Geotechnical Manual

Texas Department of Transportation

July 2020

Manual Notice 2020-1

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Manual: Geotechnical Manual

Effective Date: July 13, 2020

Purpose

This manual provides policy for geotechnical investigation and design for project development.

Contents

The revisions contained in each chapter of this version are to clarify the policy and high-level procedures published in 2018. Generally, revisions to the manual were to:

- Update information in Chapter 2 regarding investigation around suspected karst formations, and provide more guidance when recording groundwater elevations during drilling operations.
- Make minor changes to the laboratory testing protocol for shear strength determination in Chapter 2.
- Update procedure in Chapter 3 on 'Drill Hole Filling' with current standard practices using mix of bentonite and/or grout.
- Include limits of any needed Temporary Special Shoring in Retaining Wall layouts standard specifications which would apply to Temporary Special Shoring in Chapter 6.
- Eliminate prior soil parameter assumptions on nailed embankments to account for independent analysis of wall systems in Chapter 6.
- Highlight in Chapter 6 the importance of utilizing proper parameters in the RW(MSE)DD sheet to standardize design.
- Update the minimum criteria for nail diameters in rock nailed walls section in Chapter 6.
- Provide greater clarification in Chapter 7 that global stability design factors of safety should be at minimum 1.3 and 1.5.

Chapter 5 underwent significant revisions and updates, which include:

- geologic layer terminology clarification in Sections 1 and 2;
- updating guidance for Scour Summary Sheet and submission of Form 2605 into the bridge inspection system;
- updating method for calculating scour at bridge channels including reference to NCHRP reports;

- updating the scour guidance at bridge class culverts.

Supersedes

The revised manual supersedes prior versions of the manual.

Contact

For more information about any portion of this manual, please contact the TxDOT Bridge Division.

Archives

Past manual notices are available in a PDF archive.

Table of Contents

Chapter 1 — Manual Overview

Contents:

Section 1 — About this Manual

Purpose of the Manual

The purpose of this manual is to guide districts in geotechnical investigation and design for project development. Recommendations, background information, and examples for geotechnical designs are available on the TxDOT website.

Updates

Updates to this manual are summarized in the following table.

Table 1-1: Manual Revision History

Version	Publication Date	Summary of Changes
2000-1	August 2000	New Manual
2006-1	August 2006	Revision restructuring the manual to include policy and high-level procedures, with recommendations, examples, and background information now available on the Internet.
2012-1	December 2012	Clarification to policy previously established.
2018-1	March 2018	Clarification to policy previously established and updated material in Chapters 3, 4, 5, 6 and 7.
2020-1	March 2020	Clarification to policy previously established and updated material in Chapters 2, 3, 4, 5, 6 and 7.

Organization

Information in this manual is organized into the following chapters:

1. Manual Overview. Introductory information on the purpose and organization of the manual.
2. Soil Surveys. Requirements for conducting soil surveys for projects with bridges, retaining walls, slopes and embankments, sign structures, illumination, sound walls, and radio towers.
3. Field Operations. Requirements for drilling, sampling, and field testing.
4. Soil and Bedrock Logging. Description of material order, level of description, and classification.
5. Foundation Design. Guidelines for selecting foundation types, drilled shafts, piling, and requirements for scour analysis.

6. Retaining Walls. Requirements for retaining wall selection, layouts, design, and excavation support.
7. Slope Stability. Requirements for slope stability design and analysis.

Feedback

Direct any questions or comments on the content of this manual to the Director of the Bridge Division, Texas Department of Transportation.

Chapter 2 — Soil Surveys

Contents:

Section 1 — Soil Surveys

Overview

Conduct soil surveys for projects with the following features:

- Bridges
- Retaining walls
- Slopes and embankments
- Sign structures
- Illumination
- Sound walls
- Radio towers

Perform minimum required testing for all structures, including Texas Cone Penetration (TCP) testing at 5-ft. intervals and at strata changes, as well as Rock Quality Designation (RQD) and percent recovery in rock. See the remaining portions of this chapter for requirements for all explorations.

Review of Existing Data

Review all existing data before determining new data requirements. Old bridge plans are the most common source of information. Old borings containing strength data are usually adequate for new construction. If old borings are used for design, show the old boring data on the plans, and note the date of the boring. Old TCP data may have an additional value listed: the weight of the drill stem when the test was performed. Disregard this number and do not show it if the old borings will be shown in the new plans.

Hole Location

The complexity of geological conditions and the type, length, and width of a structure determine the number of holes required for foundation exploration.

Locate the test holes in an accessible area. When determining the location of test holes, always avoid overhead power lines and underground utilities. If possible, avoid steep slopes and standing or flowing water. Deviations within a 20-ft. radius of the staked location are not usually excessive, but note them on the logs and obtain the correct surface elevation.

When determining the location and depth of test holes, carefully consider the following factors:

- Test hole depth
- Lowering of gradeline
- Channel relocations and channel widenings
- Scour
- Foundation loads
- Foundation type

Bridges

The following figure shows the minimum number of test holes for common types of bridge structures. Do not space test holes more than 300 ft. apart.

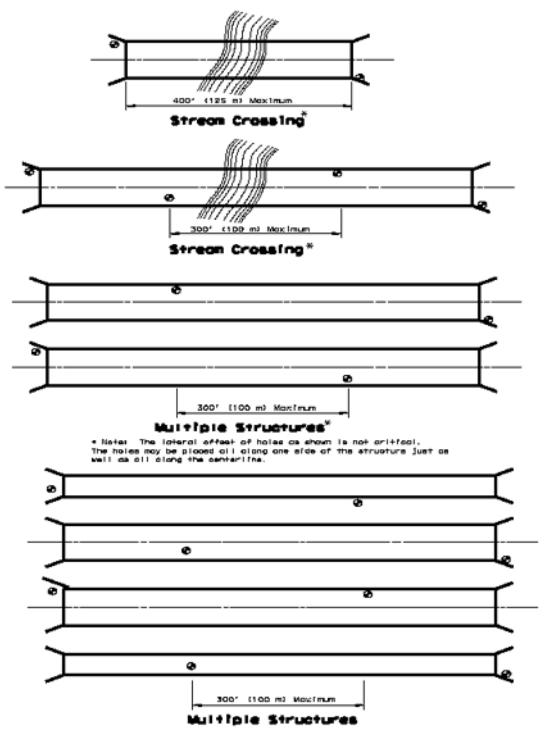

Figure 2-1. Minimum number of test holes for common types of structures

In general, drill test holes 15 to 20 ft. deeper than the probable tip elevation of the foundation. Estimate the probable founding or tip elevation from the results of Texas Cone Penetration tests and correlation graphs in Texas Cone Penetration Test and experience with foundation conditions in the area. Pay special attention to major structures where high foundation loads are expected. If the depth of the boring is questionable, consult the Bridge Division for a detailed analysis of the projected foundation loads and foundation capacities.

Stream Crossings. Structures over channels less than 200 ft. wide are classified as minor stream crossings. For these crossings, place a boring on each bank as close to the water's edge as possible.

If boring information varies significantly from one side of the channel to the other, a boring in the channel may be necessary.

Major stream crossings require core borings in the channel if no existing data is available. A site inspection by the driller or logger is necessary to evaluate site accessibility and special equipment needs.

Karst Features. Structures suspected to be in a karst formation may require more borings or geophysical survey.

Grade Separations. If the structure borings indicate soft surface soils (fewer than 10 blows per foot), additional borings and testing may be required for the bridge approach embankments.

Bridge Field Exploration. The exploration should include the following:

- Test hole spacing. Space test holes near each abutment of the proposed structure plus a sufficient number of intermediate holes to determine the depth and location of all significant soil and rock strata. If you do not get a reasonable correlation between borings (for example, TCP data, stratigraphy), consult with the project engineer to determine the need for additional holes.
- Texas Cone Penetration tests. Conduct Texas Cone Penetration tests at 5-ft. intervals beginning at a 5-ft. depth. Standard penetration test data is not acceptable for foundation design using the TxDOT design procedure.
- Near surface soil layer test. Test soft near surface soil layers (0 to 20 feet) as directed under the subsection in this chapter titled Slopes and Embankments.
- Soil and bedrock classification. Fill out a complete soil and bedrock classification and log record for each test hole on the standard log, including all information to complete the form.
- Ground water. Include ground water elevation measurements (including date of measurement) as part of the data acquisition. Obtain the groundwater elevation minimum 15 minutes after the initial encounter with ground water. Site conditions may require installation of piezometers to establish a true ground water surface elevation and method of monitoring water surface fluctuations.

Retaining Walls

Obtain soil core borings for walls taller than 10 ft. Evaluate walls shorter than 10 ft. on a case-by-case basis. TCP testing alone may be adequate to design walls and evaluate wall stability for short-term loading conditions in cohesive profiles and short-term and long-term loading conditions in cohesionless and rock profiles. A more rigorous sampling and testing program may be required for long-term evaluation of walls founded on cohesive soil.

Soil Borings. Obtain soil borings at 200-ft. spacing unless site conditions or the wall designer requires tighter or coarser spacing.

Boring Depth for Fill Walls. For MSE walls, spread footing walls, temporary earth walls, and block walls, bore to a depth as deep as the height of the wall depending on wall type and existing and proposed ground lines. The minimum boring depth is 15 ft. below the bottom of the wall unless rock is encountered. Extending borings 5 ft. into rock for fill walls is usually adequate.

Boring Depth for Cut Walls. For drilled shaft walls, tied-back walls, and soil and rock nail walls, always base the depth of boring on the final grade lines. Cantilever drilled shaft walls require the depth of boring to extend the anticipated depth of the shaft below the cut, which is typically between one and two times the height of the wall. Advance borings for soil nail and rock nailed walls through the material that is to be nailed. Extend borings a minimum of 20-ft. below the bottom of the proposed wall. Borings for cut walls may need to penetrate rock significant distances depending on the depth of the cut and height of the wall.

Soil Samples and Testing. Provide additional testing for taller walls, walls on slopes, or walls on soft foundations as necessary to completely evaluate wall stability. Additional testing includes but is not limited to obtaining samples for consolidation testing, triaxial testing, or in-place shear testing to determine soil strength. Consult with the wall designer for development of the complete soil exploration plan.

Ground Water. Include ground water elevation measurements (including date of measurement) as part of the data acquisition for retaining walls. Obtain the groundwater elevation minimum 15 minutes after the initial encounter with ground water. Site conditions may require the installation of piezometers to establish a true ground water surface elevation and method of monitoring water surface fluctuations.

Other Structures

Conduct foundation investigations for high-mast illumination, radio towers, and overhead sign structures when other borings are not located nearby. The typical depth of the boring ranges from 30 to 70 ft. but depends on existing and proposed ground lines, soil strength, and structure loading.

Slopes and Embankments

Soil Core Borings. Obtain soil core borings for cuts greater than 10 ft. or embankments taller than 15 ft. in areas with suspect foundation soils (less than or equal to 10 blows/ft.). TCP testing alone may be adequate.

The exploration should include the following:

- The soil under future embankments. Advance borings to a depth equal to the height of the embankment or 20 ft., whichever is greater. Conduct TCP testing at 5-ft. intervals.
- Soil in proposed cuts. Advance borings to a depth of 15 ft. below the bottom of the proposed cut. Conduct TCP testing at 5-ft. intervals.
- Ground water elevation measurements. Include ground water elevation measurements (including date of measurement) as part of the data acquisition for slopes and embankments. Obtain the groundwater elevation minimum 15 minutes after the initial encounter with ground water. Site conditions may require installation of piezometers to establish a true ground water surface elevation and method of monitoring surface fluctuations.

Soil Testing. Perform the appropriate field and laboratory tests necessary to determine the soil shear strength for proper soil evaluation of the structure being designed. Consider both the short-term and long-term conditions:

- Short-term conditions. Use the Texas Cone Penetration test, in-place vane shear tests, unconsolidated undrained (UU) triaxial tests, and or direct shear tests.
- Long-term conditions. Use consolidated undrained (CU) triaxial tests with pore pressure measurement and/or drained direct shear tests.

Estimate long-term strengths of clay soils based on the index properties of the soil. Use the following figure to correlate Texas Cone Penetration test results to angle of internal friction for cohesionless soil.

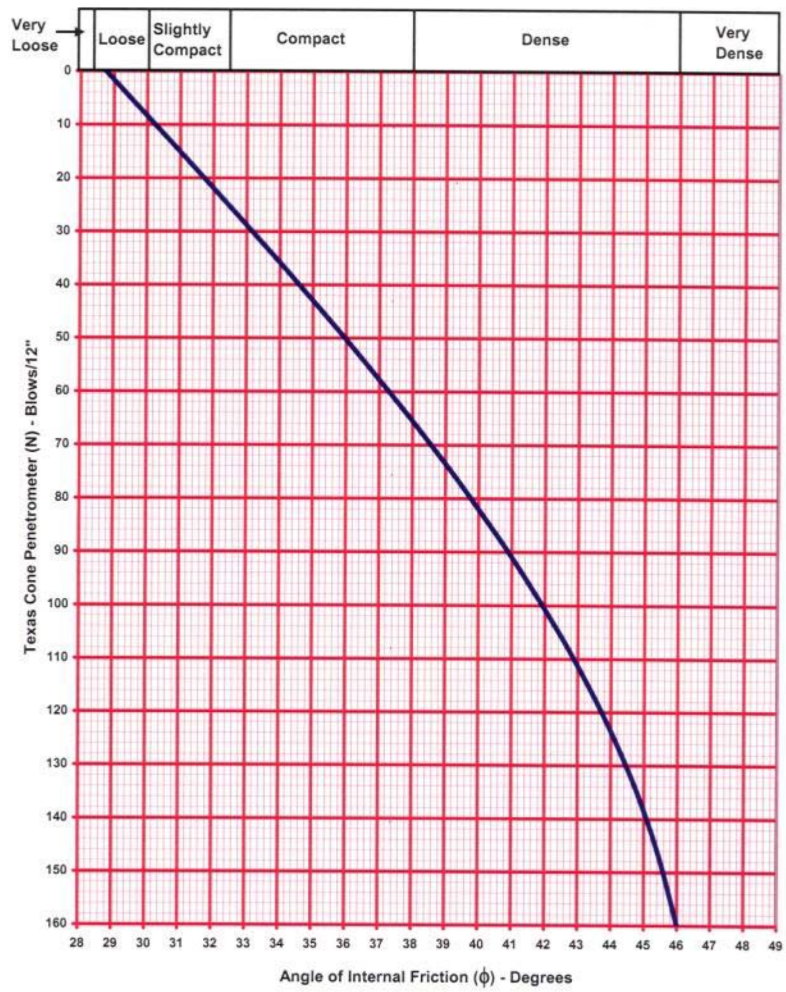

Figure 2-2. TCP vs. Angle of Internal Friction for Cohesionless Soils

Chapter 3 — Field Operations

Contents:

Section 1 — Drilling

Overview

Consider the following items before starting core drill operations:

- Core drill equipment
- Drill rig
- Site preparation
- Access
- Utility clearance
- Traffic control
- Barge work
- Drill hole filling

Access

Ensure that permission to enter private property has been secured before drilling.

Utility Clearance

Clear all locations proposed for drilling for utilities before the core drill team arrives. When utilities are present, ensure their exact locations are clearly marked by the utility company.

Call 1-800-545-6005 for utility clearance. Calls to this number automatically rotate to the three notification centers. Obtain utility clearance at least 48 hours and no more than 14 days before starting core drilling. You may contact the three notification centers directly as follows:

- Texas Excavation Safety System (TESS) 1-800-344-8377
- Lone Star Notification Center 1-800-669-8344
- Texas One Call 1-800-245-4545

Traffic Control

Provide traffic control in accordance with Texas Manual on Uniform Traffic Control Devices for approval prior to drilling.

Drill Hole Filling

Fill or plug drill holes using bentonite pellets or cement bentonite grout to prevent injury to livestock or people in the area and to minimize the entry of surface water into the bore hole. If surface contamination of lower aquifers or cross contamination is a concern, backfill the hole with bentonite pellets or grout. This is especially important in urban areas where ground contamination from leaking underground storage tanks is common. To avoid potential settlement or uplift of pavement core, backfill all borings under existing pavement shall be backfilled with bentonite pellets or cement bentonite grout to a minimum depth of 6 inches below the bottom of pavement structure. Then patch the hole with non-shrink grout to the top of pavement.

Section 2 — Sampling Methods

Overview

Use appropriate sampling methods as dictated by field conditions and laboratory tests. Provide continuous sampling between Texas Cone Penetration testing for visual classification when drilling methods allow.

Section 3 — Field Testing

Texas Cone Penetration (TCP) Test

Conduct TCP testing in accordance with test procedure TEX 132-E Texas Cone Penetration Test. Ensure that the drill rig mobilized to the drill site is equipped with test equipment that conforms to the test procedure. Use a hammer with an automated trip mechanism to regulate the fall of the hammer to 24 in. plus or minus 1/2 in.

TCP values described in this manual are either the total number of blows necessary to drive the cone 12 in. or the distance the cone advances in inches in 100 blows.

Standard Penetration Test (SPT)

The use of SPT testing for foundation design is acceptable for design methodologies in AASHTO. Conduct SPT tests in accordance with ASTM D-1586.

In-Place Vane Shear Test

Use the in-place vane shear test to determine the in-place shearing strength of fine-grained soil, which does not lend itself to undisturbed sampling and triaxial testing. Use this test when encountering organic silty clay (muck) or very soft clay. Ensure these materials are free of gravel or large shell particles because pushing the vanes through these obstructions would disturb the sample and probably cause physical damage to the vanes. Use the test with extreme caution in soil that has Texas Cone Penetration values harder than 15 blows/12 in. Correct the vane shear results to the soil index properties.

Torvane and Pocket Penetrometer

These two test devices are useful for index and classification purposes. They yield only approximate information and are not suitable for foundation design.

Chapter 4 — Soil and Bedrock Logging

Contents:

Section 1 — Logging

Material Order of Description

Keep core descriptions as simple as possible. The order of description is as follows:

1. Material
2. Density or consistency, hardness
3. Moisture
4. Color
5. Cementation
6. Descriptive adjectives
7. Unified Soil Classification System
8. Rock Quality Designation (RQD), percent recovery

Material

Keep the number of strata to a minimum. Remember that every small variation in a soil—such as a change in clay from “slightly sandy” to “sandy”—does not necessarily warrant a strata change. The logger must define strata that have significance to designers and contractors who will use the core log information. Designers and contractors are mainly interested in the primary and secondary soil or rock constituent and whether ground water is present.

Density or Consistency, Hardness

Use the following charts to determine the density or consistency and hardness of material encountered.

Table 4-1: Soil Density or Consistency

Density (Cohesionless)	Consistency (Cohesive)	TCP Values	Field Identification
Very loose	Very soft	0 to 8	Core (height twice diameter) sags under own weight
Loose	Soft	8 to 20	Core can be pinched or imprinted easily with finger
Slightly compact	Stiff	20 to 40	Core can be imprinted with considerable pressure
Compact	Very stiff	40 to 80	Core can be imprinted only slightly with fingers
Dense	Hard	80 to 5 in./100	Core cannot be imprinted with fingers but can be penetrated with pencil

Table 4-1: Soil Density or Consistency

Density (Cohesionless)	Consistency (Cohesive)	TCP Values	Field Identification
Very dense	Very hard	0 in. to 5 in./100	Core cannot be penetrated with pencil

Table 4-2: Bedrock Hardness

Mohs' Hardness Scale	Characteristics	Examples	Hardness	Approximate TCP Values
5.5 to 10	Rock will scratch knife	Sandstone, chert, schist, granite, gneiss, some limestone	Very hard	0 in. to 2 in./100
3 to 5.5	Rock can be scratched with knife blade	Siltstone, shale, iron deposits, most limestone	Hard	1 in. to 5 in./100
1 to 3	Rock can be scratched with fingernail	Gypsum, calcite, evaporites, chalk, some shale	Soft	4 in. to 6 in./100

Moisture

If any moisture exists, note the extent present. The samples will be assumed dry if the degree of moisture is not indicated. If free water is present, describe the soil as wet or water-bearing.

Color

Describe the primary color, and restrict description to one color. If one main color does not exist in a sample, call it multicolored.

Cementation

Identify the degree of cementation if any is present.

Descriptive Adjectives

Use any descriptive adjectives that might further aid in the description.

Unified Soil Classification System (ASTM D2487)

This soil system is based on the recognition of the type and predominance of the constituents considering grain size, gradation, plasticity index, and liquid limit. It contains three major divisions of soil: coarse-grained, fine-grained, and highly organic. See ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), for the procedure for determining soil classification. TxDOT test procedures, Tex-141-E, Manual Procedure for Description and Identification of Soils and Tex-142-E, Laboratory Classification of Soil for Engineering Purposes may also prove useful in the determination of soil type.

Rock Quality Designation (RQD) and Percent Recovery

Determine the RQD for rock core samples following ASTM Test Procedure D6032, Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core. Always note the RQD and percent recovery on logs of borings where rock is encountered.

Log Form

For uniformity, use the standard log form 513, Drilling Log. Group the materials encountered into strata consisting of the same or similar constituents.

Chapter 5 — Foundation Design

Contents:

Section 1 — Foundation Type Selection

Foundation Selection Factors

The designer is responsible for selecting the appropriate bridge foundation. Consider the following factors in that selection:

- Design load. The magnitude of the design load dictates the required size of the foundation from a structural standpoint.
- Subsurface stratigraphy. The depth and strength of subsurface stratigraphy determine the type of foundation chosen. In general, drilled shafts are well suited to areas with competent soil and rock. While drilled shafts have been successfully installed in soft soil, they may be less efficient than piling. In general, use piling where softer soil is present. Very hard material at or near the surface makes driven pile installation difficult.
- Corrosive conditions. Salts, chlorides, and sulfates are detrimental to foundations. Where these conditions exist, take preventive measures. Use sulfate-resistant concrete as defined in Standard Specification Item 421 for construction in seawater or soils with high sulfate content. Consult the list of recommended corrosion protection areas for specific areas of Texas that may have structures with possible corrosion due to sulfate soil or salt water. The use of steel piling in corrosive environments is not recommended. If steel piling must be used, an appropriate protective coating must be selected, additional steel section provided or a combination of these methods utilized to ensure proper performance of the foundation elements.
- Economic considerations. Consider economics in the final selection. Compare the foundation types. The cost of a drilled shaft foundation, for instance, may be less than piling. It may be feasible to use fewer piles at higher design loads, or fewer drilled shafts with larger diameters to maximize economy. If no clear economic difference exists between piling and drilled shafts, you may choose to include both and offer the contractor alternate designs in the contract plans.
- Superstructure type. The type of superstructure chosen for the bridges may dictate or eliminate certain foundation types. For instance, short-span structures over streams may work well with trestle piling, but tall, single column flyovers justify footings with multiple shafts or piling.
- Special design requirements. Special designs are sometimes necessary to straddle another structure or utilities and may require a different type of foundation than the rest of the structure.

Design foundations of new bridges as either drilled shafts or piling. Study all the available soil data, and choose the type of foundation most suitable to the existing soil conditions and the particular structure.

Foundation Guidelines for Widening Structures

Study test-boring data along with any available information regarding the existing foundation, including but not limited to drilled shaft or pile driving records. Usually, old test-boring data is adequate for widening the structure. In widening structures, consider special designs to prevent differential movement between the new and the old foundations. This is normally accomplished by founding the new foundations at approximately the same elevation as the existing foundations, if applicable. Do not use piling in widening structures founded on spread footings.

Widening Structures on Piling. Widen structures on piling with piling tipped in the same stratum, when possible. If loads for piling supporting the widened portion of the structure are the same or lower than loads for the original construction, tip the new piling at approximately the same elevation as the existing piling. If new loads are higher, longer or larger piling may be required. Avoid extreme variations between the new and existing tip elevations to minimize differential movement.

Widening Structures on Drilled Shafts. Widen structures on shafts with shafts at approximately the same tip elevations. Often existing structures with belled shafts may be widened with straight shafts tipped at the same elevation due to current higher allowable soil design loads and use of skin friction in drilled shaft design.

Widening Structures on Spread Footings. The most critical situation occurs when widening a structure founded on spread footings. If the existing footings are less than 6 ft. below natural ground and on rock, widen with spread footings at the same elevation. For abutment and interior bents on deep spread footings, widening with drilled shafts is usually more economical with the shafts founded near the existing footing elevation. This is not always practical, as in the case of widening a structure on spread footings with drilled shafts. In a case like this, evaluate the soil for shrink/swell potential.

Section 2 — Interpretation of Soil Data

Overview

A critical step in foundation design is determining strata and reasonable strengths to be assigned to each stratum. Divide the subsurface materials into strata based on material description and test values. Review all tests within each stratum to evaluate the variability of the data. If a single, unusually high strength test is present among a group of distinctly lower test values, disregard the anomalous test value. An average strength may be assigned for an entire layer as long as the test values are reasonably similar.

Avoid defining very thick strata with widely variable test values. Subdivide thick strata with test values varying from soft near the top to distinctly harder toward the bottom into two or more strata with compatible values. Failure to subdivide may result in an unconservative average strength being applied to foundations that terminate in the upper zone of that stratum.

An acceptable option to producing average unit values for strata is to calculate using a more rigorous, test-by-test basis.

Disregard Depth

Disregard surface soil in the design of drilled shafts and piling foundations. The disregarded depth is the amount of surface soil that is not included in the design of the foundation due to potential erosion from scour, future excavation, seasonal soil moisture variation (shrinkage and swelling), lateral migration of waterways, and other factors. Disregard a minimum amount of 5 ft. over non-water crossings and 10 ft. over stream crossings. For abutments, disregard the portion of foundation passing through embankment fills.

It is important to note that for projects where the existing ground line is at an elevation considerably higher than the proposed grade line (roadway is to be depressed) soil softening, swelling or heave must be accounted for in design of embankment slopes, roadways, retaining walls and foundation elements. Soils in these conditions respond to the removal of overburden (unloading). This response could have a dramatic impact on the design approach taken.

Additional information regarding disregarded depth is available online.

Texas Cone Penetration Test

Use the following charts to determine skin friction and point-bearing capacity based on Texas Cone Penetration data for drilled shaft and piling designs. Use Figure 5-1 to determine allowable skin friction for soil softer than 100 blows/12 in. Select the curve based on the description of the soil type.

Use the CH curve in clay soil identified as high-plasticity, or fat clay. Use the CL curve in clay soil identified as low-plasticity, or lean clay. In clay soil, use the CL curve if no specific identification is provided regarding plasticity. Use the SC curve for soil described as either sandy clay or clayey sand. Use the OTHER curve for soils described as silt, sand, gravel or any layers not fitting into one of the previous designations.

For drilled shaft designs, multiply the allowable design stress by a reduction factor of 0.7. The reduction factor is used to account for disturbance of the soil during drilling. Application of the reduction factor to the design of driven piling is not necessary.

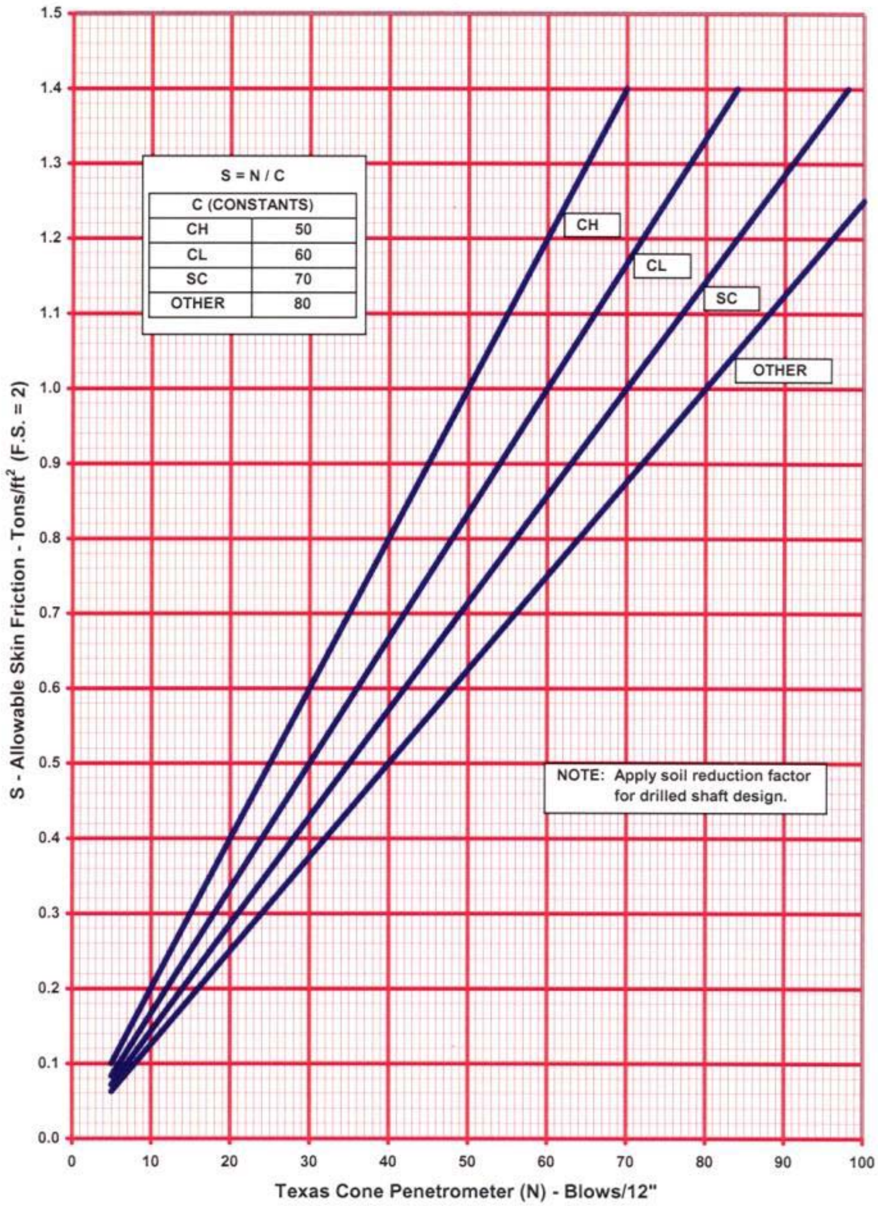

Figure 5-1. Allowable Skin Friction (TCP Values Softer than 100 Blows/12 in.)

Use Figure 5-2 to determine allowable point bearing for soil softer than 100 blows/12 in. Select the curve based on the description of the soil type, using the criteria noted for the previous chart.

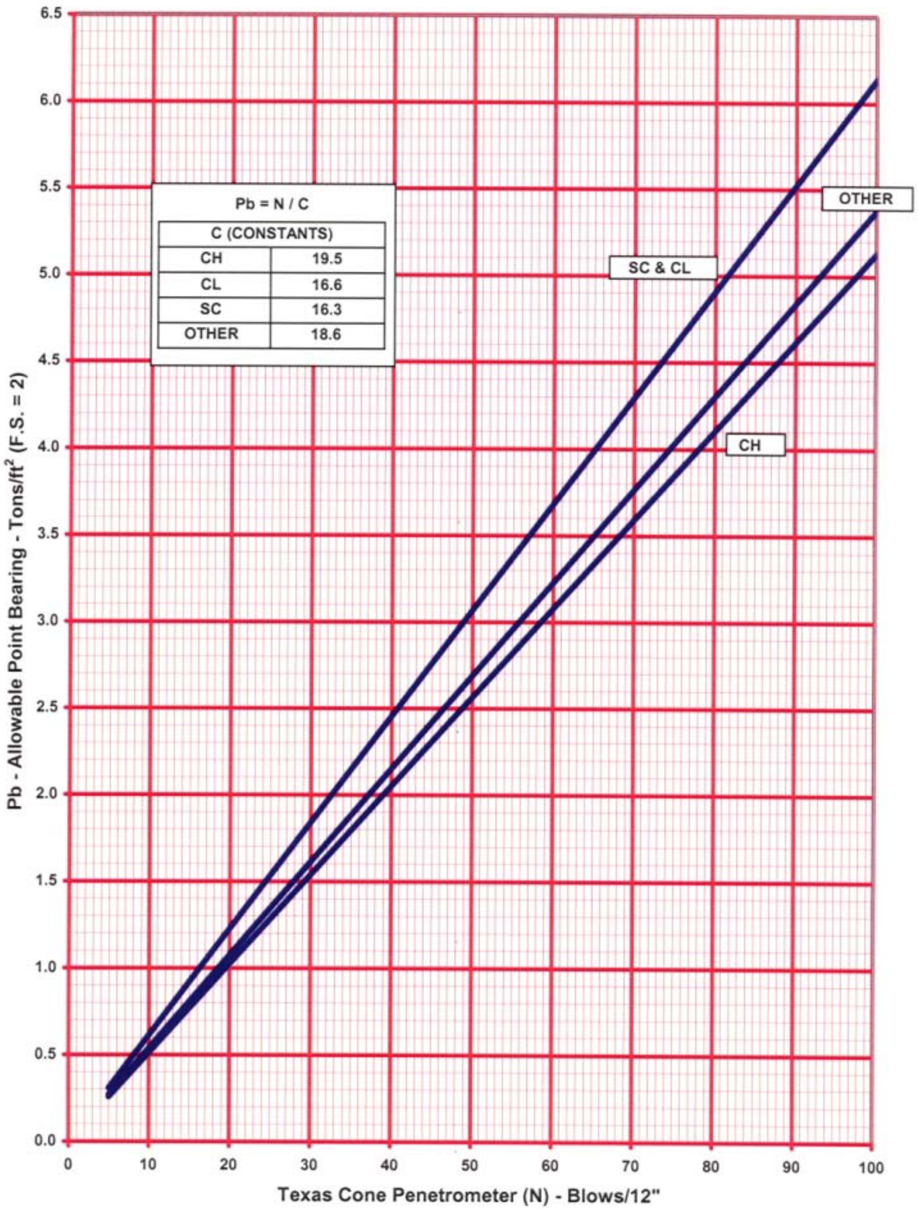

Figure 5-2. Allowable Point Bearing (TCP Values Softer than 100 Blows/12 in.)

Use Figure 5-3 to determine allowable skin friction for soil or rock strata harder than 100 blows/12 in. The upper limit of 3.25 tons/ft^2 applies for all Texas Cone Penetration values less than 2 in/100 blows. Do not apply skin friction reduction factor to values obtained from this figure because this figure is derived only for use in drilled shaft design. Piling typically cannot be driven into soil of this strength, so this figure is not generally used for piling design.

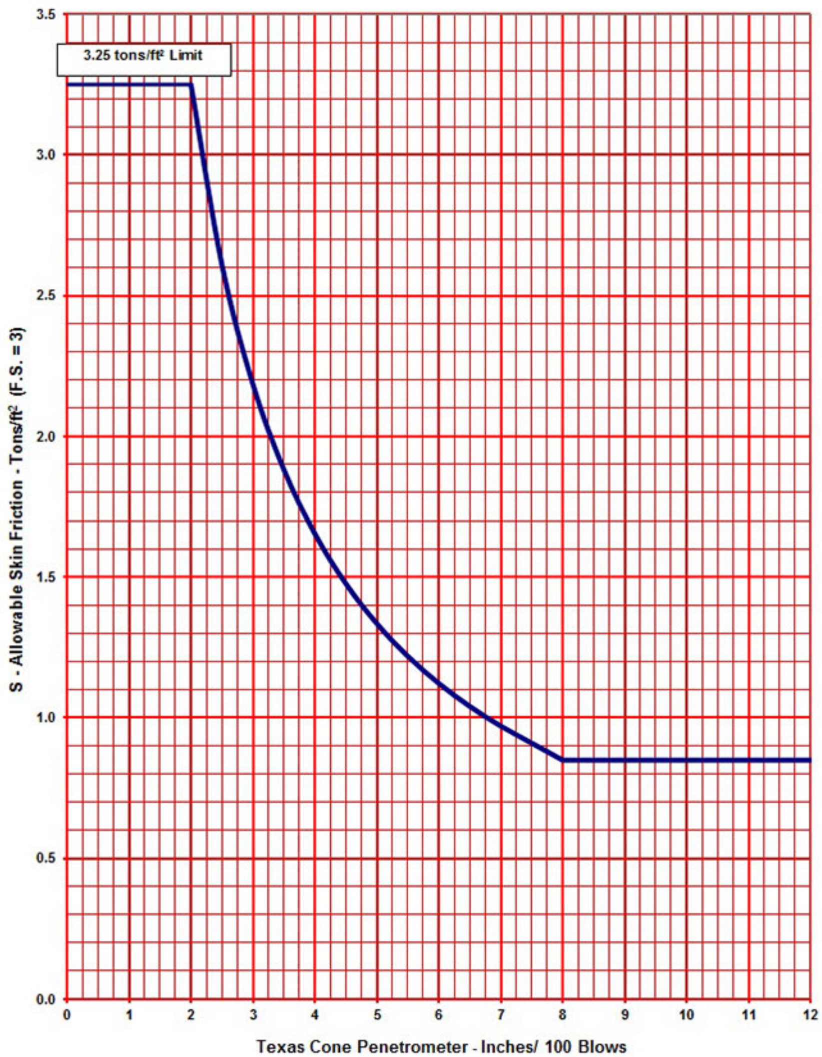

Figure 5-3. Allowable Skin Friction (TCP Values Harder than 100 Blows/12 in.)

Use Figure 5-4 to determine allowable point bearing for soil or rock strata harder than 100 blows/12 in. The upper limit of 31 tons/ft^2 applies for all Texas Cone Penetration values less than 2 in/100 blows.

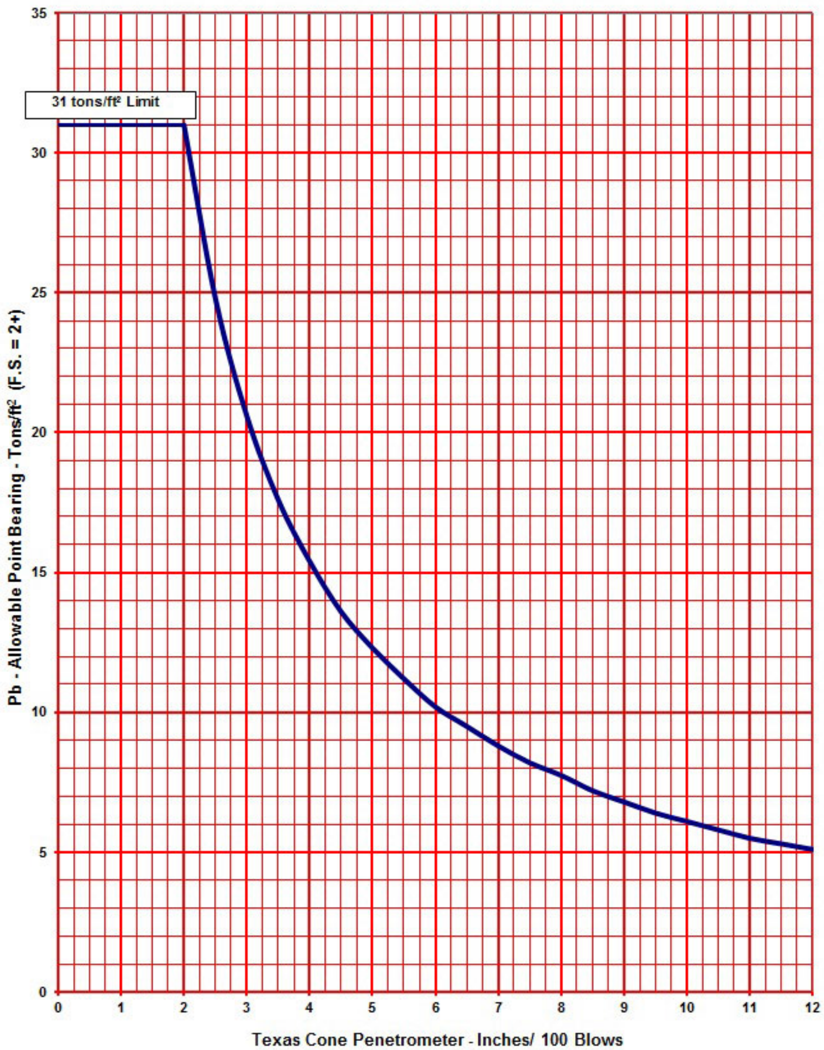

Figure 5-4. Allowable Point Bearing (TCP Values Harder than 100 Blows/12 in.)

Laboratory Test

If additional strength data is available from triaxial or direct shear testing, use this data with TCP data in the design of foundations. Determine the ultimate shear strength for each stratum using Coulomb's formula (Shear Strength = $\tau = c' + \sigma_y'$ (tan ϕ'). Determine allowable skin friction by applying a factor of safety of at least 2.0 to the ultimate shear strength. For drilled shaft design, reduce the allowable skin friction value by an additional reduction factor of 0.7 to account for soil disturbance. Determine allowable point bearing by multiplying the ultimate shear strength by a bearing capacity factor of 9 and then dividing by a factor of safety of at least 2.0.

Section 3 — Drilled Shafts

Overview

Consider both skin friction and point bearing in drilled shaft design. Calculate total allowable skin friction by multiplying the perimeter of the shaft by the unit value for allowable skin friction derived from Figure 5-1, Figure 5-3, or laboratory data or any combination thereof. Apply a reduction factor of 0.7 to allowable skin friction values derived from Figure 5-1 or from laboratory testing. Do not apply the reduction factor to allowable skin friction values obtained from Figure 5-3. Accumulate skin friction along the length of the shaft beginning at the previously defined disregard depth and continuing down to the tip of the shaft. Calculate total allowable point bearing by multiplying the area of the drilled shaft times the unit value for allowable point bearing derived from Figure 5-2, Figure 5-4, or laboratory data. If softer layers exist within two shaft diameters of the proposed tip, use allowable point bearing values for the softer layers. If drilled shafts are to be tipped in very hard material that is overlain by soft strata, the skin friction contribution of the softer strata may be disregarded in design. However, do not ignore the contribution of significant amounts of competent material in order to tip in rock. In many areas of the state, rock is overlain by thick layers of material that can support considerable loads.

Belled Shafts

Belled drilled shafts are no longer used as a foundation element for bridge foundations. Therefore, do not use belled shafts for bridge foundation design.

Standing Water

Drilled shafts installed in lakes or rivers require use of a casing placed from above the water surface to a minimum embedment into the river or lake bottom. Do not define the top of the drilled shaft in the normal manner (a set distance below finished grade). Define the top of the drilled shaft as 1 to 2 ft. above the normal water elevation. If the water level is variable, add a provision allowing the top of the drilled shaft to be adjusted based on water level at the time of construction. Allow casing required for construction to remain in place at the option of the contractor. Typically, casings left in place look no worse than the stained concrete shaft that will be visible if casings are removed. If casing is to be left in place, disregard skin friction along the length of the casing. If permanent casing is used in standing water, consideration should be given to painting the portion of casing extending above the mud line.

Wing Shafts

Found wing shafts in similar founding material as abutment shafts to minimize the potential for differential settlement.

Service Loads

See the following table for maximum drilled shaft service loads recommended without conducting a detailed structural analysis. Before final structural design, review the soil information to verify the ability of the foundation to develop desired loads.

Table 5-1: Maximum Allowable Drilled Shaft Service

Size	Load
24 in.	175 tons
30 in.	275 tons
36 in.	400 tons
42 in.	525 tons
48 in.	700 tons
54 in.	900 tons
60 in.	1,100 tons
66 in.	1,350 tons
72 in.	1,600 tons
84 in.	2,175 tons
96 in.	2,850 tons
108 in.	3,625 tons
120 in.	4,475 tons

Drilled Shaft Reinforcement

Drilled shaft reinforcement is to be designed for axial, lateral, and uplift load. The reinforcement will follow the details on the FD Standard, unless site specific designs are required which require alternate reinforcement. The longitudinal reinforcement for the drilled shaft will extend the full length of the shaft.

Drilled Shaft Integrity Testing

Various testing methods are available to determine the integrity of drilled shafts, which are Crosshole Sonic Logging, Gamma-Gamma testing, and Thermal Integrity Profiling (TIP). TIP is the preferred testing method, as it is done during the curing of the concrete and does not delay construction. Bridge Division has developed a Special Specification for TIP testing titled “Thermal Integrity Profiler (TIP) Testing of Drilled Shafts.”

TIP testing should be considered for use under the following conditions:

- Mono-shafts;
- Large diameter shafts (60” diameter, or greater);
- Drilled shafts with a diameter > 24 inches encountering water bearing sands in the soil profile and on critical roadways, such as interstate systems, high ADT roadways, emergency routes, evacuation routes, etc.

Consult with the Geotechnical Branch to determine if a specific project might be considered a candidate for TIP testing.

Layout Notes

When drilled shaft capacity depends heavily on penetrating a specific hard layer, add a plan note instructing the contractor and field personnel of the penetration requirement. If no specific penetration into a hard layer is required, no plan note is necessary:

- Hard founding layer at depth: When a hard founding layer is expected to be present more than three shaft diameters below the surface, specify a minimum penetration of one shaft diameter on the plans if the design load is reached at this location. Increase this minimum penetration if additional skin friction is required to fulfill the design requirements.

  Typical notes on bridge layouts:

  - "Found drilled shafts a minimum of one shaft diameter into hard rock," or
  - "Found drilled shafts at the elevations (lengths) shown or deeper (longer) to obtain a minimum XX drilled shaft diameter penetration into hard rock," where XX is determined by the design.

- The designer can use the control of elevation or length if elevations are not called out on the layout. Expand the words "hard rock" to distinguish the type of material anticipated. Although not a common practice, the first note allows a drilled shaft to be shortened if rock is encountered at higher than anticipated elevations, and it requires the shaft to be lengthened if rock is not encountered where expected.

  Rock at surface: When rock is present at or near the surface, consider load-carrying capacity along with the stability of the superstructure on the foundation. For these shafts, a minimum shaft length of three shaft diameters is recommended. That is, a minimum three-diameter shaft length, not a three-diameter penetration into rock. The final length of the drilled shafts should be based on both axial and lateral loading (if required). If the potential scour extends down to the top of rock then the minimum embedment of the drilled shaft should be three shaft diameters or deeper to obtain the required axial and lateral capacity.

A typical note on bridge layouts reads, "Found drilled shafts at the elevation (length) shown or deeper (longer) as necessary to obtain a minimum of three shaft diameter penetration into hard rock."

- The designer can use the control of elevation or length if elevations are not called out on the layout. Expand the words "hard rock" to distinguish the type of rock. This note does not allow a drilled shaft to be shortened from plan length, but it does require lengthening if rock is not encountered at the expected elevation.

Plan notes should be specific as to the type of material to be penetrated. If more than one material is likely to be encountered, it is acceptable to have multiple descriptions, such as “into dense sand, sandstone, and/or shale.” Avoid using vague terms such as “hard strata” or “founding material.” In stream or river environments, the channel flow line and estimated depth of scour should be considered in determining the final shaft length and necessary penetration.

Section 4 — Piling

Overview

Piling design should consider skin friction and may consider point bearing as well. Because piling has small tip areas and is generally placed in softer soil, the point bearing contribution is modest and is often disregarded in design.

Calculate total allowable skin friction by multiplying the perimeter of the pile by the unit value for allowable skin friction derived from Figure 5-1, Figure 5-3, or laboratory data or a combination thereof. The maximum recommended value for allowable skin friction for piling design is 1.4 tons per square foot (TSF). Accumulate skin friction along the length of the pile beginning at the previously defined disregard depth and continuing down to the tip of the pile. If using point bearing, calculate total allowable point bearing by multiplying the area of the pile times the unit value for allowable point bearing derived from Figure 5-2, Figure 5-4, or laboratory data. If softer layers exist within two shaft diameters of the proposed tip, use allowable point bearing values based on the softer layers. Displacement piling refuses to advance when it encounters material with TCP values harder than 100 blows/12 in. On refusal, assume that the piling has developed the maximum allowable service load for the pile.

Take care when designing piling in areas with shallow hard or dense soils. If piling cannot be driven through these areas, the contractor will need to pilot hole or jet the piling to achieve the desired penetration.

Wing Piling

Found wing piling in similar founding material as abutment shafts to minimize the potential for differential settlement.

Steel Piling Special Considerations

- Grade Separations:
  - Foundation elements for grade separations are subject to potential vehicular impact the use of steel sections in a trestle configuration in those potential impact zones is highly discouraged. Instead for grade separations, steel H piling can potentially be used under pile footings for interior bents or for abutments.
- Stream Crossings:
  - Foundation elements for stream crossings are subject to scour, drift impact and have a higher propensity for corrosion. For stream crossings, steel piling needs to be analyzed for potential corrosion over the life span of the structure and need to be evaluated for both axial and lateral loadings under the scoured condition. Steel piling that have been

evaluated for the above conditions and found to be acceptable could be used for trestle bents. However, the steel piling must be coated to a minimum depth of 15 feet below the maximum predicted scour elevation. Steel piling can be used to support pile footings as long as the footing is embedded at a depth below the maximum predicted scour depth thus minimizing the risk of exposure. Piling used in a footing configuration must be coated a minimum distance of 15' below the bottom of footing. Piling can be used for foundation elements for abutments.

Difficult Driving

If it is necessary to advance the piling through a strong or stiff layer where refusal is possible, a pile penetration note may be required. A typical note may read, “The contractor’s attention is drawn to the hard material in the soil profile, jetting and/or pilot holes may be necessary to advance the piling to the required penetration depth.”

Service Loads

See the following table for maximum piling length and structural loads recommended without conducting a detailed structural analysis. Many soils are not capable of developing these maximum loads. Before final structural design, review the soil information to verify the ability of the foundation to develop desired maximum loads.

Table 5-2: Maximum Allowable Pile Service Loads

Size	Maximum Length	Abutments and Trestle Bents	Footings (per Pile)
16 in.	85 ft.	75 ton	125 tons
18 in.	95 ft.	90 tons	175 tons
20 in.	105 ft.	110 tons	225 tons
24 in.	125 ft.	140 tons	300 tons

Dynamic Monitoring

Dynamic monitoring of a pile during driving can be accomplished using a Pile Driving Analyzer (PDA) testing system. PDA testing measures the strain and acceleration in the pile as a result of the impact of the hammer. PDA testing of a pile can help to determine the stresses in the pile during driving and monitor the pile for damage or integrity. The capacity of the pile and time dependent changes in capacity (if a restrike is undertaken) can be obtained if the PDA testing data is used with the Case Pile Wave Analysis Program (CAPWAP).

Not all piling will require dynamic monitoring. However, for critical structures, projects with a large number of piling, or in difficult soil conditions PDA testing should be considered for use. Consult with the Geotechnical Branch to determine if a specific project might be considered as a candidate for PDA testing.

Section 5 — Foundation Load Testing

Foundation load testing is a reliable means of determining the capacity of the foundation elements. Foundation load testing is governed by Standard Specification Item 405. The various testing methods that can be used are:

static load testing,

high strain dynamic testing, and

statnamic testing.

Not all foundations will require foundation load testing. Typically, load testing of foundation elements is used in conjunction with Thermal Integrity Profiler (TIP) testing. Consult with the Geotechnical Branch prior to using foundation load testing on a project.

Section 6 — Scour

Analysis

All bridges over waterways require a scour evaluation and a completed Scour Summary Sheet. The Scour Summary Sheet must be signed and sealed by an engineer and entered into the bridge inspection management system (BIMS) by District Bridge Inspection Staff. Scour evaluation documentation must also be entered into the BIMS. The results of the scour evaluation will determine the Bridge Inspection Coding for Item 113 – Scour. The table below defines the minimum scour design flood frequencies and scour design check flood frequencies for a given hydraulic design flood frequency. These values are to be used to ensure that a bridge will remain stable for a given design flood frequency.

Table 5-3: Hydraulic Design, Scour Design, and Scour Design Check Flood Frequencies

Hydraulic Design Flood Frequency, Q_D	Scour Design Flood Frequency, Q_S*	Scour Design Check Flood Frequency, Q_C*
Q_{10}	Q_{25}	Q_{50}
Q_{25}	Q_{50}	Q_{100}
Q_{50}	Q_{100}	Q_{200}
Q_{100}	Q_{200}	Q_{500}

* Use the values listed or the overtopping event, whichever is the lower event.

New Bridges with Known Foundations

Evaluate new bridges with known foundations for potential scour in accordance with the following:

- Guidelines outlined in Evaluating Scour at Bridges (HEC-18).
- Do not use abutment scour equations because none of the equations to date yield acceptable results. Use contraction scour equations to calculate total scour at abutments. Protect abutments against potential scour through use of a flexible revetment, where possible.

Determine scour at bridges using the following analysis techniques:

- Use the following table to determine susceptibility of competent rock to scour when it is present at moderate to shallow depths. Consider materials deemed either not susceptible or mildly susceptible to scour the limit of the maximum scour depth.

Table 5-4: Material Susceptibility to Scour

Material	Subtype	TCP Values	Susceptibility
Rock	Hard (granite, limestone, shale)	< 4 in./100 blows	Not susceptible
	Soft (shale)	< 12 in./100 blows	Mildly susceptible but not considered over time span of one flood event
Clays	Hard (redbed, shaley clays, very stiff clays)	< 12 in./100 blows	Mildly susceptible but not considered over time span of one flood event
	Soft to medium	> 12 in./100 blows	Susceptible to scour at a moderate rate
Sands	All	All	Very susceptible

- Monitor shales and stiff clays for long-term degradation. Shales and stiff clays tend to break down and disintegrate when exposed to repeated wetting and drying, a major problem in northeast Texas where head cutting in the Sulphur River basin has resulted in the channels down-cutting into the shale. The rate of degradation of shale in this situation is typically on the order of inches per year. As a result, most shales and stiff clays are not considered susceptible to scour during a single flood event. Consider long-term history of channel cross sections when evaluating these materials.
- For channels in cohesionless materials, such as sand and gravel, calculate contraction and pier scour using the following methods:
  - Contraction scour: use the equations in HEC-18.
  - Pier scour: use either the equations in HEC-18, Froelich's Equation, or Sheppard's Equations.
- For channels in cohesive materials, such as clay, calculate contraction and pier scour using the following methods:
  - Limit d_{50} to 0.2 mm (6.56×10^{-4} ft or 7.87×10^{-3} in). For contraction scour, use the equations in HEC-18. For pier scour, use the equations in HEC-18 with a reduction factor of 0.5 for soils with 11% or more clay.
  - Use the SRICOS Method. Refer to NCHRP Research Report 915 for determination of erodibility parameters.
  - Use Annandale's Erodibility Index Method.
- For channels in layered soil, calculate scour using the following methods:

- Conduct a scour analysis layer by layer using the methods specified above for individual layers. If the calculated scour of a given layer is greater than the thickness of the layer, remove that layer and recalculate the hydraulic variables. Then continue the scour analysis with the next layer.
- Use the SRICOS Method. Refer to NCHRP Research Report 915 for determination of erodibility parameters.
- Use Annandale's Erodibility Index Method.

Because of conservatism built into analysis techniques for calculating scour and limitations and gaps in existing knowledge, apply engineering judgment when using results from scour analyses.

Before using the scour analysis for bridge foundation design, check the scour predictions to ensure:

- the scour calculations account for layered soil/rock profiles.
- the scour calculations account for the soil/rock properties (that is, clay, silt, sand, gravel, rock, etc.)
- the calculated scour depths do not extend into competent rock.

Determine if the calculated scour exceeds the typical disregard depth of 10 feet from the channel flow line. If so, use the following to evaluate the calculated scour:

- Performance of the existing structure during past floods (compare historic data of cross section changes at the bridge with the scour predictions).
- Hydrologic characteristics and flood history of the stream and similar streams.
- Recalculation of the scour analysis using a step-wise procedure that incrementally removes material and recalculates the required hydraulic variables. This may decrease the total scour depth.

Upon completion of a scour evaluation for a new bridge, the Scour Summary Sheet for Known Foundations (Form 2605) is to be completed and entered into the bridge inspection system, along with scour evaluation documentation. All Bridge Division and District contracts for bridge design and plan preparation should include a submission of completed Form 2605 and a full scour evaluation report as a deliverable. In addition, the results of the scour evaluation are to be used to determine the Bridge Inspection Coding for Item 113 – Scour. The results of the coding need to be entered into the BIMS.

Do not show scour depths on the Bridge Layout Elevation View. All pertinent scour information must be listed on the Scour Summary Sheet in the bridge inspection system.

Existing Bridges with Known Foundations

The scour evaluation guidance for new bridges with known foundation also applies to existing bridges with known foundations.

In certain cases, existing bridges with known foundations may be evaluated for potential scour using the following:

- Texas Secondary Evaluation and Analysis for Scour (TSEAS, 1993)

The TSEAS Manual includes two parts: a) Secondary Screening Method; and b) Concise Analysis Method. The Secondary Screening Method is only applicable to low volume Off-System bridges with known foundations. The Concise Analysis Method is applicable to both On-System and Off-System bridges that are not on the interstate system or are otherwise high priority bridges. Bridges that would be considered high priority are:

- Bridges on principal arterials;
- Bridges on evacuation routes;
- Bridges that provide access to local emergency services such as hospitals; and
- Bridges that are defined as critical in a local emergency plan (i.e., bridges that enable immediate emergency response to disasters).

Upon completion of a scour evaluation for an existing bridge, the Scour Summary Sheet for Known Foundations (Form 2605) is required to be completed and entered into the bridge inspection system, along with scour evaluation documentation. In addition, the results of the scour evaluation are to be used to determine the Bridge Inspection Coding for Item 113 – Scour. The results of the coding need to be entered into the BIMS.

Existing Bridges with Unknown Foundations

Contact the Geotechnical Branch for the evaluation of existing bridges with unknown foundations.

Bridge Class Culverts

Evaluate new and existing bridge class culverts for potential scour using the following:

- Bridge Class Culverts with Bottoms
  - Assess scour coding based on field observations using the criteria listed on the Scour Summary Sheet for Bridge Class Culverts (Form 2606)
- Bridge Class Culverts without Bottoms

- Use the guidelines for either new bridges or existing bridges outlined above for scour evaluation
- New bridge class culvert without bottoms should be supported with deep foundations.

Scour Critical Bridges

Existing bridges that require a coding in Item 113 of a 3, 2, 1, or 0 are considered scour critical. For each scour critical bridge, a Plan of Action (POA) needs to be developed, implemented, and entered into the BIMS.

Stone Protection at Bridges

Protecting abutments and piers at bridges is beneficial in limiting the effects of scour. The use of stone protection is recommended over concrete riprap due to its flexible nature. Concrete riprap, due to its rigidity, masks problems. Consequently, voids can form under them and eventually undermine the pavement or approach slab.

Stone protection needs to be designed for the conditions that exist at the bridge. The recommended methodology for the design of stone protection is to use HEC – 23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Guidance (see Volume 2 for guidance on design). Upon completing the design, the appropriate D50 will be determined. This value should then be compared to the tables in Item 432 – Riprap to determine the appropriate size of the stone protection. Once the appropriate size of the stone protection has been identified then the appropriate thickness of the stone protection needs to be determined. The thickness is a function of the conditions where the stone protection is being used. However, a general rule of thumb is that the thickness needs to be equal to or larger than 1.5 times the size of the stone protection listed in Item 432. This is consistent with the procedures outlined in HEC-23 for the thickness of the stone protection, where it is typically taken as the larger of either the 100% size (i.e. maximum size) or 2 times the D50 size. If one compares the range of the D50 values for the various sizes listed in table 2 of Item 432 and then multiplies by these by 2 one will obtain approximately 1.5 times the size of the stone protection listed. In the plans Stone Protection should be specified as follows:

Riprap (Stone Protection) XX in. (where XX is the size in inches)

Thickness = YY in. (where YY is the appropriate thickness)

Chapter 6 — Retaining Walls

Contents:

Section 1 — Retaining Wall Selection

Overview

The project engineer who seals the plans is responsible for ensuring that the retaining wall selected for a given location is appropriate. Use the following criteria to choose a retaining wall:

- Geometry. Determine applicability of wall type—cut, cut/fill, or fill—based on geometry, site constraints, and wall alignment and location. Identify available right of way. Identify location and type of existing and proposed utilities. Identify location and type of existing and proposed drainage structures.
- Economics. Evaluate the total cost of wall, including needed excavation shoring. Identify required utility adjustments and costs. Identify project schedule, phasing requirements, and effect on wall construction and design.
- Stability. Evaluate all walls to ensure that minimum factors of safety are met for global stability. When possible, avoid placing walls on slopes. A slope in front of the wall dramatically reduces passive earth pressure (resistance) and can compromise global stability, increasing the probability of wall failure. For situations where walls above a slope cannot be avoided, conduct a rigorous stability analysis following conditions identified in the Design Considerations section of this chapter.
- Constructability. Determine whether walls are near water or subject to inundation. Identify access limitations for equipment. Ensure adequate horizontal and vertical clearances are provided for installation of retaining wall types, particularly tied-back, nailed, and drilled shaft walls.
- Aesthetics. Ensure that the aesthetic treatment of the wall complements the retaining wall and does not disrupt the functionality or selection of wall type. Be careful with aesthetic treatments that involve landscaping: design additional drainage measures if extensive watering is anticipated to prevent excessive hydrostatic pressures from building up behind the wall.

Section 2 — Retaining Wall Layouts

General Content Layout

In general, retaining wall layouts include the following information.

- Plan View. The plan view should contain the following items:
  - Beginning and ending wall points by station, offset, and roadway alignment
  - Additional points as necessary to describe the relationship of wall alignment to roadway alignment(s)
  - Indication of which side is the face of the wall
  - Horizontal curve information if applicable for wall alignment
  - Location of soil borings (Include boring name, station, offset, and top-of-hole elevation.)
  - Signing, lighting, etc., mounted on or passing through wall (Designate and locate the sheets that contain information for these elements.)
  - Surface and subsurface drainage structures or utilities that could affect or be affected by wall construction (Designate and locate the sheets that contain information on the structure or utilities.)
  - Limits of Temporary Special Shoring
- Elevation view. The elevation view should contain the following items:
  - Existing ground line along wall alignment
  - Proposed finished grade line at face of wall
  - Bottom of wall for payment
  - Top of retaining wall grade line (Does not include the top of rail.)
  - Soil boring information where possible, shown at the correct elevation and scale
  - Designation for “Back Face of Wall” when back of wall is shown
  - Panel numbers when applicable
  - Drainage, signing, lighting, etc., as noted above
  - Drainage structures and utilities as noted above
- Estimated quantity table. Include the estimated quantity table for each retaining wall type. Refer to a specific wall type for list of bid codes. The estimated quantity table should contain the following items:
  - Area of retaining wall
  - Linear footage of railing on wall
  - Miscellaneous quantities associated with wall (riprap, etc.)

- Typical section. A typical section should contain the following information:
  - Cross section showing the relationship of the wall to the roadway
  - Control point for horizontal and vertical alignment, typically shown at the top outermost corner of the wall
  - Indication of maximum slope on top of and in front of wall
  - Location of proposed finished grade
  - Railing type, flume, mow strip, etc., if applicable
  - Distance from back of wall panel to face of abutment cap, if applicable
- General notes. The general notes should include the following information:
  - A note stating the required wall embedment depth if the specified embedment is greater than 1 ft. for slopes up to 4:1 in front of wall or 2 ft. for slopes in front of wall that are steeper than 4:1, as well as a note stating that the wall is measured between top of wall and "X" ft. below finished grade
  - Reference to all applicable standard sheets for pertinent information
  - Other pertinent information regarding wall design and construction

Plans for Specific Wall Types

For specific retaining wall types, include the following additional information on the layout and in the plan set.

Spread Footing Walls. For spread footing walls, include the following additional information:

- Panel design designation (for example, LC-10-32) for each panel corresponding to the appropriate cast-in-place spread footing wall standard sheet. The designation includes a reference to the controlling standard drawing, design height, and panel width information.
- Location of expansion and construction joints (Assuming 32-ft. panels, every third joint is typically designated as an expansion joint.)
- Set bottom of wall (top of footing) horizontal and stepped to meet minimum embedment criteria. (Distance from one step to the next is typically greater than 6 in. Provide bottom of wall elevations for all panels.)
- Appropriate standard sheets pertaining to cast-in-place spread footing walls

Designate all information necessary for the contractor to construct the wall on retaining wall layouts for spread footing walls. This type of wall does not have a proprietary vendor to provide shop drawings, so the plan set must be complete with details.

Mechanically Stabilized Earth (MSE) Walls. For MSE walls, include the following additional information:

- Bottom of wall shown following the proposed finished grade offset at the minimum embedment depth specified
- The most recent Mechanically Stabilized Earth Panel Type Systems list (include it in the general notes of the plan set.) Appropriate standard sheets pertaining to MSE walls

Concrete Block Walls. For concrete block walls, include the following additional information:

- Bottom of wall shown following the proposed finished grade offset at the minimum embedment depth specified
- The most recent Concrete Block Retaining Wall Systems list (include it in the general notes of the plan set.) Appropriate standard sheets pertaining to concrete block walls

Tied-Back Walls. For tied-back walls, include the following additional information:

- Panel and closure-pour width dimensions
- Bottom of wall shown with a level footing elevation, also referred to as having steps. (Distance from one step to the next is typically greater than 6 in.)

Designate all information necessary for the contractor to construct the wall on retaining wall layouts for tied-back walls. This type of wall does not have a proprietary vendor; however, shop drawings are required to fully detail the panel schedule to be used on the project and information regarding proposed anchor length.

Soil/Rock Nailed Walls. For soil or rock nailed walls, include the following additional information:

- Location of expansion and construction joints spaced at intervals not to exceed 90 ft.
- Set bottom of wall horizontal and stepped to meet minimum embedment criteria. (Distance from one step to the next is typically greater than 6 in. Provide bottom of wall elevations for all panels.)
- Estimated quantity for “Soil/Rock Nail Anchors”
- Typical section showing existing or proposed foundations or other obstructions that may interfere with wall construction
- Test nail lengths, loads, and bar grade and size

Designate all information necessary for the contractor to construct the wall on retaining wall layouts for nailed walls. This type of wall does not have a proprietary vendor to provide shop drawings, so the plan set must be complete with details.

Drilled Shaft Walls. For drilled shaft walls, include the following additional information:

- Set bottom of wall horizontal and stepped to meet minimum embedment criteria
- Panel width dimensions

- Bottom of wall shown with a level footing elevation, also referred to as having steps. (Distance from one step to the next is typically greater than 6 in. Provide bottom of wall elevations for all panels.)
- Estimated quantity for “Drilled Shaft” used on wall (This quantity is broken into specified shaft diameters.)

Designate all information necessary for the contractor to construct the wall on retaining wall layouts for drilled shaft walls. This type of wall does not have a proprietary vendor to provide shop drawings, so the plan set must be complete with details.

Temporary MSE Walls. For temporary MSE walls, include the following additional information:

- Bottom of wall shown following the proposed finished grade offset at the minimum embedment depth specified
- Appropriate standard sheets pertaining to temporary MSE walls

Section 3 — Design Considerations

General Design

Design and analyze walls following accepted geotechnical engineering industry standards. In analyses, use earth pressures that follow governing sections of the current edition of the AASHTO *Standard Specifications for Highway Bridges*. For load conditions or walls that are not specifically covered by AASHTO, refer to the TxDOT web page for recommendations.

The project engineer must ensure that the retaining wall system is appropriate for its location. Check walls to ensure minimum factors of safety are met for all potential modes of failure. These include sliding, overturning, bearing pressure, and global stability. Consult governing wall standard sheets for assumptions and minimum factors of safety for various modes of failure. The minimum global factor of safety is set at 1.3 for conditions where the designer has adequate soils laboratory and field testing data on which to base the analysis. Make the global safety factor 1.5 or greater where the data obtained for the design and analysis is based primarily on strength correlations or walls that support abutment, buildings, critical utilities, or for other installations with a low tolerance for failure. If a TxDOT retaining wall standard is used for the wall design, it is the designer's responsibility to validate the strength values shown on the retaining wall standard used. If the actual soil conditions show a strength weaker than that shown on the governing standard the designer must determine what modifications, if any, are necessary to the standard and if any ground improvements are necessary to ensure wall performance.

Avoid perching walls on slopes. When walls must be placed on slopes, conduct both short- and long-term stability analyses using appropriate soil strengths, geometry, and loading conditions (live load surcharge, hydrostatic, etc.).

Design Criteria for Specific Wall Types

Spread Footing Walls. The engineer who selects this type of wall for inclusion in the plans is responsible for overall (global) stability of the wall. Ensure that the actual wall geometry and loading conditions apply to the standard drawing selected. Ensure that interruptions to the stem or footing steel by utilities or curved sections of walls do not compromise the design and performance of the wall. Ensure that skewed abutment ends do not pose conflicts with the footprint of the wall. Provide guidance or structural details when deviations from the wall standard drawings are warranted. Standard drawings provide a choice between high pressure (H) and low pressure (L) footings: selection of the appropriate standard drawing is a function of the loading, geometry, and allowable soil pressures. Standard drawings are developed based on the design parameters for foundation and retained soils of a cohesion of zero, a friction angle of 30 degrees for the retained and foundation soil, and a unit weight of 120 pcf for each. Give special consideration to walls subject to inundation. Considerations include drainage and draw-down stability analysis. Standard specification Item 423 governs the design and construction of this wall type.

MSE Walls. The engineer who selects this type of wall for inclusion in the plans is responsible for overall (global) stability and for providing information to complete the RW (MSE) DD sheet. MSE wall suppliers are responsible for internal stability of the walls and for ensuring that external stability, as defined on the RW (MSE) standard, is met. The RW (MSE) standard drawing is available, utilizing the following design parameters:

- Retained soil — a cohesion of zero and a unit weight of 125 lbs.
- Foundation soil — a cohesion of zero and a unit weight of 125 lbs.
- Select fill - a cohesion of zero, a friction angle of 34 degrees, and a unit weight of 105 pcf or 125 pcf depending on the stability analysis being conducted. Refer to the RW(MSE) standard for additional information.
- The friction angle of both the foundation soil and the retained soil must be defined by the wall designer and input on the TxDOT RW(MSE) DD sheet. Default minimum earth reinforcement is set at 8 ft. or 70 percent of the wall height, whichever is greater. The wall designer is responsible for ensuring that the minimum earth reinforcement length selected on the RW(MSE)DD sheet satisfies the factor of safety requirement with the defined friction angle of the foundation soil and the retained soil. To ensure proper performance of the wall in place, evaluate project-specific requirements for wall backfill type, wall embedment, wall drainage, conflicts within the wall reinforced zone, and other considerations as necessary. Give special consideration to walls that are subject to inundation. Type BS backfill is the default backfill for permanent walls. Type DS backfill must be specified for walls that are subject to inundation. Analyze walls subject to inundation for 3 ft. of draw-down. Refer to the RW(MSE)DD standard for guidance on the draw down design condition. Walls to be placed in front of bridge abutments should have a 1.5-ft. minimum and 3-ft. desirable clearance from back of wall panel to face of abutment cap to facilitate wall construction. Standard specification Item 423 governs the design and construction of this wall type.

Concrete Block Walls. The engineer who selects this type of wall for inclusion in the plans is responsible for overall (global) stability of the wall. Concrete block wall suppliers are responsible for internal stability of the walls and for ensuring that external stability, as defined on the RW (CB) standard, is met. The RW (CB) standard drawing is available utilizing the following design parameters:

- Retained soil — a cohesion of zero, a friction angle of 30 degrees, and a unit weight of 120 lbs.
- Foundation soil — a cohesion of zero, a friction angle of 30 degrees, and a unit weight of 120 lbs.
- Select fill — a cohesion of zero, a friction angle of 34 degrees, and a unit weight of 120 lbs.

- If the site condition soil properties differ from those indicated above then the RW(CB) standard needs to be modified to reflect the actual site soil properties.

Concrete block walls may be classified as either structural or landscape walls. The minimum strap length varies depending on the wall function. Minimum earth reinforcement lengths are 6-ft. for walls designated as landscape walls, and 8-ft. otherwise. To ensure proper performance of the wall in place, evaluate project-specific requirements for wall backfill type, wall embedment, wall drainage, conflicts within the wall reinforced zone, and other considerations as necessary. Type BS backfill is the default for permanent walls. Give special consideration to walls that are subject to inundation. Specify Type DS backfill, and analyze these walls for 3 ft. of draw-down. The maximum particle size of the select backfill is limited to ¾" for nonmetallic reinforcements. Consult the standard drawing for guidance on wall definition. Standard specification Item 423 governs the design and construction of this wall type.

Tied-Back Walls. The prestressed ground anchors (tie backs) are nearly horizontal elements that are drilled, grouted, and stressed in place. Determine tied-back loads and soldier pile bending moments from the apparent earth pressure diagrams. Fill and live load surcharges are included in the pressure diagram. Determine loads and moments by the tributary area method. The minimum tie-back length is 25 ft. This length is composed of a minimum 15-ft. debonded length and a minimum 10-ft. bonded length. The ultimate length of tie-back is determined by the wall contractor. Anchor loads and soil conditions may warrant tied-back anchors on the order of 60 to 70 ft. long. The anchors are then stressed to the load specified in the construction drawings. Consider the distance the tie backs will project behind the wall and any potential conflicts with subsurface obstructions or right of way limitation. Ensure that tie backs have a minimum 6-in. clear cover from any obstructions. Obtain permanent easements for tie backs that cross the right-of-way line. Consider equipment accessibility due to horizontal and vertical clearance restrictions. Standard specification Item 423 governs the construction of this wall type and is supported by special specifications Prestressed Ground Anchors and Prefabricated Soil Drainage Mats.

Soil Nailed Walls. Soil nails are nearly horizontal elements that are drilled and grouted in place. Walls are typically designed using a limit state equilibrium program such as Goldnail, SNAP-2 or Snail-Z. Consider the distance the nails will project behind the wall and any potential conflicts with subsurface obstruction or right of way limitation.

For permanent walls, use the following minimum criteria:

- Hole diameter — 6 in.
- Bar size — #6
- Grade — 75 ksi for permanent walls
- Bars — epoxy-coated, Dywidag or Williams threadbar, or equivalent

Standard specification Item 423 Retaining Walls and Item 410 Soil Nail Anchor govern construction of this wall type and are supported by the special specification Prefabricated Soil Drainage Mat.

Ensure that nails have a minimum 6-in. clear cover from any obstructions. Obtain permanent easements for nails that cross the right-of-way line. The top of the wall should be no more than 2 ft. above existing grade to ensure constructability of the soil nail wall; special design considerations are required when this distance is exceeded. Nail spacing depends on project-specific site and loading conditions. A 3-ft. to 4.5-ft. vertical spacing and a 3.0-ft. to 4.5-ft. horizontal spacing is typical. Soil strengths used in the design of soil nail walls are typically determined from correlations of strength to Texas Cone Penetration values conducted through the embankment to be nailed. Use ultimate strengths in the analysis. Design walls considering the proposed wall geometry and loading. Limit head strength to avoid a bad design. Unrealistic or high head strength results in shorter nails and causes the lowest nails to carry a disproportionate amount of load. In practice, head strength is the variable manipulated to achieve a reasonable distribution of nail forces and is the capacity of the nail anchorage in the fascia. Manipulate head strength until the nails in the upper half of the wall carry at least half of the total load. This distribution may not be possible for very tall walls, walls with near-infinite back slopes or layered soil systems. For these cases, increase the nail lengths to engage the upper portion of the failure surface to develop a better load distribution. Final verification on design should include a global check using the analysis mode of the design program used or an independent slope-stability program that is capable of modeling soil nail anchors.

Consider equipment accessibility due to horizontal and vertical clearance restrictions.

Rock Nailed Walls. Rock nails are nearly horizontal elements that are drilled and grouted in place. Rock nailed walls are based on an empirical design approach. Maximum nail spacings are set at 5 ft. vertically and 5 ft. horizontally. Because this is an empirical design, confirm that site conditions are conducive to this type of design. Rock nail walls are used in materials classified as rock and have TCP values of 4 in. or less per hundred blows. Consider rock nail walls for rock with TCP values less than 6 in./100 blows and more than 4 in./100 blows on a case-by-case basis. Evaluate shale for applicability of this wall type because of its tendency to revert to its parent material. Consider the dip, bedding thickness, Rock Quality Designator, percent recovery, joint spacing, and joint pattern of the rock formation. Nail lengths may be adjusted to ensure that nailed rock mass is inherently stable in the primary modes of failure (sliding and overturning).

For permanent walls, use the following minimum criteria:

- Nail diameter — 4 in.
- Tendon size — #6
- Grade — 75 ksi
- Bars — epoxy-coated, Dywidag or Williams threadbar, or equivalent

Standard specification Item 423 Retaining Walls and Item 411 Rock Nail Anchors govern construction of this wall type and are supported by the special specification Prefabricated Soil Drainage Mat.

Consider the distance the rock nails will project behind the wall and any potential conflicts with subsurface obstructions or right of way limitations. Ensure that nails have a minimum 6-in. clear cover from any obstructions. Obtain permanent easements for nails that cross the right-of-way line. The top of wall should be no more than 2 ft. above existing grade to ensure constructability of the rock nail wall; special design considerations are required when this distance is exceeded. Consider equipment accessibility due to horizontal and vertical clearance restrictions.

Drilled Shaft Walls. Drilled shafts are vertical elements that are drilled and concreted in place. They vary in size, diameter, and spacing depending on soil conditions, loading, and wall geometry. Derive wall loading using a Coulomb analysis. Soil information necessary for design includes friction angle, cohesion, and unit weight. Determine soil strengths below the proposed ground line at face of wall from correlations of strength to Texas Cone Penetration values. Use ultimate strengths in the analysis. The following soil strength reductions can be used in design:

- Reduction based on close shaft spacing (see the following figure)
- Reduction of surface soil strength based on expected swelling/softening of the soil

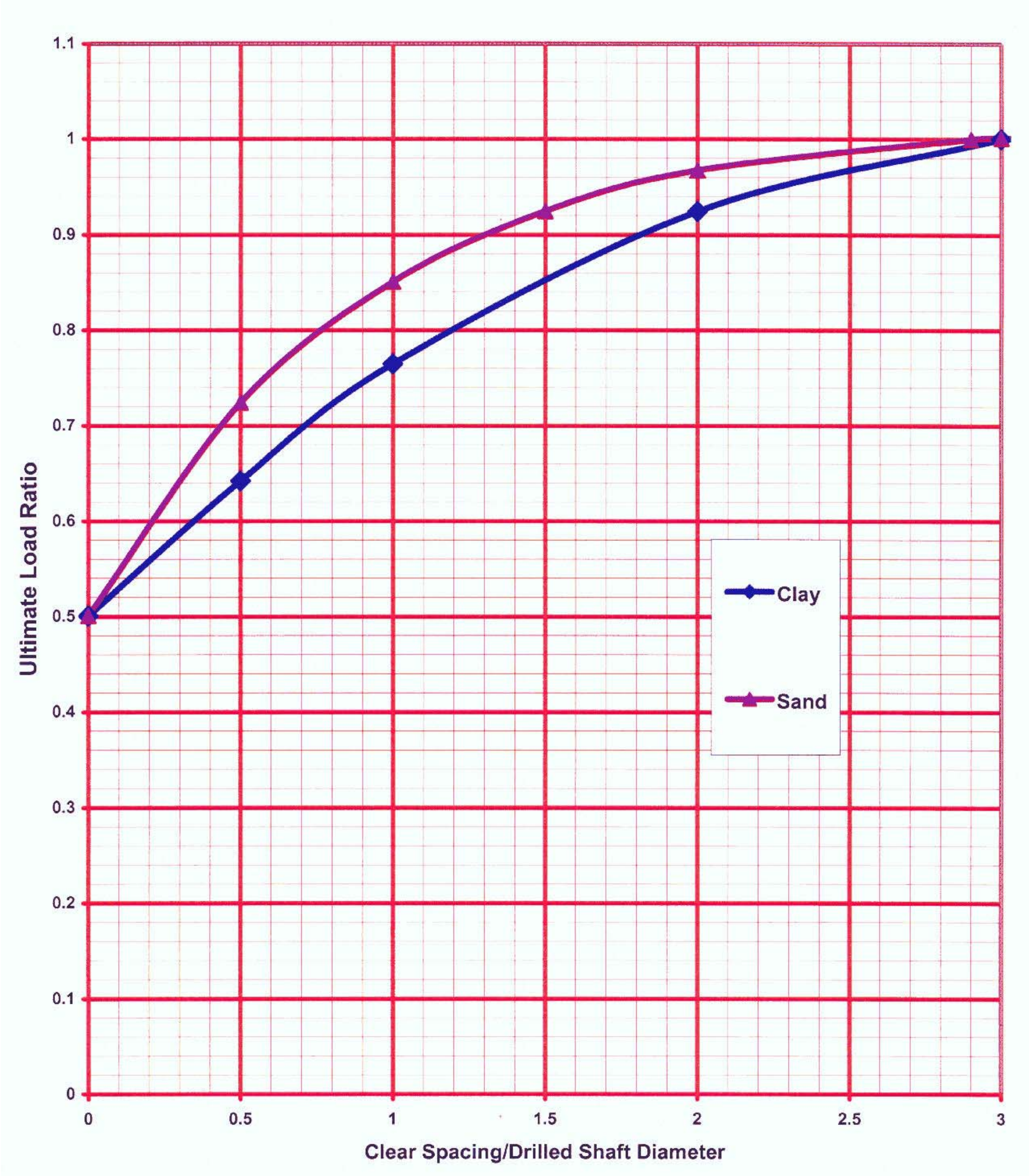

Figure 6-1. Ultimate Load Ratio vs. Clear Spacing/Drilled Shaft Diameter for Various Soil types

Rock is typically modeled as very stiff clay with a very high cohesion. Design the walls iteratively varying length of shaft for successive runs. Make a plot of shaft embedment versus top of shaft deflection to determine when additional embedment does not result in a reduced deflection. The minimum embedment length that results in no additional top of shaft deflection is defined as the depth to fixity. Typically, a final length of shaft is taken as 133% of the embedded length of shaft to fixity. Maximum tolerable top of shaft deflection is set at 1% of the wall height. The maximum steel percentage is 2.5% to 3%. Minimum clear spacing between adjacent shafts is set at 1 ft. Design wall fascia to account for the maximum earth pressure at the bottom of the wall. The load applied to the fascia should be applied through the window between the shafts assuming simple supports at the centerline of the shafts. The Contractor is responsible to ensure that face stability is maintained between shafts throughout construction. This should be addressed by a note in the plans. Consider equipment accessibility due to horizontal and vertical clearance restrictions. Standard specification Item 416 Drilled Shafts and Item 423 Retaining Walls govern construction of this wall type and are supported by special specification Prefabricated Soil Drainage Mat.

Temporary MSE Wall. The engineer who selects this type of wall for inclusion in the plans is responsible for overall (global) stability of the wall. Temporary MSE wall suppliers are responsible for internal stability of the walls and for ensuring that external stability, as defined on the RW (TEW) standard, is met. The RW (TEW) standard drawings are available based on the following design parameters:

- Retained soil — a cohesion of zero, a friction angle of 30 degrees, and a unit weight of 120 pcf.
- Foundation soil — a cohesion of zero, a friction angle of 30 degrees, and a unit weight of 120 pcf.
- Select fill — a cohesion of zero, a friction angle of 30 degrees, and a unit weight of 120 pcf.
- If the site condition soil properties differ from those indicated above, then the RW(TEW) standard will need to be modified to reflect the actual site soil properties.

Minimum earth reinforcement length is set at 6 ft. To ensure proper performance of the wall in place, evaluate project-specific requirements for wall backfill type, wall embedment, wall drainage, conflicts within the wall reinforced zone, and other considerations as necessary. Give special consideration to walls that are subject to inundation. Type C backfill is the default backfill for temporary walls. Specify Type D backfill for walls that are subject to inundation. Analyze walls subject to inundation for 3 ft. of draw-down. Backfill the 2-ft. zone immediately behind the facing with clean coarse rock or cement-stabilized backfill. A designer who prefers to use coarse rock or cement-stabilized backfill must state this in the plan documents. If a temporary MSE wall will be in service for longer than 3 years, the designer must state this in the plan documents to ensure that the wall supplier provides a design with an adequate service life. Temporary MSE walls placed adjacent to permanent MSE walls must be detailed with earth reinforcement that will prevent corrosion of the permanent earth reinforcements due to contact of dissimilar metals. This may be accomplished by providing galvanized or synthetic earth reinforcements for the temporary MSE walls.

Standard specification Items 403 and 423 govern construction of this wall type.

Section 4 — Excavation Support

Overview

An excavation is any human-made cut, cavity, trench, or depression in an earth surface formed by earth removal. A protection system for an excavation includes support systems, sloping and benching systems, shield systems, and other systems that provide protection. The two main types of excavation protection are trench excavation protection (see standard specification Item 402) and temporary special shoring (see standard specification Item 403).

For either protection system, the Contractor must be compensated for the method of choice. For example, for temporary special shoring when excavation techniques such as sloped cuts or benching are used to provide the necessary protection, the surface area of payment is calculated based on the area described by a vertical plane adjacent to the structure.

Trench Excavation Protection

Trench excavation protection is used for the installation of linear drainage or electrical features that will result in trenches deeper than 5 ft. It provides vertical or sloped cuts, benches, shields, support systems, or other systems providing the necessary protection in accordance with Occupational and Safety Health Administration (OSHA) Standards and Interpretations, 29 CFR 1926, Subpart P, Excavations.

Temporary Special Shoring

Temporary special shoring is used for installations of walls, footings, and other structures that require excavations deeper than 5 ft. Temporary special shoring is designed and constructed to hold the surrounding earth, water, or both out of a work area. It provides vertical or sloped cuts, benches, shields, support systems, or other systems to provide the necessary protection in accordance with the approved design. Unless complete details are included in the plans, the Contractor is responsible for the design of the temporary special shoring. The Contractor must submit details and design calculations bearing the seal of a licensed professional engineer for approval before constructing the shoring. The design of the shoring must comply with OSHA Standards and Interpretations, 29 CFR 1926, Subpart P, Excavations. Design structural systems to comply with *AASHTO Standard Specifications for Highway Bridges* or *AASHTO LRFD Bridge Design Specifications*. Design shoring subject to railroad loading to comply with railroad *Guidelines for Temporary Shoring* and any additional requirements of the railway being supported.

Standard specification Item 403 can be used for both cut and fill shoring. When temporary MSE walls are used for fill situations, construct these walls in accordance with the requirements of standard specification Item 423, Retaining Walls, and include the standard sheet RW(TEW). For cut situations where soil or rock nail walls may be used, include special specifications for the appropriate nailing method and for Prefabricated Soil Drainage Mat. Amend special specifications to remove pay item reference for the soil/rock nail anchors, making them subsidiary to Item 403.

Consider temporary shoring concurrently with the permanent wall layout and design or grade change requirements of any given project. The best wall design or project geometry is difficult to execute and may put both workers and the traveling public at risk if proper shoring requirements are not addressed. In extreme cases, the cost of temporary shoring required to construct a wall can exceed the cost of the permanent wall. Avoid this and reduce negative effects with proper planning and proper wall selection.

Design temporary shoring like a permanent retaining wall. Determine the proper design loading that will act on the shoring wall. Consider the effect of surcharges or slopes behind the shoring wall. Due to the impermeable nature of some shoring types such as sheet piling, you may also need to consider water pressure or additional drainage details in design.

Consider temporary shoring for the following conditions:

- At the back of fill-type retaining structures in cut situations
- In front of existing structures such as retaining walls, bridge supports, header banks
- On projects with staged construction
- Near railroads
- For bridge footings

Chapter 7 — Slope Stability

Contents:

Section 1 — Overview

Overview

Evaluate all slopes, whether a cut or a fill and whether in soil or in rock, for global stability for both short-term (undrained) and long-term (drained) conditions. Specific site conditions may require evaluation for additional types of failure, such as bearing capacity, settlement, and undercutting (for rock cuts).

Section 2 — Analysis and Design

Global Stability Analysis

Use the following data to analyze global stability of a slope:

- Geometry (cross section and loading conditions)
- Location of the water table
- Soil/rock stratigraphy
- Soil/rock properties (unit, weight, Atterberg Limits, undrained and drained shear strength)
- Additional loading conditions (traffic surcharge, railroad live load, etc.)

For global stability of a slope, a minimum factor of safety of 1.3 is required for both the long-term drained condition and the short term undrained condition. Make the factor of safety 1.5 or greater for slope or walls that support abutment, buildings, critical utilities, or for other installations with a low tolerance for failure.

Experience has shown that most exposed side slope failures begin as shallow slides and then deepen with time. With this as a guide, the following table was developed to determine the recommended upper limit on the Plasticity Index for various slope conditions to maintain a factor of safety of 1.3 for the long term or drained soil conditions using an infinite slope analysis accounting for seepage of water parallel to face of slope.

Table 7-1: Plasticity Index Range for Exposed Side Slopes Required for FS =1.3 for the Long Term or Drained Condition

Slope X:1	Plasticity Index (PI) (%)
2.5 to 1	< 5
3.0 to 1	< 20
3.5 to 1	< 35
4.0 to 1	< 55
4.5 to 1	< 85

Index