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Effect of CSL Tube Type on the Drilled Shaft Axial Load Carrying Capacity

Mohammad Bahman Naraghi Sefat[1], Shahin Nayyeri[2], Asad Esmaeily[3]
[1]Research Assisstant, Department of Civil and Environmental Engineering, Swansea University, Swansea United Kingdom,
[2]Lecturer, Department of Civil Engineering, Kansas State University, Manhattan KS, USA, [3]Professor, Department of Civil Engineering, Kansas State University, Manhattan KS, USA,

ABSTRACT: *Cross-Hole Sonic Logging (CSL) is a common type of Non Destructive Testing (NDT) method, which is currently used to check the integrity of placed drilled shafts. CSL evaluates the integrity of the concrete inside the cage and between the access tubes based on propagation of ultrasonic waves between two or more access tubes. A number of access tubes are installed inside the reinforcing cage prior to concrete placement as guides for sensors. The access tubes can be PVC or steel galvanized based on ASTM6760 [5]. The type of the CSL tubes can affect the axial strength of the drilled shaft. The objective of this study is to compare the amount of axial load capacity of drilled shafts due to using different type of CSL tubes inside the caging. To achieve this, three (3) large-scale drilled shaft samples were built and tested using a hydraulic actuator at the Florida International University's (FIU) Titan America Structures and Construction Testing (TASCT) laboratory. During the static load test, load-displacement curves were recorded by the data acquisition system (MegaDAC). Three (3) drilled shaft samples were built to evaluate the effect of the type of the CSL tube on the axial load capacity in drilled shaft foundations.*

***Keywords** - Drilled Shaft Foundations, Axial Load Capacity, PVC, Galvanized Tube, and CSL Tube*

I. INTRODUCTION

The construction of higher and heavier structures in urban areas where noise and vibration regulations make hammering of piles prohibitive, lead to the development of the drilled shaft foundation that can reach stronger soil strata where shallow foundations could not develop sufficient capacity. A drilled shaft is formed by boring an open cylindrical hole into the soil and subsequently filling the hole with concrete. Drilled shafts are applicable to a wide variety of subsurface conditions, and a single shaft can carry very large loads without the need for a cap at the top. These are some of the many reasons why the use of reinforced concrete drilled shafts as deep foundations for various subsurface media has grown significantly in the last decade. The proper performance of drilled shafts and their carrying capacity require expert knowledge and experience in the effects of construction defects on such performance.

The first use of the CSL method in the Americas was by Hertlein in 1986. This method was discussed by Baker (1993) and O'Neill (1999) [1]. CSL is a common type of NDT, which is currently used to check the integrity of placed drilled shafts based on propagation of ultrasonic waves between two or more access tubes inside the reinforcing cage. CSL is the most reliable technique for assessing the integrity of in-place constructed deep foundation elements such as drilled shafts. Sarhan et al. (2002) [2] quoted a number of sources that flaws occupying up to 15% of the drilled shaft's cross section could remain undetected. CSL establishes the homogeneity and integrity of concrete, such as voids or soil intrusions. The CSL method is used to measure the speed of ultrasonic waves between water-filled access tubes. A number of access tubes (PVC or steel galvanized) are installed inside the reinforcing cage prior to concrete placement as guides for sensors. To carry out the test, the probes with 215 mm length and 25 mm in diameter are lowered down to the toe of the tubes. The transit time of an ultrasonic compressional wave (p-wave) signal from a signal source in one access tube to a receiver in another access tube is continuously measured from the bottom to the top of the shaft. The frequency of the signal that travels between tubes is about 40 KHz. The first arrival time can be used to determine the ultrasonic pulse velocity (C), if the distance between tubes is measured.

Hajali and Abishdid (2012) [3] evaluated behavior of axially loaded drilled shaft foundations with symmetric voids outside and inside the caging. The objective of their research was to quantify the extent of loss in axial strength and stiffness of drilled shafts due to presence of three different types of symmetric voids throughout their lengths; also they evaluated the potential for buckling of longitudinal bars within the various types of voids. Hajali and Abishdid (2014) [4, 5] investigated that how many percent of the maximum applied load will be shed in side friction and how much will be transferred to the base in drilled shaft foundations. The axial capacity of the drilled shaft foundation is influenced by the size of the drilled shaft, and soil characteristics. In their study, the effect of the size and soil characteristic will be investigated on the contribution of side resistance and end bearing capacity. Also, the study presents a three-dimensional finite element modeling of a drilled shaft subjected to axial load using ANSYS12.

In homogeneous, good quality concrete, the ultrasonic wave speed is around 12,000 to 13,000 ft/s, in water is 4,800 ft/s, and in air is 1,100 ft/s. Normal density of concrete is about 150 lb/ft^3 (2,400 kg/m^3). The dynamic modulus of concrete varies from 4,060 to 5,800 ksi (28 to 40 GPa) and the Poisson's ratio of concrete is between 0.1 to 0.2. The range of the P-wave velocity is different in different types of soil (Tabsh et al. (2002) [6]). Koerner *et al.* [7] utilized spectrum analysis to determine the predominant frequency (f) of sound waves in soil in the range of 0-40 kHz. The predominant frequency band of sound waves in unconfined compression and triaxial tests was 250 Hz to 8 kHz. Soil consists of particles with different sizes and shapes which forms a skeleton whose voids are filled with water and air. Hence, the compressional wave with 40 kHz attenuates inside soil and cannot travel. Using other probes to send lower frequency can help to solve the problem inside porous material. Frequency of waves used in this study is around 10 kHz due to attenuation of compressional waves in soils with actual frequency of CSL (Withiam et al. (2002) [8], and Haramy et al. (2006) [9]).

These foundations usually carry very high design loads; that is why they need to be built with a high level of quality assurance and control applied to each in-place constructed deep foundation element. Part of the axial load carrying capacity of the drilled shafts is resisted by the soil below the tip, which is the end-bearing capacity of the shaft. The other part is resisted by the side friction developed along the shaft or skin friction capacity, which can be affected by the shape of the drilled shaft after construction. Therefore, evaluating the effect of different parameters that can affect the axial load capacity of the shaft is crucial in determining its actual axial load carrying capacity.

II. TESTING PROGRAM

Three (3) drilled shaft samples were tested at FIU's TASCT laboratory under axial compression using a hydraulic actuator with a maximum load capacity of 235 kips (1046 KN). Axial load and vertical displacement at top of the shaft sample were recorded during the tests. The length and diameter of the shafts, lateral tie spacing, and type and strength of concrete were kept constant in all samples.

III. TEST SPECIMENS

Table 1 summarizes the characteristics of the test specimens used in this study. All of the considered shaft specimens were one-fourth scale of a typical full-scale drilled shaft in Florida which has a diameter of 3 feet (91.4 cm) and length of 16 feet (487.7 cm). The diameter and length of the shaft samples were kept constant at 9 inches (22.86 cm) and 4 feet (122 cm), respectively. The shaft samples were longitudinally reinforced with 6 No. 4 steel bars, equally spaced around the perimeter. This area of steel corresponded to 2 percent of the gross cross-sectional area of the shaft. The longitudinal bars were Grade 80 with the nominal yield strength of 80 ksi (551.6 MPa). The lateral ties used were No. 3 and were spaced along the axis of the shaft at 4 inches O.C.. The clear cover used on all steel reinforcement was 1 inch (2.54 cm).

Experimental work consisted of testing three specimens with PVC, galvanized CSL tubes, and control specimen (Specimens 1, 2, and 3). All three specimens were tested in pure axial compression. The eccentricity of the applied load was approximated to be ±1 inch (±2.54 cm).

The casting forms for the drilled shaft specimens consisted of cardboard Sonatube with an inside diameter of 9 inches (22.86 cm). Before the steel cage was positioned inside the Sonatube, eight 1 inch (2.54 cm) plastic spacers were inserted throughout the length of the cage in order to keep the cage at the center of form, and to ensure the 1 inch (2.54 cm) concrete cover. It is important to place and center the reinforcing steel cage in the Sonatube prior to placing concrete. Figure 1 shows the steel cage of a shaft and the plastic spacers on it before concrete placement. A wooden formwork was built and placed at the bottom of the Sonatube to ensure that the steel cage was aligned properly, and to secure the fluid concrete during casting.

Figure 1: Steel Cage of Specimen

Concrete was pumped vertically inside the Sonatubes for all the specimens to ensure uniformity. Concrete placement was continued in one operation to the top of the shaft. Concrete for drilled shafts was also designed and placed in such a manner that it could be pumped, or flow easily through the rebar cage by gravity to the bottom of the shaft without the nedd for any vibration. Concrete was not vibrated after casting to simulate actual conditions where concrete in drilled shafts is not consolidated. All specimens were tested 30 days after casting. Figure 2 shows all the specimens ready to be tested.

Figure 2. Specimen 1 with PVC Tube and Specimen 2 with Galvanized Tube

IV. Material Properties

The concrete used in this study was normal weight concrete (150 lbs/ft^3 or 23.565 kN/m^3). Standard concrete cylinder samples with 4-inch diameters and 8-inch lengths were tested using the Concrete Compression Machine in the laboratory at FIU. The average measured axial compressive strength for three standard cylinders was 37,900 lbs (168588 N) at 28 days. Therefore, the cured concrete cylinders had a compressive strength at 28 days equal to 3,015 psi (20.8 MPa). The concrete slump was measured to be 4 inches at the time of casting, and the maximum coarse aggregate size (rounded river gravel) was 0.5 inch (1.27 cm). Fine aggregate was based on ASTM C33 natural sand with a fineness modulus of 3.0. The cement was type I Portland cement and comprised about 24 percent of the weight of the mix. The water to cement ratio varied between 0.4 and 0.42, depending on the moisture content of the aggregate. Sonatube with inside diameter of 9 inches (22.9 cm) was used as a formwork for the concrete. All shaft specimens were cast in a vertical position without vibration after concrete placement to simulate actual conditions.

A No. 3 bar was tested using a Universal Tensile Testing Machine in the laboratory at FIU. The tensile test loading ratio used was 100 lbs/sec (445 N/sec). The longitudinal steel and lateral ties in all the tested specimens were Grade 80, with yield strength of 80 ksi. The actual yield strength was less than the nominal value (75 ksi), and the modulus of elasticity was 29×10^6 ksi (2×10^8 MPa). The stress-strain curve obtained for the No. 3 steel rebar is shown in Figure 3.

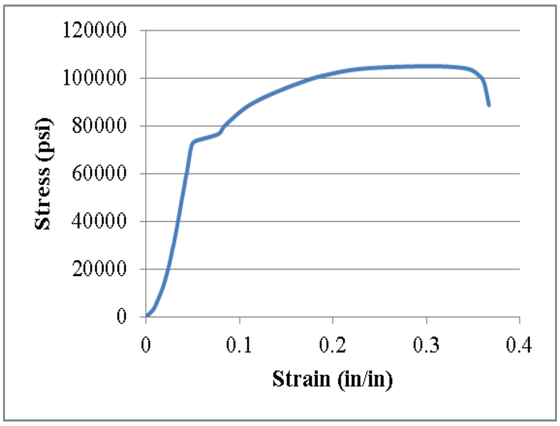

Figure 3: Stress-Strain Curves of Steel Rebar

a. Testing Procedures

Load tests were performed in general accordance with American Society for Testing and Materials (ASTM) D1143 test method for shafts under axial compressive load. All tests were performed in the same laboratory temperature to minimize variances due to thermal effects. All load tests were carried to structural failure. The test program was consisted of testing three specimens (Specimens 1, 2, and 3) with PVC, galvanized CSL tubes, and one control specimen. The eccentricity of the applied load was approximated ±1 inch (±2.54 cm).

The machine used for axial testing of the drilled shaft specimens was a Shore Western hydraulic actuator with a maximum load capacity of 235 kips (1,046 kN) as shown in Figure 4. The actuator moves from -10 inch to +10 inches (25.4 cm), which is total of 20 inches (50.8 cm) of displacement from top to bottom. A displacement control procedure was adopted for all the tests at a rate of 0.012 in./min (0.305 mm/min). The hydraulic actuator was equipped with a manually controlled electric pump, which allowed having a constant loading. All instruments were connected to a data acquisition system, which is a MegaDAC with a sampling frequency of 1 Hz. The actuator deflection and shaft head displacement were recorded with the Linear Displacement Transducer (LDT), and the loading was recorded with the actuator's load cell.

Figure 4: Hydraulic Actuator Machine Used for the Tests

A solid steel plate with a thickness of 1 inch (2.54 cm) was placed at the bottom of the specimens to provide a strong base. Two 2×2×6 ft^3 (61×61×183 cm^3) concrete blocks were constructed to use as lateral base support. These blocks kept the specimens immobile during the loading process. Angle bars of 1.5×1.5×0.25 in^3 (3.8×3.8×0.63 cm^3) were cut and used to support the specimens. Two supports were used: one at the bottom and another at the middle of the specimen in order to prevent buckling of the samples in the first mode before failure, as shown in Figure 4. Figure 4 also shows the instrumentation scheme, geometry, and loading procedure for the specimens loaded axially.

V. Test Results and Discussion

Type of the CSL tube will affect the axial load capacity of the shafts. ASTM D6760 [10] allows using the PVC or galvanized tube to perform the CSL test after drilled shaft construction. Three drilled shaft samples were also built to evaluate the effect of CSL tube type, one sample without tube, one sample with PVC tubes and one sample with galvanized tube. Three drilled shaft specimens were built for considering the effect of CSL tube on axial load capacity as summarized in Table 1. Specimen 1 had three 1/2” PVC tube installed inside the cage with actual inside diameter of 0.5 inch (1.27 cm) and outside diameter of 0.84 inch (2.13 cm) and weight of 0.16 Lbs/ft (0.235 KN/m), (Figure 2). Specimen 2 had three 1/2” galvanized steel pipe with outside diameter of 0.62 inch (1.57

cm), inside diameter of 0.5 inch (1.27 cm) and weight of 0.85 Lbs/ft (1.25 KN/m), (Figure 2). Specimen 3 was the control specimen and did not have any CSL tube. Specimens 1, 2, and 3 were constructed without anomalies and all of them had six (6) equally spaced No. 4 longitudinal rebars around the perimeter. The CSL tubes were cut to have a smooth surface at top of the shaft before axial load testing. All specimens were tested 30 days after casting. Figure 2 shows the specimens were ready to test with the actuator and Sonatubes were removed since concrete were hard. Specimen 3 was the control specimen for this group cast with concrete compressive strength of 3015 psi (20.8 MPa) and Specimens 1 and 2 had cast with the same concrete.

Table 1: Characteristics of Tested Drilled Shaft Specimens for CSL

Specimen No.	Concrete Strength psi	Concrete Strength MPa	Diameter inch	Diameter cm	Longitudinal Steel	CSL Tube
1	3015	20.8	9	22.9	6 No. 4	PVC
2	3015	20.8	9	22.9	6 No. 4	Galvanized
3	3015	20.8	9	22.9	6 No. 4	No Tube

The axial load versus vertical displacement for Specimens 1, 2 and 3 is shown in Figure 5. CSL access tubes are installed inside the cage to perform the CSL test after drilled shaft construction. Before performing the CSL test, CSL tubes are filled out with water. All water shall be removed from the access tubes. The tubes shall then be completely filled with an approved grout having strength properties equivalent to or better than those of the drilled shaft concrete. The tubes in the shaft shall not be filled with grout until all testing is completed and the shaft has been accepted by the inspector. In this study, the tubes were not filled with grout before axial load testing. Results show that the strength of Specimen 3 at failure was 137.8 kips (613 KN), Specimen 2 was 122.2 kips (543.6 KN), and that of Specimen 1 was 106.9 kips (476 KN). It shows that specimen with PVC CSL tube cause 12% reduction in axial load capacity of the drilled shaft in comparison to specimen with galvanized CSL tube.

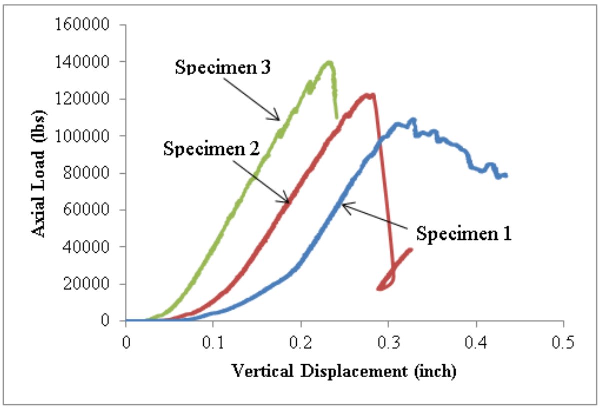

Figure 5: Axial Load versus Vertical Displacement for Specimens 1, 2, and 3

VI. Specimens Failure

Figure 6 shows the fractured specimens after the conclusion of the testing. Generraly, it can be seen that cracks in specimens started around and in the vecinity of the pipe location, and weakened the specimens during loading. In Specimens 1 and 2, it can be seen that the fracture occurred due to the crushing of the concrete at the top of the specimen and large cracks around the void section. It can be said that the fractures were clearly due to the lack of confinement of the concrete and tube material in the vicinity of the tube. Most of the growth cracks in Specimens 1 and 2 were in the longitudinal direction of the shaft, and they show a shear failure in the shafts under axial loading (Figure 6). In these specimens, material crushing was in the region where the actuator was bearing on the specimens. Therefore, failure in specimens was due to shear failure.

From Figure 6, it can be seen that the failure cracks in specimens 1 and 2 (without voids) started from the top support location and grew in the longitudinal direction towards the top of the specimens. It can be said that fracture occurred due to concrete crushing around the CSL pipe. Also, the compressive axial load resulted in pure compression failure and material crushing in the region where the actuator was bearing on the specimens. In specimen 3, without CSL tube, fracture was due to crushing and shearing of the concrete and it shows a shear failure in the specimen. Specimen 3 without CSL tube was tougher than those with PVC or galvanized CSL tubes.

Specimen 1, Specimen 2, Specimen 3

Figure 6: Failure in Shaft Specimens after Testing

VII. Conclusions

This paper presented the results on three (3) drilled shaft specimens tested at the TASCT laboratory at FIU under axial compressive load. Evaluation of the effect of the type of the CSL tube on the axial load capacity shows that specimen with PVC CSL tube will cause 12% reduction in axial load capacity of the drilled shaft in comparison to specimen with galvanized CSL tube inside the cage. Observation of fractured specimens shows that in specimens 1, 2, and 3, buckling was the main reason of failure. Most of the growth cracks in specimens without voids were in the longitudinal direction of the shaft, and they show a shear failure.

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