ODOT BRIDGE FOUNDATION DESIGN PRACTICES AND PROCEDURES

OREGON DEPARTMENT OF TRANSPORTATION

BRIDGE ENGINEERING SECTION

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FOREWORD

This document was developed to assist Geotechnical Engineers in the design of bridge foundations according to the most current ODOT Standards of Practice. The information presented should also be useful to Engineering Geologists who may be responsible for certain phases of the work. The final product of this work typically includes the preparation of a Foundation Report. The Foundation Report is the end result of work that includes office research, foundation exploration, soil sampling and laboratory testing, evaluation of various substructure types and design concepts, foundation analysis and design, foundation construction considerations, project special provisions and the preparation of a Foundation Data Sheet.

This document covers two areas: 1) ODOT Foundation Design Practice and 2) Foundation Report Content. For design, references are usually provided to standard AASHTO, FHWA & ODOT design manuals that are typically used in ODOT foundation design. The purpose of this document is to provide Geotechnical Engineers and Engineering Geologists (either ODOT or not) information regarding ODOT's foundation design procedures and also to provide some specific details regarding ODOT foundation design practices. It is not intended to be prescriptive in nature nor does it include all ODOT Foundation Design practices and procedures.

The information that should be contained in a typical Foundation Report is also presented. The ODOT Bridge Section Foundation Engineer should be contacted as needed for additional information and details regarding ODOT Bridge Foundation design policies, procedures and report content.

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I. Scope

Foundation Design work entails assembling all available foundation information for a structure, obtaining additional information as required, completing the foundation analyses and combining the information into a report that includes the specific structure foundation recommendations. ODOT foundation design currently follows the Allowable Stress Design (ASD) procedures described in the most current version of the AASHTO manual "Standard Specifications for Highway Bridges", with all interim revisions. Design specifications provided in this document are based on the ASD approach. FHWA design manuals are also acceptable for use in foundation design and preferable in some cases. ODOT foundation design is currently in the process of implementing the newly approved re-write of Section 10 of the AASHTO LRFD Bridge Design Specifications. ODOT foundation design standards related to the new LRFD design code will be forthcoming in a later document.

II. Foundation Reports

For most projects, two documents are generated by the foundation designer; the TS&L Foundation Design Memo (or preliminary Geotechnical Report) and the Foundation Report. Descriptions of each document follow:

TS&L Foundation Design Memo – The purpose of this memo is to provide sufficient data for developing TS&L plans and cost estimates and for permitting purposes. The memo is generally provided before the subsurface investigation is completed but may contain any preliminary subsurface information, such as drilling results, performed up to that date. It provides a brief description of the proposed project, the anticipated subsurface conditions (based on existing geologic knowledge of the site, as-built plans and any other existing information) and presents preliminary foundation design recommendations such as foundation types and preliminary capacities. The rational for selecting the recommended foundation type should be presented. The potential for liquefaction and associated effects are also briefly discussed. The memo is to be provided no later than two-thirds of the way through the TS&L design process. The document should be stamped by the Geotechnical Engineer of Record and (if appropriate) the project Engineering Geologist. The memo may be distributed in the form of an email message or a full report depending on the size and scope of the project. If the memo is distributed by email a hard copy should also be printed out, stamped and sealed by the Engineer, and placed in the project file.

Foundation Report – This report is to be provided by the end of the Preliminary Bridge Plans Design phase, which is usually 60% structural design completion. It provides the final foundation design recommendations for the structure and a preliminary Foundation Data Sheet for inclusion in the plans. In order to conduct a proper foundation investigation and complete this report the Foundation Designer will need the following information:

- Bent locations and layout
- Proposed roadway grade (fill heights)
- Anticipated foundation loads
- Foundation size/diameter and depth required to meet structural needs.
- Allowable structure settlements (total and differential)

- Proposed retaining wall locations and geometric information
- Estimated scour depths (from Hydraulics Report)
- Construction or Environmental constraints that could affect the type of foundation selected.

The Foundation Report will contain all the geotechnical data gathered and created regarding the site including final boring logs, Foundation Data Sheets, laboratory test result summaries, final foundation soil design parameters, recommended foundation types, sizes and capacities, and other recommendations. Construction recommendations are included along with project specific specifications, which are to be included in the contract Special Provisions. Seismic foundation design recommendations are provided including site characterization and soil type coefficients, design peak horizontal ground accelerations, design magnitudes and discussions regarding any liquefaction mitigation measures considered necessary.

The Foundation Report is used to communicate and document the site and subsurface conditions along with the foundation and construction recommendations to the structural designer, specifications writer, construction personnel and other appropriate parties. The importance of preparing a thorough and complete foundation report cannot be overemphasized. The information contained in the Foundation Report is referred to during the design phase, the pre-bid phase, during construction, and occasionally in post-construction to assist in the resolution of contractor claims. An adequate site inspection, office study, appropriate subsurface exploration program and comprehensive foundation analyses that result in foundation recommendations are all necessary to construct a safe, cost-effective structure.

III. Foundation Data Sheet

A Foundation Data Sheet should be prepared for each bridge and all retaining walls attached to bridges. The Foundation Data Sheet should provide an accurate and detailed presentation of the subsurface conditions at the project site. The data sheet represents a compilation and condensation of the information contained on the project exploration logs and is included in the contract documents, usually as the second sheet, behind the Plan and Elevation sheet for the structure. All subsurface information that would significantly affect foundation construction should be clearly shown on the data sheet. Include rock compressive strength test results in the table of rock core for each boring if available. If pressuremeter or cone penetrometer tests were performed, show the locations of these tests on the data sheet and provide a reference for obtaining the test data. Make a note of any non-standard tests such as oversized SPT samples. A sample Foundation Data Sheet is provided in the Appendix. Refer to the Bridge Design and Drafting Manual (Vol. II) for drafting guidelines for the data sheet.

IV. Foundation Design Process

A. Office Research

Office research generally includes a review of foundation information on the existing or other nearby structures. The structure owner may have subsurface information such as soil boring logs or "as-constructed" foundation information such as spread footing elevations, pile tip elevations, or pile driving records. The maintenance and construction

records for the existing structure(s) should also be reviewed. These records are available in the Bridge Engineering Library or from the Bridge Achieves. Bridge drawings are available online through the ODOT Intranet Bridge System page.
(http://intranet.odot.state.or.us/CF/BDS/startup.htm)

The office research work typically includes (but should not be limited to) the following information for the existing structure(s):

1. Location and structure dimensions
2. Number of spans and span lengths
3. Year constructed
4. Superstructure type (e.g., RCDG, composite, steel beam)
5. Subsurface Data (e.g. boring logs, data sheets, groundwater conditions, etc.)
6. Type of foundation (e.g., spread footings, piles, shafts)
7. Applicable "as-constructed" foundation information such as:
   a. Spread footing elevation, size, and design or applied load.
   b. Pile type and size, pile tip elevations or lengths, design or driven pile capacity, and dynamic formula (e.g., ENR, Gates) used during construction.
   c. Drilled shaft diameter, tip elevations
   d. Construction problems (e.g., groundwater problems, boulders or other obstructions, difficult shoring/cofferdam construction).
8. Foundation related maintenance problems (e.g., scour, rip rap placement, corrosion, approach fill or bridge settlement, slope stability/drainage approach fill problems).

A review of old roadway design plans, air photos, soil and geology maps and well logs may also be useful. Particular attention should be given to locating any existing or abandoned foundations or utilities in the proposed structure location. Any obstructions, or other existing conditions, that may influence the bridge design and/or bent layout should be communicated directly to the bridge designer as soon as possible in the design so these conditions can be taken into account in the design of the bridge.

This information should be summarized and provided in the Foundation Report. All applicable "as-constructed" drawings for the existing structure should be included in the Foundation Report Appendix.

B. Foundation Investigation

1. Site Inspection

Gathering site information is the initial step in obtaining the necessary data to develop comprehensive foundation recommendations. An inspection of the proposed structure site can be very helpful in planning the subsurface exploration program and in assessing the site conditions in terms of construction constraints and potential construction difficulties. Existing structures can be inspected to access their present condition. Observations concerning: topography, surface materials (exposed bedrock, large boulders), existing foundations, utilities, evidence of past instability and/or settlement problems, stream channels/bank stability, scour potential, surface water, access for exploration equipment and high water levels provide valuable information. Information on existing riprap, or other large boulders or obstructions, in stream areas that may influence temporary or permanent foundation construction should be noted and evaluated with regard to any potential affects on environmental permitting. Photographs and/or a video of the site are very useful as a visual reference and documentation of the site conditions.

2. Exploration Program & Materials Testing

Project information such as a vicinity map, a project narrative, preliminary structure plans/layout (pre-TS&L) and hydraulics information (if applicable) should be obtained to allow for proper planning of the subsurface exploration program. The proposed bent locations should be obtained from the bridge designer. The extent and heights of any proposed fills should be obtained.

Accurate and adequate subsurface information at, or as near as possible to, each structure support is extremely important, especially for drilled shaft and spread footing designs. The guidelines described in the AASHTO "Manual on Subsurface Investigations" (1988) should be followed, including all pertinent ASTM test methods. In addition, the FHWA Geotechnical Engineering Circular No. 5, "Evaluation of Soil and Rock Properties" (FHWA-IF-02-034) provides an excellent reference for subsurface investigation procedures. The AASHTO "Standard Specifications for Highway Bridges" (current edition) can also be referenced for guidance on subsurface exploration and laboratory testing requirements.

The standard sampling and field testing methods presently used by ODOT include disturbed sampling (Standard Penetration Test, ASTM D 1586), undisturbed sampling Shelby tube (ASTM D 1587), in situ testing (e.g. cone penetrometer or pressuremeter) and rock coring. ODOT owns a Texam Pressuremeter which is available for use on Agency designed projects. The pressuremeter requires predrilled boreholes. ODOT also owns a Vane Shear, a Point Load Tester and a Geoprobe. Contact the Pavements Unit to schedule use of the Geoprobe equipment. Geophysical investigation methods should also be considered at some locations. The procedures outlined in the ODOT "Soil and Rock Classification Manual" are used to describe and classify subsurface materials.

The following information resulting from the investigation work should be provided in the report:

- Exploration logs of all borings or test pits, along with any other field test data such as cone penetrometer tests (CPT), pressuremeter testing (PMT) or seismic shear wave velocity profiles.
- Plan map showing the locations of all explorations, borings and test pits.
- General geology of the area and a detailed summary of the foundation materials and conditions.
- Details regarding groundwater conditions.
- Laboratory test result summaries.
- Soil and rock parameters for use in design.

The groundwater elevation is a very important item and should be provided in the report. The measured depth of groundwater levels, and dates measured, should be noted on the exploration logs and discussed in the report. Groundwater elevations should also be noted in the report. It is important to distinguish between the groundwater level and the level of any drilling fluid. Also, groundwater levels encountered during exploration may differ from design groundwater levels. Any artesian or unusual groundwater conditions should be noted as this often has important effects on foundation design and construction.

C. Bridge Approach Embankments

The embankments at bridge ends should be evaluated for stability and settlement. The FHWA manual: "Soils and Foundations, Workshop Manual", Second Edition, revised 1993 (FHWA HI-88-009) should be referenced for guidance in the analysis and design of bridge approach embankments. New embankment material placed for bridge approaches should be evaluated for short term (undrained) and long term (drained) conditions. The FHWA program "EMBANK" (FHWA-SA-92-045) is available for use in estimating embankment settlement. If the estimated post-construction settlement is excessive, consider the use of waiting periods, surcharges, wick drains or other ground improvement methods to expedite or minimize embankment settlement, if necessary, and allow for bridge construction. Consider relocating the bridge end if large embankment settlement and stability concerns result in extreme and costly measures to facilitate embankment construction. Also evaluate long term embankment settlement potential and possible downdrag effects on piles or drilled shafts and provide downdrag mitigation recommendations if necessary. In general, design for the long term settlement of approach embankments to not exceed 1" in 20 years.

Bridge end slopes are typically designed at 2(H):1(V). If steeper end slopes such as 1½: 1 are desired, they should be evaluated for stability and designed to meet the required factors of safety. If embankment stability concerns arise, consider the use of staged construction, wick drains, flatter slopes, soil reinforcement, lightweight materials, subexcavation, counterbalances, or other measures depending on site conditions, costs and constraints. Any instrumentation, or other embankment monitoring needs, should be described in detail in the report.

For global stability, the static factor of safety for bridge end embankments should be at least 1.30. The programs XSTABL5.2 and Slope/W are available for evaluating slope stability. Dynamic (seismic) slope stability, settlement and lateral displacements are discussed under "Seismic Foundation Analysis and Design".

D. Selection of Foundation Type

In the Foundation Report, describe and discuss the various foundation design options considered for the structure. Clearly describe in the report the reason(s) for recommending the foundation design(s) selected. The foundation design selected should result in the design of the most economical bridge, taking into account any constructability issues or constraints. Some of the factors to consider include:

- Foundation soils, bedrock and groundwater conditions
- Structure loads (especially seismic loads) and performance criteria
- Liquefaction and scour potential (extreme events)

- Environmental constraints including:
    - In-water work periods, confinement requirements
    - Noise or vibration effects
    - Hazardous materials
    - Piling driving effects on fish, wildlife, humans
- Construction access, traffic staging requirements, shoring, cofferdams or any other construction constraints
- Permit constraints

This is the most important step in the foundation design process. The above issues should be discussed with the structural designer. Bridge bent locations may need to be adjusted based on the foundation conditions, construction assess or other factors listed above to arrive at the most economical and appropriate project design.

E. Foundation Design

1. Spread Footings and Retaining Walls

The AASHTO "Standard Specifications for Highway Bridges" (current edition) should be used for the design of spread footings and most retaining wall foundations. Other acceptable methods are provided in the References. For Mechanically Stabilized Earth (MSE) bridge abutments, the FHWA manual: "Mechanically Stabilized Earth Walls and Reinforced Slopes, Design and Construction Guidelines" should be referenced.

The bottom of spread footings should be below the estimated depth of scour for the check flood (typically the 500 year flood event or the overtopping flood). The top of the footings should be below the depth of scour estimated for the design flood (either the overtopping or 100-year event). As a minimum, the bottom of all spread footings should also be at least 6 feet below the lowest streambed elevation unless they are keyed into bedrock that is judged not to erode over the life of the structure. Lateral migration of the stream channel should be assumed, unless otherwise permanently restricted, and therefore footings for bridge abutments should also adhere to the minimum "6 feet below streambed" requirement. Spread footings are not recommended on soils that are predicted to liquefy under the design seismic event. If spread footings are recommended, provide the following design recommendations in the Foundation Report:

Footing Elevations – The elevations of the proposed footings should be provided along with a clear description of the foundation materials the footings are to be constructed on and minimum cover requirements. Specify whether or not the footings are to be keyed into rock. Check with the bridge designer to see if a "fixity" condition is required in rock. On sloping rock surfaces, work with the structural designer to determine the best "bottom-of-footing" elevations.

Bearing Capacity and Settlement – The ultimate and allowable bearing capacities should be provided for various effective footing widths likely to be used. A factor of safety of 3.0 should be used for bridge spread footings and a factor of safety of 2.5 should be used for MSE wall bearing capacity. Factors of safety for use with scour estimates are described in Section G; "Scour and Foundation Design".

The FHWA program "CBEAR – Bearing Capacity Analysis of Shallow Foundations" (FHWA SA-94-034) is available to perform bearing capacity analysis. Allowable bearing capacities that correspond to 1 inch of footing settlement should also typically be provided unless other settlement limits are established by the structural designer or the footing is on bedrock and settlement is not an issue. Allowable footing/wall settlement is a function of the structure type and performance criteria and the structural designer should be consulted to establish allowable structure settlement criteria. Refer to AASHTO or the FHWA manual on the design of Shallow Foundations for additional guidance on tolerable settlements. For soil conditions, the bearing capacities provided assume the footing pressures are uniform loads acting over effective footing dimensions B' and L' (i.e. effective footing width and length ((B or L) - 2e) as determined by the Meyerhof method. For footings on rock, the capacities provided should assume triangular or trapezoidal stress distribution and maximum toe bearing conditions.

Minimum footing setback on slopes and embedment depths should be provided in the report.

Sliding, Stability and Eccentricity - Provide the following soil parameters for calculating frictional sliding resistance and active and passive earth pressures.

Effective Soil Unit Weight, (soil above footing base)
Soil Friction Angle, φ , (soil above footing base)
Active Earth Pressure Coefficient, Ka
Passive Earth Pressure Coefficient, Kp
At-Rest Earth Pressure Coefficient, Ko, if restrained against rotation
Location of Earth Pressure Resultant
Coefficient of Sliding, $\mu = \tan\varphi$

The minimum factor of safety against sliding should be 1.5 for normal conditions and 1.1 under seismic loading conditions.

Global Stability – For spread footings and bridge abutment walls, provide a factor of safety of at least 1.5 (1.1. for seismic loading conditions) against global stability. A factor of safety of 1.3 may be used for global stability of typical stand-alone retaining walls (walls or footings that do not support bridge abutments or interior bents). The above factors of safety are to be used in cases where soil and rock parameters and ground water levels are based on in-situ and/or laboratory tests. The programs XSTABL5.2 and Slope/W are available for evaluating global stability. Usually, bearing capacity will control the design of footings on slopes but not always. For MSE walls, reinforcement lengths may need to be increased in some cases for global stability. If so, the minimum required reinforcement lengths required for slope stability should be provided in the report and shown on the plans.

Earth Pressure Diagrams – Recommended earth pressure diagrams for retaining wall design should be provided as required by the structural designer.

Drainage for Retaining Walls – Free-draining granular material should be placed behind retaining walls to provide for drainage of ground water and prevent the build up of hydrostatic wall pressures. MSE Granular Backfill materials (Section 00596.10(g)) are not considered free-draining and a granular drainage blanket should be provided behind the MSE backfill if these materials are used. Granular Wall Backfill (Section 510.12) or equivalent should be used.

2. Pile Foundations

Refer to the FHWA manual, "Design and Construction of Driven Pile Foundations" (FHWA-HI-97-013, 1996) for design of pile foundations and other pertinent information. Other design references are listed in the References. FHWA design manuals should be used for the design of piles using CPT or Pressuremeter methods. Read, and be familiar with, the ODOT Standard Specifications for Driven Piles (Section 00520) and the Standard Special Provisions for Section 00520 which supplement the Standard Specifications. These are available online through the ODOT Specifications and Standards web page. (Specifications and Standards)

ODOT office practice procedures related to some specific design items are listed below:

Pile Types

The pile types generally used on most permanent structures are steel pipe piles (both open and closed-ended) and steel H-piles. Either H-pile or open-end steel pipe pile can be used for end bearing conditions. For friction piles, steel pipe piles are often preferred because they can be driven closed-end (as displacement piles) and because of their uniform cross section properties, which provides the same structural bending capacity in any direction of loading. This is especially helpful under extreme seismic loading conditions where the actual direction of lateral loading is not precisely known. Uniform section properties also aid in pile driving. Pipe piles are available in a variety of diameters and wall thickness, however there are some sizes that are much more common than others and less expensive. The most common pipe pile sizes are:

PP 12.75 x 0.375
PP 16 x 0.500
PP 20 x 0.500
PP 24 x 0.500

Timber piles are occasionally used for temporary detour structures and occasionally on specialty bridges, for retro-fit or repair, and, on rare occasions, "in-kind" widening projects. ODOT standard prestressed concrete piles are rarely used due to the following reasons:

- They typically have less bending capacity than steel piles for a given size
- They are difficult to connect to the pile cap for uplift resistance
- They are inadequately reinforced for plastic hinge formation
- Handling, pile driving and & splicing difficulties
- Cost, (typically more expensive than steel for a given capacity)

Prestressed concrete piles may however be appropriate in some areas like low seismic zones or highly corrosive environments. The use of prestressed concrete piles is not prohibited in ODOT if they are properly designed and cost effective.

Allowable Pile Stresses for Axial Loading

ODOT permits the design (allowable) axial pile stress for steel piles to be up to 1/3 of the pile steel yield strength (Fy) under static loading conditions. Higher-grade steel may be required in some cases due to lateral bending stresses or high compressive driving stresses. Refer to AASHTO for allowable design stresses for other pile types. The highest pile stresses occur during pile driving and, depending on subsurface and loading conditions, a Wave Equation analysis may be needed to determine if compressive driving stresses could be a problem. The compressive driving stresses in steel piles should generally be limited to 0.9Fy. Allowable compressive stresses for prestressed concrete and timber piles are as recommended in AASHTO.

Pile Capacity

The ultimate pile capacities (Qult.) should be provided in the report along with estimated pile lengths for one or more pile types. This information may be in the form of tables or in graphs of Qult versus pile tip elevation. Qult should be modified as necessary to account for reduced capacity from scour, liquefaction or downdrag conditions. Provide the Factor of Safety for each design condition (or allowable capacity) as applicable. Also provide the recommended method of construction control (i.e. ODOT Gates Equation, wave equation, PDA, etc.).

Downdrag loads, if present, should be provided in the report along with the depth, or thickness, of the downdrag layer and an explanation of the cause of the downdrag loads and how they will be accounted for in design. A factor of safety (or load factor) of 1.0 should typically be used with the downdrag loads. Refer to the FHWA Pile Design Manual for downdrag calculation methods. Pile downdrag loads can be reduced by the use of bitumen coating or pile sleeves. The NCHRP Report 393, "Design and Construction Guidelines for Downdrag on Uncoated and Bitumen-Coated Piles" should be referenced for more guidance on downdrag mitigation methods.

Uplift pile capacities should be provided if needed by the structural designer. In general, the ultimate uplift resistance is the same as the pile friction (side) resistance. A factor of safety of 3.0 is applied to the ultimate friction resistance to obtain the allowable uplift capacity under static loading conditions. A factor of safety of 1.1 may be used under seismic loading conditions. Friction resistance in downdrag zones should be considered available for uplift resistance.

Pile group effects should be evaluated according to the FHWA manual "Design & Construction of Driven Pile Foundations". Pile group settlement, and effects on the axial and lateral capacity of pile groups should be evaluated. The p-y multiplier method described in the FHWA manual is recommended for use in evaluating lateral pile group capacity and deflection.

For steel piles, an "Engineers Estimated Length" is required for the Special Provisions. The following table format is recommended to supply this information. The table should be modified as necessary to account for reduced capacities due to scour, liquefaction, downdrag or other conditions.

TABLE 1

Pile Type: PP16x0.500"

Bent	Qult. (kips)	Qall. (kips)	C.O. Elev. (ft.)	Est. Tip Elev. (ft.)	Engr's Est. Length, (ft.)	Req'd Tip Elev. (ft.)
1	450	180	210	130	80	150
	350	140	210	145	65	150
2	450	180	170	120	50	135
	350	140	170	130	40	135
3	450	180	200	125	75	140
	350	140	200	135	65	140

Pile Capacities & Estimated Lengths (Br. 12345)

Legend & Table Notes:

Qall. = Allowable pile capacity
Qult. = Ultimate pile capacity
C.O. = Pile cutoff elevation

Pile Driving Criteria and Factors of Safety

The method of establishing pile driving criteria must be selected for each pile driving project. ODOT typically uses two methods: 1) Dynamic Formula (ODOT Gates Equation) and 2) Wave Equation Analysis (WEAP). The pile driving analyzer (PDA) is also sometimes used combined with signal matching techniques such as CAPWAP. Full scale load tests are rarely performed but are recommended for large scale projects where there is potential for substantial savings in foundation costs. Each method is described separately below. Factors of safety for use with scour estimates are described in Section G; Scour and Foundations Design.

ODOT Gates Equation

The default dynamic relationship used to establish pile driving criteria is the ODOT Gates Equation (Section 00520.42(b)). When using this equation a factor of safety of 3.0 is applied to the ultimate static axial capacity to determine the allowable static axial capacity.

Wave Equation Analysis Program (WEAP)
Wave Equation driving criteria is generally used for the following situations:

- Ultimate axial pile capacities of 540 kips or greater.
- Where driving stresses are a concern (e.g., short end-bearing piles or required penetration through dense strata).
- Very long friction piles in granular soils

A Factor of Safety of 2.5 is applied to the ultimate static axial capacity to determine the allowable static axial capacity for wave equation projects.

When the wave equation method is specified, the contractor is required to perform a WEAP analysis of the proposed hammer and driving system and submit the WEAP analysis as part of the hammer approval process. The soils input criteria necessary to perform the WEAP analysis needs to be supplied in the contract Special Provisions. The following table format is provided as an example.

Bridge 12345; Bents 1 & 2

Pile Type	**Pile Length (ft.)**	**Quake (in.)**		**Damping (in./sec.)**		**Friction Distribution (ITYS)**	**IPRCS** (Note 2)	**R_{ult} (kips)**
		Skin	**Toe**	**Skin**	**Toe**			
PP16 x 0.50	85.0	0.10	0.15	0.20	0.20	Note 1	95	620

Note 1: Use a rectangular distribution of skin resistance over the portion of the pile under ground.
Note 2: IPRCS is the percent skin friction (percent of Rult that is skin friction in the WEAP analysis).

Refer to the Standard Special Provisions for Section 00520 for additional specification requirements. Provide WEAP input data for the highest (worst-case) driving stress condition, which may not always be for the pile at the estimated tip elevation.

Pile Driving Analyzer (PDA)
Large pile driving projects may warrant the use of dynamic pile testing using a pile driving analyzer for additional construction quality control and to save on pile lengths. Generally the most beneficial use of PDA testing is on projects with large numbers of very long, high capacity friction piles. However, there may be other reasons for PDA testing such as high pile driving stress conditions, testing new pile hammers, questionable hammer performance or to better determine the pile skin friction available for uplift resistance. A factor of safety of 2.25 can be applied to the ultimate axial capacity determined by PDA. A signal matching (CAPWAP) analysis of the dynamic test data should always be used to determine the axial capacity. The Case Method may be used for determining the ultimate axial capacity providing it is calibrated with the dynamic test signal matching analysis. The piles should be tested after a waiting period if pile setup or relaxation is anticipated. The first piles driven should be PDA/CAPWAP tested to determine the pile driving criteria for the remaining piles on the project. At least 5% of the production piles should be PDA tested for the 2.25 factor of safety to apply.

Additional testing may be required depending on the variability of foundation soils conditions. Special Provisions for past PDA/CAPWAP projects are available on the ODOT "Geosite" web page under the GEO-SPECIFICATIONS folder:

scdata\Geosite\G-H Geotech Common\GEO-SPECIFICATIONS

Required Pile Tip Elevation

Provide a required pile tip elevation for piles at each bent. The required tip elevation represents the highest acceptable tip elevation that will still provide the required capacities and performance under all loading conditions. The required tip elevation ("Minimum Tip Elevation") is typically based on one or more of the following conditions:

- pile tip reaching the required bearing layer or depth
- providing required uplift resistance
- providing required embedment for lateral support
- satisfying settlement and/or downdrag criteria
- providing sufficient embedment below scour depths or liquefiable layers

The required tip elevation may require driving into, or through, very dense soil layers resulting in potentially high driving stresses. This condition may require a wave equation driveability analysis to check make sure the piles can be driven to the required embedment depth.

Pile Tip Reinforcement

Specify steel pile tip reinforcement if piles are to be driven through very dense granular soils containing cobbles and boulders. Also, in cases where difficult driving is predicted before reaching a required tip elevation, inside-fit pipe pile shoes are sometimes used to retard the formation of a soil plug at the pile tip. Make sure Section 02520 of the standard special provisions is included in the project specifications for specifying the proper steel grade and other requirements. Outside fit pile reinforcement can also reduce the friction resistance of driven piles and this effect should be taken into account in design before specifying outside fit shoes.

Pile Splices

Specify the number of anticipated pile splices that might possible be needed due to variability of the subsurface conditions. This number of splices should be included as a bid item in the contract documents. For steel piles, ODOT pays for splices as follows:

00520.87 Pile Splices:
(a) Steel Piles - No measurement will be made for splices to steel piles within the estimated lengths as listed in 00520.11 of the Special Provisions, as these splices will be considered incidental and included in the unit price for the pay item "Furnish (Test) Piles". Splices incorporated in the finished structure that were made to increase the length of the pile (1.5 m (5 feet) or more for estimated pile lengths of 18 m (60 feet) or less and 3 m (10 feet) or more for estimated pile lengths of over 18 m (60 feet)) beyond the estimated pile length will be paid at the Contract unit price for the item "________ Steel Pile Splices". Only one splice will be paid for per pile.

3. Drilled Shafts

Refer to the FHWA Manual: "Drilled Shafts: Construction Procedures and Design Methods" (FHWA-IF-99-025) for drilled shaft design procedures and other pertinent information. Read, and be familiar with, the ODOT Standard Specifications for Drilled Shafts (Section 00512) and the Standard Special Provisions for Section 00512 which supplement the Standard Specifications. These are available online through the ODOT Specifications and Standards web page.

Consider the use of drilled shafts for bridge foundations if foundation conditions are favorable and the design is economical (relative to other deep foundation designs). Environmental restrictions or lateral load requirements may also dictate the need for drilled shafts. Some foundation conditions (such as hazardous material sites, artesian groundwater pressures, very unstable soils) are not favorable for drilled shaft applications. Shaft constructability is an important consideration in the selection of drilled shafts. Exploration borings should be located at every bent if at all possible and especially at every large single shaft support location.

Decide early on with the bridge designer if permanent casing is desired since this will affect both structural and geotechnical designs.

Shaft Diameter, Capacity and Settlement – The diameter of shafts will usually be controlled by the superstructure design loads and the configuration of the structure but consideration should also be given to the foundation materials to be excavated. If boulders or large cobbles are anticipated, attempt to size the shafts large enough so the boulders or cobbles can be more easily removed if possible. Shaft diameters may also need to be increased to withstand seismic loading conditions.

If a minimum rock embedment depth is required, specify the reason for the embedment (rock socket). Try to minimize hard rock embedment depths if possible since this adds substantially to the cost of drilled shafts. Specify each shaft as either a "friction" or "end bearing" shaft since this dictates the final cleanout requirements in the specifications.

The ultimate shaft capacities (Qult.) should be provided in the report along with estimated shaft tip elevations for one or more shaft diameters. This information may be in the form of tables or in graphs of Qult versus shaft tip elevation. Qult should be modified as necessary to account for reduced capacity from scour, liquefaction, group effects or downdrag conditions. A factor of safety of 2.5 is generally applied to the ultimate axial geotechnical capacities assuming that there is very good subsurface design information and relatively homogeneous stratigraphy. Provide shaft uplift capacities if requested by the structural designer. Factors of safety for use with scour estimates are described in Section G; Scour and Foundation Design.

Settlement may control the design of drilled shafts in cases where side resistance (friction) is minimal, loads are high and the shafts are primarily end bearing on compressible soil. The shaft settlement necessary to mobilize end bearing resistance may exceed that allowed by the bridge designer. Confer with the bridge designer to determine shaft service loads and allowable amounts of shaft settlement. Refer to the FHWA methods to calculate the settlement of individual shafts or shaft groups. Compare this settlement to the maximum allowable settlement and modify the shaft design if necessary to reduce the estimated settlement to acceptable levels.

Shaft Group Effects – For group lateral load analysis refer to the p-y multiplier methods described in the FHWA Manual "Drilled Shafts: Construction Procedures and Design Methods". Refer to Appendix B in this manual for guidance on axial group efficiencies for drilled shafts.

Crosshole Sonic Log (CSL) Testing – Access tubes for crosshole sonic log testing are typically provided in all drilled shafts unless otherwise recommended by the Foundation Designer. Typically one tube is provided per foot of shaft diameter with a minimum of 3 tubes provided per shaft. CSL testing is the primary method used by ODOT for the quality control and acceptance of drilled shafts. The amount of CSL testing needs to be determined on each project and provided in the special provisions. Refer to the standard Special Provision for 00512 for more details. The amount of testing depends on the subsurface conditions and the redundancy of the foundation system. The first shaft constructed is always tested to confirm the contractor's construction procedure and workmanship. Subsequent tests are based on the following guidelines and good engineering judgment:

- Test every single-shaft bent
- Minimum of 1 CSL test/bent (shaft group) or 1/10 shafts
- Depends on:
    - Redundancy in the substructure/foundation
    - Soil conditions (potential construction difficulties)
    - Groundwater conditions (dry hole vs. wet)

See further guidelines, attached in the Appendix, regarding CSL testing procedures during construction.

4. Lateral Load Analysis

Lateral loading of foundation piling and drilled shafts should be evaluated to determine the amount of lateral foundation capacity available to support the structure loads while staying within the design limits, or criteria, for pile/shaft deflection. The structural designer should be provided with the soil parameters necessary to develop p-y curves and perform the lateral load analysis. The soil and rock parameters required are those described in the manual titled "Laterally Loaded Pile Analysis Program for the Microcomputer", FHWA-SA-91-048 (COM624P) or those required for the LPILE4 proprietary computer program. The FHWA and/or LPILE manuals should be referenced for more information. It is important that the foundation designer maintain good communication with the structural designer to determine the kind of soil parameters necessary for the lateral load analysis of the structure. If liquefaction of foundation soils is predicted, soil parameters should be provided for both the liquefied and non-liquefied soil conditions. Below is an example of a table format for presenting the required data for a non-liquefied soil condition.

Bents 1 & 3

ELEVATION (ft.) From	To	KSOIL*	k (lbs/in^3)	SOIL PARAMETERS γ,(pci)	c,(psi)	e_{50}	φ	COMMENTS
63.5	55.0	3	500	0.06	3.5	.007	--	Sandy Clayey Silt to Silty Clay (fill)
55.0	30.0	2	1000	0.07	13	.005	--	Silt w/ trace sand & clay to Clayey Silt, low plasticity
30.0	10.0	2	2000	0.072	20	.004	--	Clay to Silty Clay, med.-high plasticity, very stiff

Soil Parameters for Lateral Load Analysis

* KSOIL is a COM624P reference to soil types. For the LPILE program provide the appropriate soil type from the default types listed in LPILE4 or provide custom p-y curves if necessary.

F. Seismic Foundation Analysis and Design

ODOT seismic design practice is to evaluate the response and performance of the bridge and foundation materials under both the 500 and 1000-year return events. The peak ground acceleration (PGA) and other seismic ground motion values should be obtained from the 2002 USGS Seismic Hazard Maps for the Pacific Northwest Region. These maps are available in the ODOT Bridge Design and Drafting Manual or from the USGS web page (http://eqhazmaps.usgs.gov/).

The bridge and the approach fill embankments should meet or exceed the following performance criteria unless otherwise approved:

500-year event:
(10% exceedance in 50 yrs.)

The bridge should be accessible to emergency traffic immediately following this event (and after inspection).

1000-year event:
(5% exceedance in 50 yrs.)

This level of shaking should not result in total collapse of any part of the bridge. The embankments (approach fills) may experience large amounts of displacement as long as the displacements do not result in the collapse of any part of the structure.

Refer to the paper: "ODOT Seismic Foundation Design Practice" (October, 2005) for more detailed guidance in ODOT seismic foundation design practices. Also refer to, and be familiar with, Section 1.1.4; "Foundation Modeling", of the ODOT Bridge Design and

Drafting Manual. This section describes the various methods bridge designers use to model the response of bridge foundations and also the geotechnical information required to perform the analysis.

In general, ultimate capacities are used in seismic design except for pile and shaft uplift conditions. A factor of safety of 1.1 should be maintained for piles and shafts in uplift under seismic loading. A factor of safety of 1.0 is allowed for all other seismic loading conditions.

Seismic foundation design generally consists of the following procedures:

- Determine the Peak Horizontal Ground Acceleration (PGA) for the bridge site from the 500 & 1000-year USGS seismic hazard maps
- Determine the Site Soil Coefficient based on Soil Profile Type (AASHTO Division IA, Section 3.5)
- Determine liquefaction potential of foundation soils
- If liquefaction is predicted:
    - Estimate embankment deformations, bridge damage potential and approach fill performance for both the 500 and 1000 events.
    - Determine seismic fill settlement (and downdrag potential if applicable)
    - Provide soil properties for both the liquefied and non-liquefied soil conditions for use in the lateral load analysis of deep foundations.
    - Evaluate the reduced capacities and effects on proposed bridge foundation elements.
    - Provide liquefaction mitigation design recommendations if necessary
- If needed, conduct ground response analysis (SHAKE) and develop site-specific response spectra

If the foundation soils are determined to be susceptible to liquefaction, then spread footings should not be recommended for foundation support of the structure unless proven ground improvement techniques are employed to stabilize the foundation soils and eliminate the liquefaction potential. Otherwise, a deep foundation should be recommended.

Deep foundations (piles and drilled shafts) supporting structures that are constructed on potentially liquefiable soils are normally checked for two separate loading conditions; i.e. with and without liquefaction. Capacities and soil-pile interaction parameters should be provided for both nonliquefied and liquefied foundation conditions. Communication with the structural designer is necessary to insure that the proper foundation design information is provided.

If the predicted amount of embankment deformation (lateral spread) is excessive then assessments will have to be made of approach fill performance and the potential for bridge damage. The need for possible liquefaction mitigation measures will then have to be evaluated. Refer to the "ODOT Liquefaction Mitigation Policy" (Oct., 2004), attached in the Appendix, for more guidance on ODOT liquefaction mitigation policies.

G. Scour and Foundation Design

Structures crossing waterways may be subject to damage by scour and erosion of the streambed, stream banks, and possibly the structure approach fills. Bents placed in the streambed increase the potential for scour to occur. The degree and depth of scour will have a significant affect on the selection of the most appropriate foundation type. The Hydraulic Report should be consulted for scour predictions.

Scour depths are typically calculated for both the 100-year ('base flood") and 500-year ("check flood") events. However, if overtopping of the roadway can occur, the incipient roadway overtopping condition is then the worst case for scour because it will usually create the greatest flow contraction and highest water velocities at the bridge. This overtopping condition may occur less than every 100 years and therefore over-ride the base flood (100-yr) design condition or it could occur between 100 and 500 years and over-ride the 500-year (check flood) condition.

All bridge scour depths are calculated for the following flood conditions, depending on the recurrence interval for the overtopping flood:

- $Q_{overtopping} > Q_{500}$: Both the 100-year and 500-year flood scour depths are analyzed
- $Q_{100} < Q_{overtopping} < Q_{500}$: The 100-year flood and the overtopping flood scour depths are analyzed
- $Q_{overtopping} < Q_{100}$: Only the overtopping flood scour depth is analyzed

The top of the footing should be set below the potential scour elevation for the 100-year scour or the roadway-overtopping flood, whichever is the deepest. The bottom of the footing should be set below the potential scour elevation for the Check Flood, which will be either the roadway-overtopping flood or the 500-year flood.

Minimum pile and drilled shaft tip elevations and spread footing elevations should be determined to provide a minimum Factor of Safety of 1.0 with the estimated 500-year flood scour depths or with the scour depths from the overtopping flood if the recurrence interval of the overtopping flood is greater than 100-years. A minimum Factor of Safety of 2.0 may be used in foundation design with the estimated 100-year flood scour depths. However, if the recurrence interval of the overtopping flood is less than 100 years, the factor of safety should be evaluated on a case by case basis using engineering judgment and assessing the long term hydraulics and scour potential of the site. Overtopping recurrence intervals that are much less than every 100 years are not considered extreme events and therefore factors of safety associated with the no-scour condition may be more appropriate to use.

For footings constructed on bedrock, provide recommendations regarding the scour potential of the bedrock to the Hydraulics designer. Some types of "bedrock" are very weak and extremely susceptible to erosion and scour. At present, there are no specific recommendations or guidelines to use to determine the scour potential of bedrock types typically found in Oregon. Good engineering judgment should be used in estimating the scour potential of marginally "good" quality rock, taking into account rock strength, RQD, joint spacing, joint filling material, open fractures, weathering, degradation characteristics and other factors. See if any exposed bedrock at the site shows signs of erosion or degradation or if there is a history of bedrock scour in the past. If any doubts remain, the footing should be either keyed full depth into the bedrock or drilled shafts should be considered.

Bridge abutment footings should be constructed assuming the same scour depths as piers in the main channel. Refer to the ODOT Hydraulics Manual for more guidance regarding scour, riprap protection and footing depth requirements. Loose riprap is not considered permanent protection. Design riprap protected abutments according to the guidance and recommendations outlined in FHWA's HEC-18 manual, "Evaluating Scour at Bridges" (FHWA NHI-01-001).

H. Construction Recommendations

Most foundation construction recommendations should be included in the project Special Provisions or shown on the plans if they are to be contractually recognized. Construction recommendations should be included in the report as appropriate and may include discussions or recommendations on the following items:

- Temporary shoring requirements
- Control of ground water in excavations
- Temporary excavation slopes
- Difficult pile driving conditions
- Boulders or other obstructions expected in the area of foundation construction or excavations
- Existing foundations in the area of proposed foundations or excavations
- Monitoring of adjacent structures or facilities (preconstruction surveys)
- Underwater acoustic monitoring of pile driving or "bubble curtains"
- Monitoring of fill settlement and excess pore pressure
- Existing utilities, drainage pipes or other feature that may influence foundation construction

Other unique foundation construction recommendations or quality control issues should be appropriately addressed.

V. Project Specifications

The report should include all applicable Special Provisions for the project related to the foundation design work. Review the ODOT Special Provisions at:

http://www.odot.state.or.us/tsspecs/02-00500.htm

Coordinate with the bridge designer to make sure all necessary special provisions are supplied. Consult with the "owner" of the special provisions if any major changes are to be made. Supply additional information in the project Special Provisions as necessary that further describes specific geotechnical conditions that may affect the contractor's work and bid. Sections typically requiring input from the Geotechnical Engineer include 00330, 00510, 00512, 00520, and 00596.

Some unique geotechnical special provisions can be obtained from the ODOT Intranet server "Geosite" at the following address:

scdata\geosite\G-H Geotech Common\GEO-SPECIFICATIONS

These are project-specific specifications that are not often used but are available for use as needed for more unique geo-applications. Read the "readme.txt" file first.

VI. Report Review and Quality Control

Quality control of foundation design work should be an ongoing process occurring regularly throughout the entire design process. The subsurface investigation program, materials classification and testing, recommended foundation type, all design calculations, reports and foundation data sheets should be thoroughly reviewed by an independent geotechnical engineer with intimate knowledge of the project. This internal review should be thorough enough to verify and confirm all design assumptions and calculations leading to the recommendations made in the report. Important geologic interpretations made for foundation design purposes should be reviewed and approved by a registered Engineering Geologist (C.E.G.), and noted by stamping and sealing the final Foundation Report. All reports should be stamped and signed by a professional engineer (Engineer of Record) registered in the state of Oregon, whose area of expertise is in geotechnical engineering. Foundation Data Sheets may be stamped by either a registered engineer (PE) or a Certified Engineering Geologist. It must be recognized that the Foundation Data Sheet often forms the basis for resolution of contract claims submitted by contractors under the Differing Site Conditions Section (00140.40). Therefore, the person stamping the Foundation Data Sheet should have a complete understanding of what is being constructed based on the data sheet and how the data sheet information can effect the foundation construction, contract bidding and claim potential.

VII. Foundation Report Outline/Checklist

The attached Foundation Report Outline/Checklist should be used to check the content and completeness of Foundation Reports prepared by ODOT or prepared by non-ODOT sources and submitted to ODOT for review. The checklist should be completed by the Engineer of Record for the project. The checklist questions should be completed by referring to the contents of the Foundation Report. For each question, a yes, no, or not applicable (N/A) response should be provided. A response of "I don't know" to any applicable section on the checklist is not to be shown with a check in the "Not Applicable" (N/A) column. All checklist questions answered with **NO** should be fully explained.

A copy of the completed checklist, and all comments and explanations, should be included with the Foundation Report when submitted for review by ODOT.

VIII. Foundation Report Distribution

The Foundation Report should be distributed to the following personnel:

- Bridge Designer
- Roadway Designer
- Specification Writer
- Project Leader
- Project Manager (more copies if requested for contractors)
- Hydraulic Engineer
- Project Geologist
- Bridge Engineering Section

For large projects, or projects with unusual or especially difficult foundation construction issues, consider putting the complete Foundation Report, including exploration logs, laboratory data, foundation data sheets and rock core photos, on the ODOT web page.

REFERENCES

"Standard Specifications for Highway Bridges"
American Association of State Highway and Transportation Officials (AASHTO), Current Edition with Interims.

"ODOT Bridge Design and Drafting Manual"
Oregon Department of Transportation, Bridge Engineering Section, Vols. I & II, 2004.

"Standard Specifications For Highway Construction"
Oregon Department of Transportation, 2002 Edition and related Standard Special Provisions.

"ODOT Bridge Standard Drawings"
http://www.odot.state.or.us/tsspecs/std-dwg-br-02.htm

"Manual on Subsurface Investigations"
American Association of State Highway and Transportation Officials (AASHTO), 1988.

"Evaluation of Soil and Rock Properties", Geotechnical Engineering Circular No. 5, U.S. Department of Transportation, Federal Highway Administration, FHWA-IF-02-034, April, 2002.

"ODOT Highway Division Hydraulics Manual, Volume I",
Oregon Department of Transportation, Geo-Environmental Section, 2004.

"Scour at Bridges"
U.S. Department of Transportation, Federal Highway Administration, Technical Advisory T5140.20 CHG. 1, 1988.

"Soil and Rock Classification Manual"
Oregon Department of Transportation, Highway Division, 1987.

"Soils and Foundation Workshop Manual"
U.S. Department of Transportation, Federal Highway Administration, FHWA HI-88-009, 1993.

"Spread Footings for Highway Bridges"
U.S. Department of Transportation, Federal Highway Administration, FHWA/RD-86/185, 1987.

"Shallow Foundations"
U.S. Department of Transportation, Federal Highway Administration, Geotechnical Engineering Circular No. 6, FHWA-IF-02-054, 2002.

"Mechanically Stabilized Earth Walls and Reinforced Slopes, Design and Construction Guidelines", U.S. Department of Transportation, Federal Highway Administration, Demonstration Project 82, Publication No. FHWA-SA-96-071, August, 1997.

"CBEAR, Bearing Capacity Analysis of Shallow Foundations, Users Manual", U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-94-034, 1996.

"EMBANK, A Microcomputer Program to Determine One-Dimensional Compression Settlement Due to Embankment Loads, Users Manual", U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-92-045, 1993.

"XSTABL, An Integrated Slope Stability Analysis Program for Personal Computers", Version 5, Interactive Software Designs, Inc., under license to ODOT.

"SLOPE/W 2004, Slope Stability Analysis", Geo-Slope International, under license to ODOT.

"Design and Construction of Driven Pile Foundations", Volumes I & II,
U.S. Department of Transportation, Federal Highway Administration, FHWA-HI-97-013, 1996.

"Design and Construction Guidelines for Downdrag on Uncoated and Bitumen-Coated Piles", NCHRP Report 393, Transportation Research Board, Project 24-5, 1997.

"The Pressuremeter Test for Highway Applications", U.S. Department of Transportation, Federal Highway Administration, FHWA-IP-89-008, 1989.

"The Cone Penetrometer Test", U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-91-043, 1992.

"Drilled Shafts: Construction Procedures & Design Methods"
U.S. Department of Transportation, Federal Highway Administration, FHWA-IF-99-025, 1999.

"COM624P - Laterally Loaded Pile Analysis Program for the Microcomputer (Version 2.0)" U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-91-048, 1993.

"Handbook on Design of Piles and Drilled Shafts Under Lateral Load" U.S. Department of Transportation, Federal Highway Administration, FHWA-IP-84-11, 1984.

"LPile Plus, Version 4", A Program For Analyzing Stress And Deformation Of A Pile Or Drilled Shaft Under Lateral Load; Ensoft, Inc., 1985-2003

"ODOT Seismic Foundation Design Practices"
Oregon Department of Transportation, Bridge Engineering Section, August, 2004.

"Ground Motions and Soil Liquefaction During Earthquakes"
H. Bolton Seed and I. M. Idriss, Earthquake Engineering Research Institute, 1982.

"Foundation Analysis and Design - Fourth Edition"
Joseph E. Bowles, McGraw-Hill Book Company, 1988.

APPENDIX

FOUNDATION REPORT OUTLINE/CHECKLIST

SAMPLE FOUNDATION DATA SHEET

CROSSHOLE SONIC LOG (CSL) TESTING &
EVALUATION PROCEDURES

ODOT LIQUEFACTION MITIGATION PROCEDURES

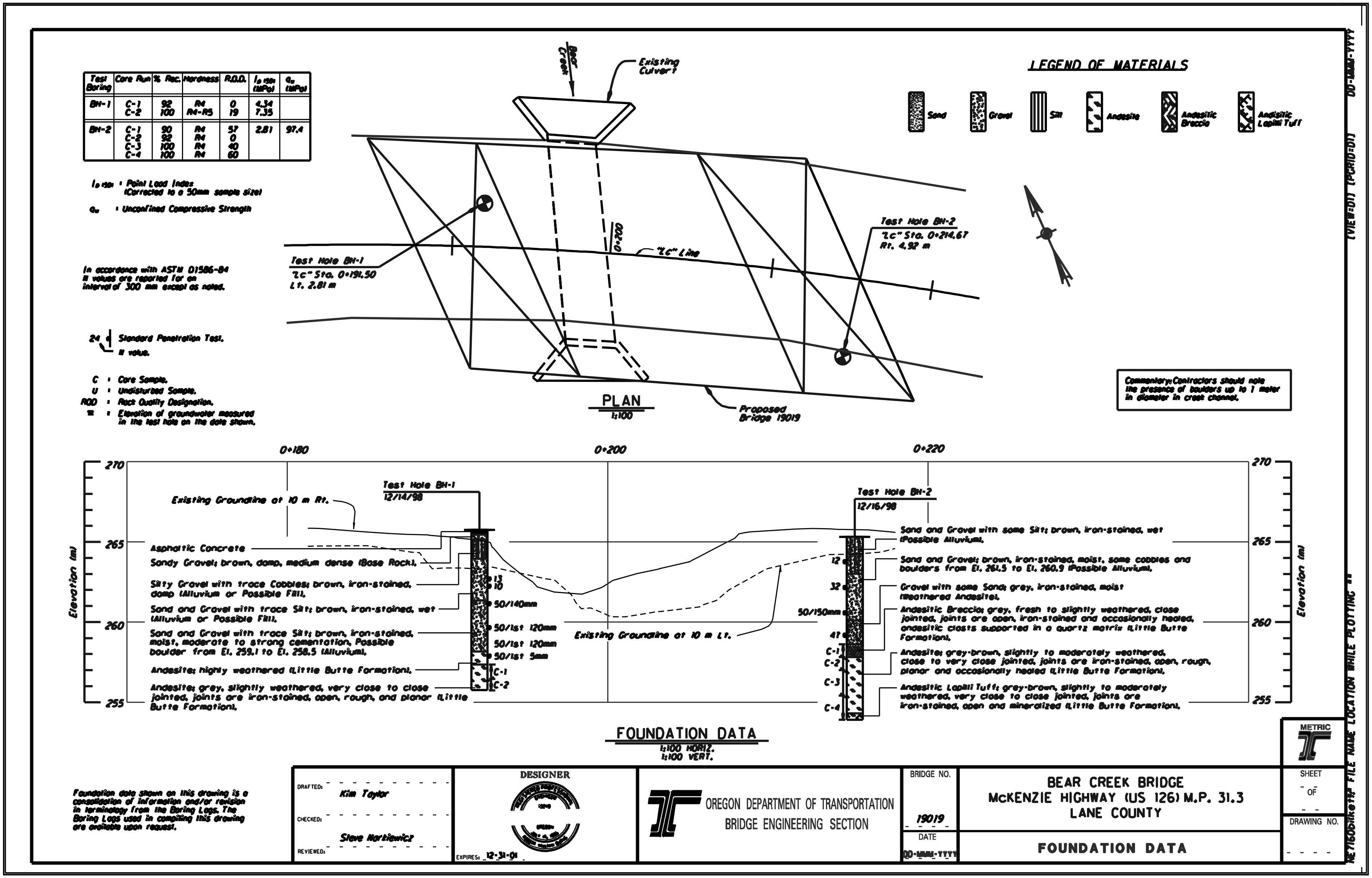
FOUNDATION REPORT OUTLINE/CHECKLIST

(August, 2005)

YES	NO	N/A	
			1 Title/Cover Page
			1.1 Heading “Foundation Report” in larger letters
			1.2 Bridge Name
			1.3 Bridge Number
			1.4 Section Name
			1.5 Highway & Milepoint
			1.6 County
			1.7 Key Number
			1.8 Date
			2 Table of Contents
			3 Detailed Vicinity Map
			4 Body of Report
			4.1 Introduction
			4.1.1. Is project scope and purpose summarized?
			4.1.2 Is a concise description given for the general geologic setting and topography of the area?
			4.2 Office Research
			4.2.1 Summary of pertinent records that relate to foundation design and construction.
			4.3 Subsurface Explorations and Conditions
			4.3.1 Is a summary of the field explorations, locations, and testing given?
			4.3.2 Is a description of general subsurface soil and rock conditions given?
			4.3.3 Is the groundwater condition given?
			4.4 Laboratory Data
			4.4.1 Are laboratory test results (e.g., natural moisture, Atterberg Limits,
			shear strengths, etc) discussed and summarized in the report?
			4.5 Summarize Hydraulics Information that affects Foundation Recommendations
			4.5.1 Bridge options providing required waterway
			4.5.2. 100 and 500-year scour depths and elevations
			4.5.3. Riprap protection class, depth, and extent
			4.6 Seismic Analysis and Evaluation
			4.6.1 Bedrock acceleration coefficient and AASHTO soil profile type
			4.6.2 Liquefaction assessment and recommedations
			4.7 Foundation Analyses and Design Recommendations
			4.7.1 Foundation Options and Discussion
			4.7.2 Pile Foundations
			4.7.2.1. Type (steel H-pile, pipe pile, concrete, displacement/friction or end-bearing)
			4.7.2.2. Material specification (e.g., grade), size (e.g.,O.D. and thickness) and options, open or closed-ended, tip protection
			4.7.2.3. Ultimate axial capacity, estimated cutoff elevation, estimated tip elevation. “estimated” or “order” length and
			minimum required tip elevation.
			4.7.2.4. Allowable axial capacity and factor of safety
			4.7.2.5. Ultimate uplift capacities for multi-span bridges
			4.7.2.6. Lateral capacity
			4.7.2.6.1. Soil parameters for LPILE or COM624P analysis (e.g., p-y data)
			4.7.2.7. Pile group settlement
			4.7.2.8. Downdrag
			4.7.2.8.1. How are downdrag loads to be accounted for or mitigated?
			4.7.2.9. Reduced pile capacities (axial, uplift, lateral, etc) as a result of liquefaction
			4.7.2.10. Driving Criteria and Driveability Analysis
			4.7.2.10.1. Gates Equation where driveability or stress problems are not expected
			4.7.2.10.2. Wave Equation for ultimate capacities greater than 2400 kN or expected stress problems.
			4.7.2.10.2.1. The owner must have the capability to perform or be able to obtain
			4.7.2.10.2.2. Wave Equation parameters provided
			4.7.2.11. Is a load test recommended? Who monitors?
			4.7.3. Drilled Shafts
			4.7.3.1. Shaft type (i.e., end-bearing or friction)
			4.7.3.2. Ultimate axial capacity provided for various diameters and lengths
			4.7.3.3. Estimated settlement substantiates shaft type
			4.7.3.4. Allowable axial load and factors of safety
			4.7.3.5. Lateral capacity
			4.7.3.5.1. Soil parameters for LPILE or COM624P analysis (e.g., p-y data)
			4.7.3.6. Is a load test recommended? Who monitors?
			4.7.4. Spread Footings
			4.7.4.1. Ultimate bearing capacity as function of effective footing width and depth of
			embedment for a given settlement under allowable loads (see example)
			4.7.4.2. Maximum elevation for base of footing
			4.7.4.3. Description and properties of the anticipated foundation soil

YES	NO	N/A	
			4.7.5. Retaining Walls
			4.7.5.1. Ultimate bearing capacity as function of effective footing width and depth of embedment for a given settlement under allowable loads (see example)
			4.7.5.2. Maximum elevation for base of footing
			4.7.5.3. Description and properties of the anticipated foundation soil
			4.7.5.4. Global stability
			4.7.5.5. Wall type options
			4.7.6. Engineered Fills
			4.7.6.1. Are gradation and compaction requirements provided for the engineered fill?
			4.7.6.2. See example
			4.7.7. Are appropriate recommendations provided for Temporary and/or Detour Structures?
			4.8 Construction Recommendations
			4.8.1. Pile Foundations
			4.8.1.1. Minimum hammer field energy (if using Wove Equation)
			4.8.1.2. Have potential obstructions (e.g., boulders) been identified?
			4.8.1.3. Set period and redriving (freeze)
			4.8.1.4. Preboring required?
			4.8.1.5. Jetting permitted?
			4.8.1.6. Is tip protection required?
			4.8.1.7. Have the effects of driving on adjacent structures been evaluated?
			4.8.1.7.1. Is a preconstruction survey recommended to document existing conditions?
			4.8.2. Drilled Shafts
			4.8.2.1. Alternate construction methods discussed and evaluated (e.g., temporary or permanent casing)
			4.8.2.2. Boulders and/or obstructions expected to be encountered?
			4.8.2.3. Quality control methods (e.g. concrete integrity tests)
			4.8.3. Spread Footings
			4.8.3.1. Anticipated foundation material adequately described
			4.8.4. Retaining Walls
			4.8.4.1. Anticipated foundation material adequately described
			4.8.4.2. Backfill requirements identified
			4.8.5. Falsework Support
			4.8.5.1. Falsework foundation type recommendations
			4.8.6. Excavations
			4.8.6.1. Shoring and bracing
			4.8.6.2. Cofferdams
			4.8.6.3. Groundwater mitigation method
			4.9. Special Provisions
			4.9.1. Are unique special provisions provided?
			4.10. Limitations
			4.11. General
			4.11.1. Has the report been independently reviewed?
			4.11.2. Is the Foundation Report stamped, dated, and signed by a registered PE licensed to practice in Oregon?
			5 Appendices
			5.1. Foundation Data Sheet (see example)
			5.1.1. Plan Section
			5.1.1.1. Are the locations of the proposed, existing, and detour structure(s) and other important features shown?
			5.1.1.2. Are the locations (station and offset or State Plane Coordinates of all explorations shown on the plan?
			5.1.2. Profile Section
			5.1.2.1. Is the groundline profile(s) shown?
			5.1.2.2. Are the explorations plotted on the profile at the correct elevation and location?
			5.1.2.3. Is on identification number and the completion date shown for each exploration?
			5.1.2.4. Are the subsurface conditions depicted with soil and rock descriptions in conformance with the ODOT Soil and Rock Classification Manual? Are the graphic symbols clear, distinct and appropriate?
			5.1.2.5. Is the sample type shown on the profile at the correct depth?
			5.1.2.6. Are SPT results ("N" values) shown on the profile?
			5.1.2.7. Are the highest measured Groundwater levels and the date shown on the profile?
			5.1.2.8. Are percent rock core recovery, rock hardness, and RQD values shown in a summary table?
			5.1.3. General
			5.1.3.1. Is the presentation of the subsurface information adequately shown on the Foundation Data Sheet?
			5.1.3.2. Has the Foundation Data Sheet been independently reviewed?
			5.1.3.3. Is the Foundation Data Sheet stamped, dated, and signed by a registered PE or CEG licensed to practice in Oregon?
			5.2. Exploration Logs
			5.3. Plan and Elevation of Existing Bridge
			5.4. In situ Test Data/Results
			5.5. Laboratory Test Data/Results
			5.5.1. Results in a tabular format
			5.6. Photographs
			5.7. Other References as Needed
			6 Foundation Analyses and Design Calculations Attached

SAMPLE FOUNDATION DATA SHEET



CROSSHOLE SONIC LOG (CSL) TESTING & EVALUATION PROCEDURES

The following outlines the procedure to use when conducting CSL testing for quality control of drilled shafts on ODOT projects. CSL testing is not always a conclusive test and the results often require interpretation and further in-depth review. The results can sometimes be misleading. The foundation and bridge designers should both understand, and be familiar with, the CSL testing procedures and have training in the use and interpretation of CSL test results.

Field Testing:

- Contractor provides the CSL subcontractor to do the testing (see SP 0512). This is included in the contract with bid items for mobilization of equipment and number of tests per bridge.
- CSL testing performed according to ASTM D6760-02
- CSL testing is performed on the first shaft constructed and others as described in SP 0512
- Additional shafts are tested if construction methods change or shaft construction results in questionable quality shafts. This is especially true for uncased shafts, excavated below the water level in soils.

Test Results:

- CSL test results should be forwarded to Bridge Designer and the Foundation Designer for review, regardless of what the CSL report says.
- Both engineers should concur that the shaft is acceptable or needs further investigation.
- Structural and/or geotechnical analysis may be necessary at this point to assess the load carrying capacity of the shaft based on interpretation of the CSL test results.

Further Testing/Inspection:

- If an anomaly is detected that warrants further investigation (i.e. possible defect) the following procedures should be considered to further quantify the affected zone:
    - First, thoroughly review the inspection records of the drilled shaft in question, and review the closest drill log, to see if there is a correlation between the detected anomaly and something that occurred during the shaft construction process or present in the soil profile.
    - Perform additional CSL testing after some period of time to see if the anomaly is the result of delayed concrete set or curing. CSL tomography (3D Imaging) could also be used at this time to try and better define the extent of the anomaly.
    - Perform core drilling at the locations of suspected defects
    - Insert downhole cameras (in drilled core holes) for visual examination of defects
    - Excavate around the perimeter of the shaft to expose near-surface defects.

If additional investigation is necessary confer with the Drilled Shaft Inspector regarding all aspects of shaft construction to determine what could have happened at the depth of the anomaly. This is a very important decision in that if, upon further investigation, there is no shaft defect found, ODOT may be responsible for paying the investigation costs along with additional compensation to the contractor for delaying drilled shaft construction due to the additional investigation work. If any defects are found, regardless of whether they are repaired or not, the full cost of the shaft investigation (coring and/or other work) is paid by the Contractor with no time extension.

Core Drilling:

If core drilling is necessary the following procedures should be followed:

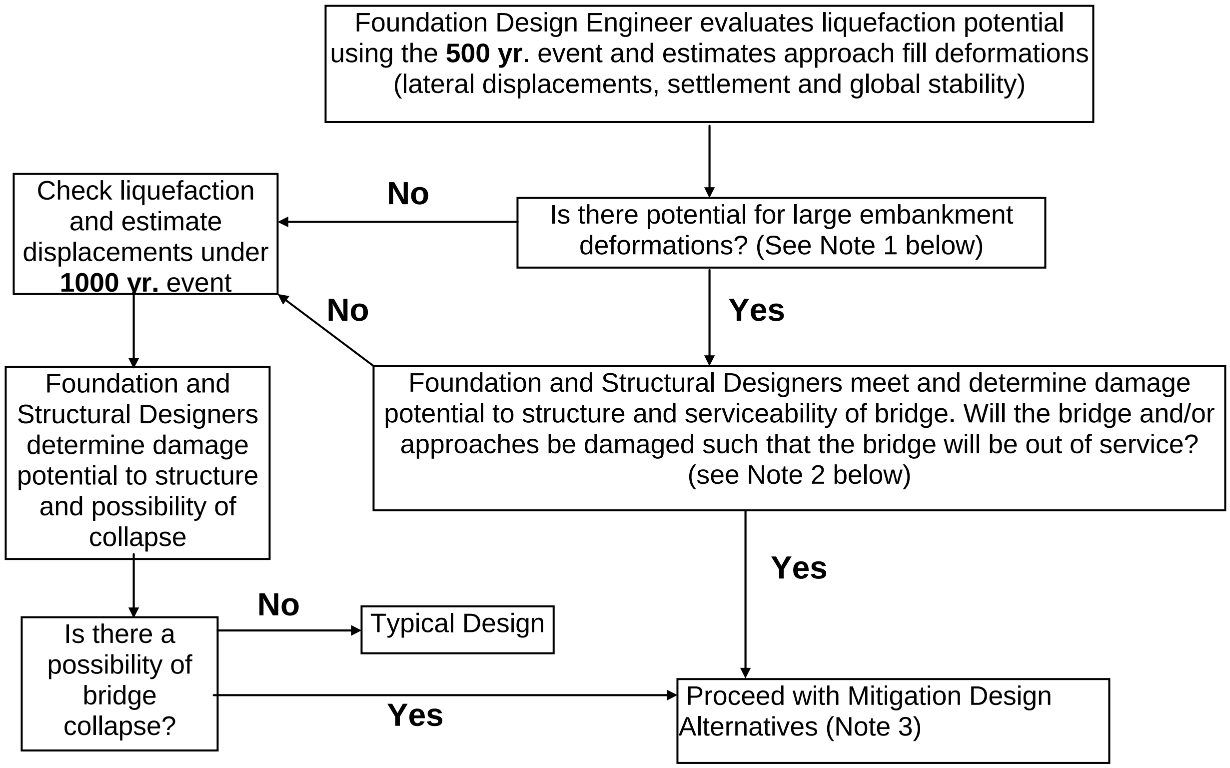
- The foundation or bridge designer should plan the number, location and depth of all core holes based on the CSL test results and inspection reports. Target the area(s) where the CSL results indicate possible defects. Do not let the contractor select core hole numbers, locations and depths.
- Carefully log all core holes like typical geotechnical bore holes, closely measuring depths, rate of advancement, any sudden drops in drill steel (indicating voids), percent recovery, concrete quality, breaks, fractures, inclusions and anything that does not indicate solid, good quality concrete.
- Core at least 3” away from any rebar if possible and do not core through any steel reinforcement without the clear, expressed approval of the structural designer.
- Take photos of the core recovery.
- Keep notes of any driller remarks regarding the nature and quality of the shaft concrete.

- Keep the contractor (or Drilled Shaft subcontractor) informed throughout this investigation. The core holes may also be able to be used by the contractor for repairing shaft defects, using pressure washing, pressure grouting or other techniques.
- Cored holes could also be filled with water and used for additional CSL testing.
- If necessary:
    - do core breaks (qu) on suspected core samples retrieved from defect area.
    - use down-hole cameras to help quantify the extent of defect area.

Shaft Defects:
Based on the results of the additional investigation work and an assessment of the shaft integrity, the bridge and foundation designers will confer and determine if a defect is present that requires repair. This determination should be based on an assessment of the effect the defect has on the shaft's ability to perform as designed (both for geotechnical and structural purposes). If a shaft defect is determined to be present, it is the contractor's responsibility to submit a repair plan and repair the defect at no cost to ODOT. All shaft repair proposals should be submitted to the foundation and bridge designers for review and approval. Shaft repair should not be allowed without approval of the Engineer of Record. If shaft defects are severe enough to warrant complete shaft replacement or redesign, the contractor shall submit a plan for the redesign or replacement according to Section 00512.41.

Remaining Shafts:
The cause of any defects should be ascertained if at all possibly so the contractor can modified shaft construction procedures and avoid repeating the same defects in the remaining drilled shafts.

ODOT Liquefaction Mitigation Procedures



Note 1: Lateral deformations up to 12" are generally considered acceptable under most circumstances.

Note 2: The bridge should be open to emergency vehicles immediately after the 500-year design event. If the estimated embankment deformations (vertical or horizontal or both) are sufficient enough to cause concerns regarding the serviceability of the bridge, mitigation is recommended.

Note 3: Refer to ODOT research report SPR Project 361: "Assessment and Mitigation of Liquefaction Hazards to Bridge Approach Embankments in Oregon", Nov. 2002 and FHWA Demonstration Project 116; "Ground Improvement Technical Summaries, Volumes I & II", (Pub. No. FHWA-SA-98-086) for mitigation alternatives and design procedures.

As a general guideline, along centerline, the foundation mitigation should extend from the toe of the end slope to a point that is located at the base of a 1:1 slope which starts at the end of the bridge end panel. In cross section, the mitigation should extend as needed to limit deformations to acceptable levels.