Deep Foundations for Transportation Facilities

Mark McClelland, P.E., Geotechnical Branch Manager

Texas Department of Transportation, Austin, TX 78701
E-mail: mmcclell@dot.state.tx.us

The Texas Department of Transportation (TxDOT) is a major user of deep foundations to support transportation facilities, namely bridges. In the past 12 months, approximately 850,000 linear feet (160 miles) of piling and drilled shaft have been let to contract.

TxDOT bridges are currently founded exclusively on deep foundations. Spread footing foundations were used occasionally into the 1970's to support bridges in competent soil or rock, but the increasing economy of drilled shafts resulted in an end to the use of spread footings. With current emphasis on scour vulnerability of bridges, we are particularly fortunate to have the vast majority of our bridges over waterways on either piling or drilled shafts. States with significant inventories of structures on shallow foundations are now spending considerable time and resources to manage scour at those bridges.

Driven piling constitute approximately 30% (250,000 lf) of the deep foundations let to contract in the past year. Over 99% of the piling driven on TxDOT projects are prestressed concrete piling, with only a few hundred feet of steel H-piling driven each year. Concrete piling are more effective than steel H-piling in our softer soils because they are displacement piling, which seem to develop more reliable skin friction than non-displacement piling. Texas has an extremely well developed and competitive precast concrete industry, and prestressed concrete piling are very cost effective in soft soils, with in-place prices running $25 to $40 per linear foot. Concrete piling are used extensively along the Gulf Coast and to a lesser extent in northeast Texas. Common prestressed pile sizes are 16, 18 and 20 inch square. For larger structures 24 and even 30 inch square piling have been utilized.

For small structures, piling are often driven in a trestle bent configuration. In trestle bents the piling function as both foundation element and the bridge column, and are embedded directly into the cap supporting the bridge beams. This provides rapid and cost effective construction, as the need to form and place a footing and separate column are eliminated. This configuration also works well in standing water where placement of footings underwater requires construction of an expensive cofferdam. Trestle pile bents are limited to structures with relatively low heights (<20') and short spans (< 100') and are often used for bridges on county and farm-to-market roads.

For taller, heavier structures, piling are driven in groups and capped by a structural footing. A separate reinforced concrete column is extended up from the footing and into the cap. Most pile footings contain 3, 4 or 5 piling, and support a round 30 or 36 inch diameter column. Footings for larger structures may contain dozens of piling and support very large columns up to the size of the towers supporting cable-stayed bridges.

Loads for piling range from as little as 35 tons per pile on smaller trestle bents up to 200 tons or more on piling in footings. Because piling are generally used in areas with softer soils, their lengths are seldom shorter than 30 feet, and may extend to as long as 110'. The limiting length on concrete piling is controlled by handling and transport of the piling, and TxDOT does not utilize pile splices to couple piling to longer lengths. We instead manipulate pile size and number to keep loads at levels that allow an unspliced pile to carry the load.

Construction issues with concrete piling are generally associated with driving the piling to required grade without damaging the pile. Concrete piling are sensitive to tensile forces during driving, and will crack if excessive tension occurs. TxDOT standard details call for concrete piling to be prestressed to approximately 800 psi, which adequately offsets most tensile driving forces encountered. However, in soft soils and during initial driving, contractors and inspectors must be aware of the need to reduce hammer energy and provide fresh new cushioning at the top of the piling. At the opposite end of the spectrum are problems associated with installing piling into hard ground, or ground with hard layers or lenses. Concrete piling cannot be driven reliably into ground with Texas Cone Penetrometer (TCP) values exceeding 100 blows per foot. For ground with discrete hard layers or lenses near the surface it is possible to drill a pilot hole to allow the piling to penetrate. The size and depth of the pilot hole must be controlled to prevent unanticipated loss of resistance. If material harder than 100 blows per foot is present, the drilled shaft becomes the preferred foundation type.

Drilled shafts constitute approximately 70% (500,000 lf) of the deep foundations let to contract in the past year. TxDOT has used drilled shafts to found bridges since the late 1940's, and is generally considered to be the largest user of drilled shafts in the United States. Much of the pioneering work on drilled shafts was funded by TxDOT beginning in the 1970's and continuing to present. Drs. Lymon Reese and Mike O'Neill performed the bulk of this research at the University of Texas and later the University of Houston. Dr. Cumaraswamy Vipulanandan (Vipu) has ongoing research projects with TxDOT in drilled shafts and augercast piling. Texas has a large corps of experienced drilled shaft contractors in the state, and is the home of the Association of Drilled Shaft Contractors / International Association of Foundation Drilling. Drilled shafts are used statewide, with in-place prices ranging from $50 per linear foot for smaller diameter shafts in simple conditions, up to several hundred dollars per linear foot for larger sizes in difficult conditions. Common drilled shaft diameters range from 24 to 48 inches. Shafts as small as 12 inches are used for sign structures, while shafts up to 144 inches in diameter have been used in special circumstances.

The most common configuration for drilled shafts is the use of single 30 or 36 inch diameter shafts directly supporting matching diameter columns. Narrow structures may have only two drilled shaft/columns supporting the cap, while wider structures may use six or more of these elements, typically spaced at approximately 20 feet down the centerline of the cap. As structures get taller the diameter of the drilled shaft will increase to provide the necessary moment capacity to the column. While 16 to 20 inch prestressed concrete piling are rather limited in bending capacity and must be grouped under footings as column height increases, drilled shafts can simply be increased in diameter and reinforcing to provide the necessary structural capacity. Single shaft/column elements of up to 96 inches in diameter have been used to support structures over 100 feet tall.

For very tall and/or heavy structures, drilled shafts may be placed in groups under columns. A common configuration is to use a pair of 48 or 60 inch diameter shafts capped with a footing to support a single rectangular column of a flyover ramp. Two shafts provide an efficient couple to resist the lateral forces due to wind and eccentric loading from the curved structure. For more severe loading, a group of four shafts may be placed in a rectangle, again with a cap supporting a single column. Four shafts provide couples in both the lateral and longitudinal directions. Seldom are more than 4 drilled shafts utilized in a footing.

Loads for drilled shafts range from as little as 70 tons per shaft on small bridges using 24 inch shafts to over 100 tons on large diameter shafts socketed into competent rock. Shafts placed into solid rock may be as short as 6 feet, while heavily loaded shafts placed in soft soils or scour vulnerable rivers may extend to over 150 feet in length.

Construction issues with drilled shafts most commonly involve maintaining stability of the excavation and making certain that the hole is completely filled with good quality concrete. Excavation stability is a function of the types of soil or rock being excavated, the groundwater conditions, and the methods being utilized by the contractor. Most contractors and inspectors would prefer to see all drilled shafts excavated into stiff dry soils, allowing a simple excavation and dry placement of concrete. On TxDOT projects we estimate that less than 30% of drilled shafts fall into this category. The majority of shaft excavations encounter soft or caving ground and/or groundwater at some depth, requiring use of casing or slurry to stabilize the excavation. In some areas use of a casing will allow the contractor to dry up the excavation, and place concrete in the dry. However, approximately half of the drilled shafts constructed on TxDOT projects require placement of concrete either underwater or under slurry.

Appropriate drilled shaft concrete mix design has become a priority at TxDOT. In the 2004 Standard Specifications we are requiring smaller coarse aggregates, higher slumps, and for the first time, testing for slump retention. We have found that placement of concrete with large aggregate and low slump is resulting in defects in drilled shafts. On large jobs in which placement of concrete may take hours, we have also determined that slump loss during the concrete pour has led to defects in the shafts.

In addition to conventional driven piling and drilled shafts, TxDOT has sponsored research on the use of augercast piles (ACIP) to support bridge structures. One bridge has been completed in the Houston area, with two other bridges currently under contract in the Lufkin area. This foundation type may provide an economic third foundation option.

Finally, TxDOT is evaluating the technique of post-grouting the base of drilled shafts to increase capacity and reliability. We have completed a small bridge on post-grouted drilled shafts in the Harlingen area, with a large structure currently under construction west of Houston.