limits; frequent use of continuous sampling instead of more-usual five-foot intervals is encouraged. Use of the CPT will generate much continuous data by means of correlations. Other tests within boreholes (e.g., vane shear) should be considered. Finally, a design-build project might have different requirements than a conventional design-bid-build project. **Note:** On most jobs it is necessary to reasonably determine the water level. This task usually requires observation wells that must be read for some time. The client should be made aware of the importance of reliably determining the approximate water level. Be aware that several water levels may exist from perched water tables.

	Type of Structure	Study level or expected foundation type	Investigation Density: Suggestions for study locations or boring density or frequency of geophysical traverses (double for slopes)	Suggestions for depths of exploration
1	Large one-story structures, such as warehouses, commercial centers and manufacturing facilities	Preliminary study	Every 15,000 ft^2, minimum 5 borings, approximately one boring per two acres, maximum spacing 300 feet	Take at least one of the borings or soundings to a depth 10 times the expected width of footings; take the remainder to 4 times this width (measured from bottom of footing). If piles are expected, exploration depth should reach 10 times the pile width below the pile tips.
		Footings, final report	Every 2,500 to 7,000 ft^2, typical spacing 60-120 feet in each direction, 4 corners and at center, 3 to 4 borings per acre. In some locations, consider test pits to substitute for borings.	Borings should extend at least three footing widths below the expected depth of footing, except for special situations, such as analysis of fills that might induce settlements, where deeper borings and specific tests might be required. In karst regions, additional exploration (geophysics) might be necessary.
		Piles, final report	Every 4,000 to 9,000 ft^2, typical spacing 80-140 feet between borings, 4 corners and center; 3 to 4 borings every 40,000 ft^2.	Borings should be drilled at least 10 pile diameters below pile tips.
2	Isolated structures such as relatively-small self-standing buildings within larger commercial lots	Preliminary	One boring per building - greatly depends on building geometry and site conditions; structures on slopes will require greater investigation density and cross-sections	The boring should be taken to a depth no less than twice the building width. Any new fill thickness will induce settlements and affect investigation requirements.
		Final	Three borings lengthwise or diagonal, no less than one boring per 2,500 ft^2, maximum spacing 70 feet; as above, greatly depends on building geometry and site conditions; structures on slopes will require greater investigation density and cross-sections.	The depth of final-study borings depends on conditions found while drilling and the geometry of fill to be placed. For pile foundations, take borings at least 10 times the pile width. For footings, borings will typically be 3 to 5 times the footing width, with at least one boring taken to a depth similar to the building width.
3	Two-story and 3-story structures, rectangular tanks, multistory commercial centers, walkup apartments, small parking buildings and small industrial buildings	On footings	Every 2,500 ft^2, minimum 5 borings depending on geometry (e.g., corners and center). Distance between borings should be 50 to 100 feet.	At least one of the borings should be taken to a depth 10 times the footing width; the remaining borings can be taken to 4 times the expected footing width (measured below the footing).
		On piles	Every 5,000 ft^2, minimum 5 borings depending on geometry (e.g., corners and center). Distance between borings should be 100 to 150 feet.	The borings should surpass the pile tips by approximately 10 times the pile diameter.
4	Buildings taller than 4 stories, hotels, large parking buildings, large housing apartments or condominums, structures with footprints greater than 10,000 ft^2, auditoriums, stadiums or sports centers	Mat or footings	For preliminary studies, do at least one boring per 20,000 ft^2 of lot size, or per 10,000 ft^2 of building footprint, if known. For a final investigation, do a boring or sounding every 2,000 to 5,000 ft^2 of footprint, with at least five SPT borings or CPT soundings, or combination. Typical spacing for borings or soundings will be 65 to 100 feet. Concentrated loads require further investigation, depending on footprint geometry.	For preliminary investigation, take at least one of the borings to a depth 10 times the expected footing width, or 3 times the mat width. For a final report, go to 3 times the mat width or 4 times the footing width. If a preliminary report was not done before the final report, also include deep borings as specitfied for preliminary report.
		Piles	For a preliminary investigation, do one boring for each 10,000 ft^2 of building footprint. For a final investigation, do one boring every 5,000 ft^2, minimum 5 borings or soundings, spaced 80 to 120 feet apart. If drilled shafts are used, follow FHWA guidelines: one boring per shaft for shaft diameters (ϕ) greater than 1.83 m; one boring per 2 shafts for ϕ of 1.22 m to 1.83 m; one boring per 4 shafts for $\phi < 1.22$ m.	The depth of borings should exceed the length of piles by 10 to 20 pile diameters. Although investigation density might be less than for spread footings, beware of false sense of security using piles.
5	Initial review of large land parcels that will be subdivided into large commercial or housing developments, to be followed by subsequent analyses and designs as the properties are developed (e.g., strip malls)	Conceptual	One boring every 12,000 to 36,000 square feet; if site has been previoulsy filled, consider other borings with continuous sampling.	The required depth is that which answers important questions at time of lot purchase or before design. Settlements from compression of soft soils, and rippability, are usually important factors to consider. Detailed site reconnaissance and photo interpretation is important.
		Predevelopment	One boring every 8,000 to 16,000 square feet	Once the design of final grades is complete or once the footprint of buildings has been determined, use guidelines shown for other sections of this list. For example, for housing projects, see #6; for industrial projects, see #10.
6	For housing developments, with the following exception: In karst areas, alternate supplementary or complementary methods should be considered, in addition to SPT borings or continuous soundings. Resistivity lines are indicated for many cases, although other methodologies also exist and should be considered to improve interpretations from borings. Consider cross-hole seismic surveys (In karst do not use surface seismic). Photointerpretation analyses are essential. In some cases. GPR could be usable. See #8.	Preliminary	One SPT boring or CPT sounding every four acres, minimum 4 borings. Approximate spacing 300 to 600 feet. In karstic zones, do at least one geophysical survey, L=300 feet, every 10 acres.	For housing developments, the width and thickness of necessary fills are determining factors in planning of a geotechnical investigation. The borings should be extended below any compressible layer that will be affected or below zones where cavities might be present. Drill borings or take soundings to a depth at least 15 times the expected footing width, or four times the width of the houses or structures that are being designed, measured from bottom of footing.
		Final	On relatively flat lots, do a boring every two acres or every 10 to 25 houses (obviously depends on lot sizes). Minimum suggested number of borings is 8 per site. Projects with sloped ground or fill slopes require further analysis. Maximum boring spacing approximately 250 to 400 feet. In karstic zones, also do a geophysical survey every 5 acres, approximately.	Same as above, although shallower borings are feasible if fill width and extent are determined for final stage. Any areas with slopes on fill, or into natural soil, will require at least 2 to 3 borings perpendicular to slope direction, repeating groups of borings every 80 to 160 feet. Consider cross-hole seismic refraction in karst areas.
7	Multifamily housing in long apartment rows, walkups, 2 storeys or more	Preliminary	One CPT sounding or SPT boring every 3 to 6 housing modules. Distance between boreholes no greater than 400 feet or 3 borings every 120,000 ft^2.	Take borings or soundings one to three times the building width.
		Final	One boring every 4,000 ft^2 and at least 2 per building, spaced 40 to 100 feet apart.	Take borings or soundings at least twice the building width. For lower buildings with less-intense loading, consider some shorter borings.
8	Isolated structures with large loads, e.g., transmission towers, or unspecified loads such as electrical substations, distiribution points, transformer pads	Footings or piles	Do at least one boring per location (large structures might require at least one boring per footing or pad or leg).For narrow transformer banks, drill a boring every 20 to 30 feet along the length of the structure. Do at least 2 borings per structure and one boring per 2,500 ft^2.	For new or geotechnically-unknown locations, refer to Case 1. More than one boring could be required, depending on results and possible foundation problems. Unless it has been established that bearing capacity is not a problem, take borings or soundings below footings 3 times footing width or 5 times below probable tip of piles. Consider sesimic refraction at each location if need for rock drilling is suspected. Geologic reconnaissance is highly recommended.
9	Sinkhole investigations	Generally	For injection sinkholes, borings should reach the proposed depth of injection. A reasonable number appears to be 3 boreholes per sinkhole, but this will depend on sinkhole size and flows to be injected.	The borings should be complemented with resistivity surveys, cross-hole seismic refraction surveys, or large-scale injection tests as the first injection well is constructed. The depth of injection will depend on the subsurface profile and the presence of nearby structures, and generally will surpass 100 feet. Borings in fragmented rock should be drilled using NX or larger cores, not SPT.
10	Lots for industrial development, not including geotechnical design of each structure	Preliminary study	One boring every two to four acres (adjust density to include structure types, e.g., warehouses); typical spacing 500 feet	Not less than 30-40 feet into competent layer below any compressible layers
		Final report	Two borings per acre (adjust density if study includes preliminary or final geotechnical analysis for specific well-defined structures); typical spacing 250 feet	No less than 30 feet, including 20 feet into competent layer and below compressible layers
11	Existing dumps and sanitary landfills (for transfer stations, see #1)	Generally	See recommendations for industrial developments (#10) and slope stability analyses (#21). Slope stability and effect of settlements on final landfill cover, or new structures over landfill, are crucial aspects of analysis.	Given large size of footprint, for settlement calculations, investigation should reach rock. For hydrogeologic analyses, greater depth might be required. Presence of stiff clay or rock quality will be determining factors in establishing the final exploration depth.
12	Circular tanks, steel or concrete	Preliminary study	One sounding or boring at center, or borings at 150 feet	Drill center boring to a depth 3-times the tank diameter or 20 feet in rock with RQD>40%. Consider seismic refraction or resistivity, depending on type of rock.
		Final report	Place borings or soundings at center, along perimeter and intermediate locatoins (at half-diameters, or middle of quadrants) so that investigation locations are not spaced more than 100 feet apart. Investigation density will vary from one per 2,000 square feet to one per 8,000 square feet for large tanks (diameter ~300 feet or more).	Perimetral borings could be shorter. The investigation depth depends on subsoil conditions and need for cuts or fills but will likely require a depth of 2 to 3 times the tank radius. Space or distribute borings or soundings evenly within tank area.

13	Parks, tennis courts or similar, running tracks, community centers	Final report	One boring every 20,000 ft^2 of total area or one boring every 2,500 square feet of structure area	Short borings will generally be sufficient, say 15 feet, and 3 times the structure widths. However, the boring depths will also depend on other factors, such as fill thickness and settlements induced.
14	Major pipelines (~24-inch-diameter, 600 mm, or larger); small or short pipelines require special analysis; culverts; electrical bank stations	On bedding, solely based on borings or soundings	Every 250 to 600 feet for final reports; every 1,500 feet for preliminary reports.Add a boring or test pit at each vertix or change in direction; try to include manholes.	Take borings to 3 times external pipe diameter. If zone is to be covered with new fill, extend investigation below any compressible zones.
		On bedding, but using borings, soundings and geophysical investigations	Do seismic refraction survey along pipeline every 250 to 600 feet with borings every 600 feet, depending on topography. Add a boring per vertix and try to cover each manhole.	idem
15	Tunnels	Preliminary study	Every 300 to 1,000 feet; the geological characterization of the site - e.g., presence of faults - will be quite important. Depending on the tunnel size, consider horizontal borings along the tunnel axis.	Vertical borings should be taken at least one diameter below tunnel floor.
		Final report	Every 150 feet, unless supplemented with seismic refraction lines at ground surface or using cross-hole seismic refraction, or horizontal borings.	The borings must be taken at least one diameter below tunnel bottom. Seismic refraction will be of great help. Consider horizontal borings and pilot holes. Tunnel width will impose additional requirements.
16	Pump stations, drydocks	Underground structures. Critical factors are uplift or flotation, and excavation-dewatering issues.	For a preliminary investigation, do a borehole towards the proposed center and/or every corner, depending on footprint size; minimum spacing 100 feet. For a final design, do at least two borings per 2,500 ft^2 of footprint, spaced at 50 feet. See suggestions for excavations in #17.	Proposed bottom elevation is required, since it affects depth of investigation. Even in rock, the investigation must be deep enough to predict flow patterns and excavation methods, although these issues usually require greater analysis during construction. It is suggested to take borings to a depth equal to the foundation level plus one-half the footprint width.
17	Excavation designs, dewatering (Certain situations might require pump tests.)	Open cut excavations	One boring per 2,500 ft^2 of excavation footprint for preliminary design, or every 500 ft^2 for final design. Area is horizontal, calculated at surface level, including additional area required by slopes.	Take borings to a depth equal to depth of structure plus twice the excavation width. Continuous sampling is required given the large impact of minor subsurface details such as thin seams. For preliminary permeability estimates, use falling head tests. For important dewatering and excavation projects, pump tests in wells are highly recommended.
		Sheeted excavations	One boring per 1,000 ft^2 of footprint for preliminary design, or every 500 ft^2 for final design, based on structure footprint.	
18	Sheetpiles, retaining structures, reinforced concrete or mechanically-stabilized earth walls, tiedback walls or soil or rock anchors or soil nails	Final	Every 75 feet along wall and 2 or 3 borings or soundings perpendicular to wall (soil profile should extend to cover a length equal to twice the dredging depth or channel or port depth. *Check FHWA guidelines (GEC Number 4 and Soil Nail Manual), which suggest wall borings at 30 meter intervals, plus a line of borings behind the wall at 150-foot spacings.* In gently-sloping ground, drill borings to depths equal to 1.0 to 1.5 times the wall height. In sloping ground (assume >20 degrees) go to 2H. FHWA mentions that half of the locations can use CPT instead of SPT. Test pits or test cuts are recommended to document stand-up time and obtain other data.	As indicated in FHWA GEC No. 4, take borings at or behind wall to twice the wall height; take borings in front of wall to a depth equal to the wall height. Take borings below any potential failure zones. In case of sheetpiles, take borings at least 20 feet below sheetpile tips. For anchored walls (active or passive anchors) the investigation should include the zone of restraint. Deep alluvial deposits will require greater investigation density than shallow alluvial or residual deposits. Drill to cut depth and extract at least 10 feet into rock, if found.
19	Embankments, bridges and highway viaducts, trains	Embankments	One boring every 150 to 500 feet; for viaducts or bridges, consider at least one boring per pier depending on width of pier. Consider need for transversal sections, minimum 3 per profile or section.	Borings should be taken a depth equal to width of embankment plus 50% (x1.5), at least.
		Bridges and viaducts	If drilled shafts are used, follow FHWA guidelines (*Standard Specifications 17th Ed. 2002*): one boring per shaft for pile diameters (ϕ) greater than 4.0 feet; one boring per 2 shafts for ϕ of 4.0 to 6.0 feet; one boring per 4 shafts for $\phi < 4.0$ ft.	For pilecaps, borings should be taken at least 10 diameters below the pile tips. As capacity increases, more boreholes or soundings might be required, up to one per pile. AASHTO requires that boreholes be taken 20 feet below the pile tips and that they also extend below the pile by twice the pilecap width.
		Cuts and slopes	In cut areas, need groups of at least 3 borings perpendicular to cut to define profiles. These profiles should be obtained at least every 100 to 150 feet along cut.	Take boreholes below cut and below potential failure sufaces.
20	Earth dikes or levees	Usually river banks or low-lying areas	Do borings every 1,000 feet for preliminary review. Final report will require investigations points at 100 to 300 feet spacings. Keep in mind that river banks will include young heterogeneous deposits and that a detailed investigation is required, no matter how similar initial borings might appear to be.	For structures such as bridges and culverts, see other sections of this table. Fos stability analyses it is usually necessary to reach competent layers. Minimum depth of exploration should exceed three times width of dike or levee. Consider explorations using both SPT and CPT.
21	Slopes (slope failures, isolated or sporadic investigations)	Emergencies	Need at least one longitudinal profile. The minimum investigations should include groups or lines of 2 to 3 borings, every 30 to 250 feet.	Depth of borings depends on the problem. Slope analyses will require borings taken to a depth at least equal to 1.5 times the slope height. The analysis should consider results from inclinometers, piezometers and continuous sampling.
22	Airport fields	Generally	Need at least one boring or sounding every 2,500 square feet.	Investigation depth depends on subsoils and need for cuts or fills, presence of compressible soils or possibility of liquefaction. Consider continuous sampling with SPT or CPT with seismic cone.
23	Dams	Conceptual design	At this stage, should try to perform one or two borings at center or deepest section, and at each abutment. For earth dams, test pits at probable borrow sites are needed early. Consider 3 to 8 test pits, with compaction testing and classifications.	Drill to a depth that exceeds probable base width by a factor of two, or drill 15 to 20 feet into rock with RQD>50%.
		Preliminary	For earth dams or roller compacted concrete dams, do at least one boring every 350 feet along main axis. Borings will also be required at shells and abutments. Borings and/or test pits will be required at borrow pits. Number of borings for preliminary analysis will be approximately three, every 350 feet along main axis.	At least 40 feet into rock with RQD>50%. Need continuous sampling towards surface to define flow zones or liquefiable layers or soft layers. Depth of slurry walls or impervious layers will affect depth of investigation.
		Final	Depends on type of dam and potential problems: earth dams will require more exploration towards shells. Final study will require at least 3 borings every 150 to 300 feet along the principal axis. For budget purposes, the final number of borings should be approximately 3 every 150 feet along the main axis, plus numerous test pits.	Depends on potential problems with liquefaction, slope stability or flow that have been identified in the preliminary investigation. In this phase, geophysical investigations will be of great use. Numerous test pits or test trenches will be necessary along potential probleam areas or borrow pit areas.
24	Remodeling and additions to existing structures	In general	Investigation density will greatly exceed previously-stated suggestions on investigation densities due to concerns regarding differential settlements and quality of previous design and construction.	Follow previous suggestions, depending on specific case. Enginering fees will greatly exceed cost of investigation.
25	Quarries	In general	Consider seismic refraction. Borings or trenches, if necessary, should reveal earth cover. Rock fragmentation important. Space at least 2 lines of borings every 200 feet of cut face.	Take borings below expected cut depth. For seismic refraction, length of survey should generally be 3 to 4 times expected excavation depth.
26	Parking areas, pavements only	Pavements	One boring every 25,000 ft^2, depending on specific site conditions	Boring depths depend on drainage system and settlement allowances. Check width and height of any fill areas, to determine probable settlements.
27	Previously-filled areas	Deep fill review	Space borings or soundings at least every 150 feet for preliminary study, every 50 feet for final study.	Boring depths depend on probable depth of fill and type of underlying soils. Use continuous sampling. Require greater boring or sounding density.
28	Marinas	In general	Depends on length and width of docks and pile loads. Do boring or sounding every 75 to 150 feet of dock length.	Boring depths will depend on expected loads. Take borings or soundings at least 30 feet below expected pile tips. A detailed investigation could reduce subsequent pile load test requirements.

Note: In most cases, work in karst zones will probably require double the investigation density stated above.

Additional references:

FHWA General Engineering Circular No. 4, Ground Anchors and Anchored Systems, June 1999
FHWA Standard Specifications for Highways and Bridges, 17th Edition, 2002
FHWA Manual for Design and Construction Monitoring of Soil Nail Walls, October 1998
Drilled Shafts: Construction Procedures and Design Methods, by Michael W. O'Neill and Lymon C. Reese
FHWA Publication IF-99-025, August 1999