Generally there are two types of foundations used to support WisDOT structures. These include shallow foundations (spread footings) and deep foundations. Within the category of deep foundations are piling, drilled shafts and mircopiles/augercast piles.

There are many factors that influence the selection of the proper foundation type for a particular structure. These include:

- Magnitude and direction of loads.
- Depth to suitable bearing material.
- Potential for liquefaction, undermining or scour.
- Frost potential.
- Performance requirements including deformation (settlement), lateral deflection, eccentricity, global stability, resistance to bearing, uplift demands, lateral/sliding/overturning forces, vibration concerns, and cofferdam/seal requirements.
- Ease, time and cost of construction.
- Environmental impact of design and/or construction.
- Site constraints including restricted right-of-way, overheard and/or lateral clearance, construction access and staging, underground utilities/obstructions.
- Proposed structure type/details/etc.

Based on these items, an assessment of the various foundation types is made by the geotechnical engineer. The geotechnical engineer generally works closely with the structural engineer to select/design the best foundation for a particular site and structure. If spread footings are feasible, they are typically the most cost-competitive type of foundation. Further detailed information related to structure foundations can be found in the WisDOT Bridge Design Manual located within the Bureau of Structure's website, and the AASHTO specifications.

7-2.1 Shallow Foundations

Shallow foundations (spread footings) are used on a limited basis for WisDOT structures. Although it is possible to design a spread footing for any type of sound material, WisDOT general practice has been to limit their application to sites with shallow bedrock or highly competent soils. Founding a shallow foundation on even a good quality soil will usually require a relatively large footing to accommodate normal structure loads. Sites where sound bedrock can be reached by an excavation of 10 feet or less from the base of the substructure unit, should be considered for a spread footing. At sites where bedrock is deeper, the depth and cost of the required excavation generally make spread footings impractical.

7-2.2 Deep Foundations

When competent bearing soil/rock is not present near the base of the proposed foundation base, structure loads must be transferred to a deeper stratum by using deep foundations. There are three types of deep foundations that the Department may use. These include piles, drilled shafts and micropiles/augercast piles. These are discussed in greater detail below.

7-2.2.1 Piles

Driven piles are the most common method of foundation support for WisDOT bridges, and are used on approximately 90% of all substructure units. The factored axial compression resistance (design load of the pile) and the required driving resistance (construction resistance of the pile) are provided in Table 10.3-5 of the WisDOT Bridge Design Manual.

Driven piles may be separated into two distinct categories which are: end bearing piles and friction piles. Although there are two categories, in reality, all piles achieve some capacity through both friction and end bearing. Since methods of analysis and application are different, these pile categories will be discussed separately.

7-2.2.1.1 End Bearing Piles

As the name suggests, end bearing piles are driven to bedrock or very dense materials (N>50, or IGM [Inter-Geo Materials]), and act as a column to transmit all the foundation loads to the underlying material. Steel HP-sections (often called H-piles) are the most commonly used pile for this application, but open end thick wall steel pipe piles, or oil filed pipe can also be used.

End bearing piles are usually recommended when the following conditions are encountered:

- Bedrock is encountered at relatively shallow depths of 10 to 60 feet, rendering the full development of friction piles unlikely or impossible.
- At bedrock depths greater than 60 feet, if the geotechnical engineer determines that a friction pile is estimated to drive to a distance of ≤10 feet above the bedrock surface. Since end bearing piles usually have a lower unit cost than friction piles, it is normally more economical to drive the end bearing pile a few extra feet to the bedrock surface. Also, if the friction pile should drive long and reach the bedrock surface, the potential for damage to the pile increases due to its thinner steel shell thickness.

Before recommending end bearing piles, the geotechnical engineer needs to conduct a careful examination of the subsurface soil conditions and the encountered bedrock strata. The rock cores and split spoon refusal depths must be used to develop an estimated tip elevation for end bearing piles. For greater depths to bedrock, it may be necessary to determine estimated lengths for friction piles and compare these to anticipated end bearing pile lengths. Any variations in the slope or elevation of the bedrock surface which may influence driving/pile lengths should be noted.

Attempting to drive an end bearing pile into a bedrock surface to achieve a high loading is not an acceptable practice. There is a high potential for damage to the pile, which could seriously affect the resistance of the pile. There are commercially available hardened steel pile points (also called tips or shoes) which can be welded to a steel pile before driving. These pile shoes have the function of protecting the end of the pile and allowing a better grip ('bite') into a sloping bedrock surface. They should not be used in an attempt to drive an end-bearing pile deeper into a bedrock surface, since these attempts will nearly always fail and/or damage the pile.

WisDOT Standard Specifications for Highway and Structure Construction (Standard Spec 550) describes the methods and procedures to determine the required driving resistance. Once the minimum penetration is reached, continued driving on end-bearing piles should not occur. Imparting excessive energy to the pile to achieve deeper penetration may lead to serious structural damage of the pile, which could significantly reduce pile capacity.

7-2.2.1.2 Friction Piles

Friction (displacement) piles derive their load carrying capacity by two actions. First, load is transferred over the length of the pile from its wall to the surrounding soil by the means of friction, or adhesion, between the pile and the soil. The pile also transfers load from its tip directly to the underlying soil. While the interaction of these two load transfer mechanisms is complex, in the static analysis of friction piles, both are considered to act at the same time. Thus the resistance of a friction pile is determined by adding the contribution of sidewall friction/adhesion to that of end bearing, to reach a total resistance for the pile.

A number of forms and materials are available for use as friction piles. However, on WisDOT projects, the cast in place (CIP) concrete pile comprises the majority of friction piles used. A pile of this type consists of a round relatively thin steel shell with a closed end, which is driven to the required resistance and then filled with concrete. Generally a flat end plate is welded to the pile tip to seal the bottom. The resistance of the pile is determined by the compressive strength of the concrete. Although the steel pile shell does add to the CIP structural capacity, it is ignored when determining design capacities.

Precast concrete piles are also allowed by WisDOT specifications, but are not typically used at the present time. In some parts of the country, piles of this type are the standard. Wood piles were also once very common, but increasing material costs, relatively low resistance values, and limited available lengths and splicing issues have greatly reduced their use. WisDOT no longer includes wood piles in its Standard Specifications. Steel H-piles may also be used as friction piles, but they tend to be inefficient when compared to round cast-in-place piles. WisDOT experience has shown that H-section piles often drive up to 20% deeper than comparably-loaded cast-in-place piles. If an H-section is used as a friction pile, only the outer perimeter (boxed) area of the total section is used to compute skin friction, not the complete steel surface area (web and flanges). WisDOT also uses only 50% of the outer perimeter (boxed) area when computing end bearing for H-piles. This has been found to correlate well with driven pile construction records.

Friction piles become the preferred choice for pile foundations when bedrock or end bearing material is at greater depths, and substantial zones of dense granular soils or very stiff cohesive soils occur in the upper soil layers. Borings must be continued to the point where the geotechnical engineer is assured that any proposed pile will reach the plan resistance above the end of the boring, in the dense or very stiff materials. Developing estimated pile resistance by assuming that soil conditions will extend beyond the end of a boring is not an acceptable practice. Soil conditions can change, so founding a pile beyond the end of the boring can lead to a number of problems including excessive pile lengths, inadequate/unknown long-term pile capacity, and/or unacceptable pile movement.

7-2.2.2 Drilled Shafts

A drilled shaft is a large diameter (generally 3 to 12+ feet) cast-in-place, reinforced concrete column used to transfer load to rock or other suitable material. Specialized equipment is used to bore a large diameter hole to the required depth. The borehole may be either cased or uncased depending upon soil conditions. Once the borehole reaches the required depth and meets design criteria, a steel reinforcing cage is lowered into the borehole and concrete is placed by means of a tremie, or pumping. The resulting column can then be used to support a footing, or may be extended and used as an above-ground pier column.

Drilled shafts can support large loads and can be used in place of either piles or spread footings. They have good application under the following conditions:

1. As pier support in rivers where sound bedrock is found at shallow depths, and cofferdam construction would be difficult.
2. Piers located in deep water crossings, where cofferdams are very expensive.
3. As support for piers or abutments subject to large vertical and/or lateral loads such as a lift bridge.
4. As support for a pier or abutment where sound rock is relatively shallow (10 to 40 feet) and large numbers of piles are required.
5. As foundation support in crowded or congested areas where normal construction methods/foundations may not be practical or suitable, or where construction vibrations are a concern.

WisDOT has only used drilled shafts on a limited number of bridge projects. However, there are situations when they are the best choice for foundation support, so they should be considered when reviewing foundation options. In most previous WisDOT applications, drilled shafts have been designed as end bearing columns to transfer load directly to the underlying sound bedrock by means of a socket into the bedrock. The depth of the socket is normally 1.5 times the diameter of the shaft. The full design procedures for drilled shafts go beyond the scope of this manual, and can be found in Federal Highway Administration Publication, FHWA/NHI-10-016.

The subsurface investigation plays a critical role when drilled shafts are contemplated for a bridge. The normal procedure of strata identification, sampling and testing must be followed to the bedrock surface so that any special conditions which may be encountered in the overburden materials can be considered. Once the bedrock surface is encountered, coring must begin. As a general rule, the minimum core depth should be at least the sum of 1.5 shaft diameters plus 10 feet, to ensure there is competent bedrock within the zone of shaft load distribution. The cores must be examined by an experienced geologist for the presence of voids, weathered zones, shear zones, or any other condition that could limit the load carrying capacity of the rock. If any of these irregularities are of sufficient magnitude to cause concerns, coring should be extended until 10 feet of competent rock is found. At least one core must be obtained at each substructure unit. If the bedrock is questionable or highly variable, a second core may need to be obtained. Based on the information developed by the coring, the geotechnical engineer and the geologist will determine a base elevation for each substructure shaft unit. Variations in the slope of the bedrock surface and in the quality of the bedrock must be considered. The recommended drilled shaft base elevation is then reported to the structural engineer.

It is normal practice to require additional coring by the contractor for each drilled shaft during construction. Cores reaching a minimum of 10 feet below the estimated shaft base elevation must be obtained and examined by an experienced geologist and the geotechnical engineer. If the core meets the anticipated design conditions, construction of the drilled shaft may proceed. If variations in the rock are noted, the shaft base depth may need to be adjusted. Additional coring may then be required to provide the specified 10 feet of core depth below the revised shaft tip elevation. Since this coring is generally completed prior to any construction shaft excavation, the coring information will also be useful to the contractor in determining the best methods/procedures to advance the shaft excavation. All of these coring requirements must be included in the project contract bid documents.

Drilled shafts may also be ‘tip grouted’. Tip (or base) grouting involves the placement of pressure grout at the base of a cured drilled shaft in an attempt to preload the base to increase the end resistance of the drilled shaft and increase the resistance factor for the design. Tip grouting is a rather new technology, and not typically done on WisDOT drilled shafts.

While drilled shafts are a viable method of foundation support for bridges, the overall cost must be carefully examined. When some of the special conditions describe above are encountered, drilled shafts may be the most cost-effective foundation support method. However, under more normal conditions, this may not be the case. Experience on past WisDOT projects has shown that the cost of drilled shafts per support load ton, is generally higher than the cost of piles, and can be highly variable. While this may change with time and increased usage, the cost differential must be considered when selecting the most economical foundation support.

7-2.2.3 Micropiles and Augercast Piles

These are non-typical deep foundation alternatives that have been used by WisDOT.

Micropiles consist of short, rather small-diameter (5.5 - 12”) open steel cylindrical shells (with a lead-end cutting edge) that are rotated during advancement, while the interior soil is being removed using an auger. These short (generally 5-foot) sections have threaded ends to facilitate connection to create a continuous steel shell. After the design termination depth is reached, the auger is removed and grout is injected into the steel cylinder which remains in place. After completion of grouting, typically a single reinforcement bar is inserted into the fluid grout. The micropile is allowed to cure, and then the member is then attached to the structure foundation. There is no way to accurately determine the capacity of a micropile, so it is based on the micropile static design. These members provide good lateral and axial resistances. They are generally more costly than driven piles, but offer the benefits of less construction vibration, ability to be installed in restricted headroom areas, ability to accommodate rather large loads, ability to underpin existing foundations, and ability to generally be advanced in all soil types. They are more commonly used in the building industry, rather than the transportation sector.

Augercast (or auger cast-in-place, ACIP) Piles consist of a hollow-stem flight of augers that is advanced into the ground. The required torque to advance the auger is used to estimate the resistance that the foundation element can provide. After the target torque is achieved, the auger removes all the soil within the flights and a sand-cement grout (or concrete) is injected from the bottom as the auger is backed out. This leaves a continuous grouted column. A single steel re-bar is often inserted into the fluid concrete. After curing, the augercast pile can be incorporated into the foundation, similar to a typical pile. Since the augercast pile resistance is based on the installation torque, there is no way to accurately confirm the resistance of the element (other than a load test). Augercast piles are typically not used at sites that contain cobbles or boulders, as they cannot be effectively advanced in those conditions. They can be effective when vibrations/disturbance must be minimized, and in areas of restricted access and/or vertical clearance.