THE INFLUENCE OF A STEEL CASING ON THE AXIAL CAPACITY OF A DRILLED SHAFT

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A series of field load tests was performed to investigate the effects on the axial capacity of drilled shafts when casings could not be pulled. The tests show that leaving casing in place is detrimental, but grouting proved an effective remedial measure when the casing was placed in an oversized excavation. Even though grouting was found to improve the capacity of a shaft where casing was left in place, procedures should be used in the field that will insure that casing will be removed. Shafts cast in the normal manner perform better than do shafts where casing has been grouted. Useful data were obtained on the distribution of axial load from drilled shafts to the supporting soil.

Introduction

The casing method of construction of drilled shafts is a common procedure and is applicable to sites where soil conditions are such that caving or excessive deformation will occur when a hole is excavated. Examples of such sites are clean sand below the water table or a sand layer between layers of cohesive soils. If it is assumed that some dry soil of sufficient stiffness to prevent caving exists near the ground surface, the construction procedure can be initiated with the dry method. When the caving soil is encountered, a slurry is introduced into the hole and the excavation proceeds. Drilling is continued until the stratum of caving soil is pierced and a stratum of impermeable soil is encountered. A casing is introduced at this point and is rotated and pushed into the impermeable soil a distance sufficient to effect a seal. The slurry is bailed from the casing and a smaller drill is introduced into the hole, and the drilling is carried to the projected depth. During the additional drilling, slurry is contained in the annular space between the outside of the casing and the inside of the upper drilled hole.

If reinforcing steel is to be used with drilled shafts constructed by the casing method, the rebar cage must extend to the full depth of the excavation. After any reinforcing steel has been placed, the hole should be completely filled with fresh concrete with good flow characteristics. Under no circumstances should the seal at the bottom of the casing be broken until the concrete is brought above the level of the external fluid. The casing may be pulled when there is sufficient hydrostatic pressure in the column of concrete to force the slurry that has been trapped behind the casing from the hole.

The slurry in the excavation is designed to prevent the collapse of the drilled hole and usually is effective, but on a number of occasions it has been found that the casing is "seized" by the surrounding soil and cannot be recovered. It should be noted that the resistance to pulling the casing comes not only from soil resistance along the sides of the excavation but from soil resistance at the seal and from friction between the concrete and the inside of the casing.

In the event the casing cannot be pulled, it is critical that the design and specifications be such that the field engineer has clear and unequivocal directions. He must immediately be able to decide whether or not the drilled shaft, with casing in place, will be adequate. However, because the performance of a drilled shaft where a casing has been left in place is adversely affected, every effort should be made to withdraw a casing.

The objective of this study was to develop information of the load-carrying capacity of drilled shafts where the casing is left in place and to develop possible solutions to the problem. Results of field tests at three different sites are analyzed in the report. The most definitive tests were conducted at a site in Galveston, Texas, and only those tests are presented in this summary report.

Construction of Test Shafts

The soil profile at the Galveston site is shown in Fig 1. Three test shafts were constructed at the site between August 5, 1980, and August 15, 1980. A 48-in.-diameter by 60-ft-long test shaft, G-1, was constructed by the casing method. The first step was to drive a 48-in.-diameter casing with a vibratory hammer to a depth of 52 ft. Then a 46-in.-diameter auger was used to excavate the soil inside the casing and to advance the hole to its final depth of 60 ft. A rebar cage, instrumented with Mustran cells, was lifted with a crane and carefully placed in the hole.

Concreting was done with the help of a tremie which was lifted and positioned inside the steel cage by means of a crane. A slump test was done and the concrete slump was found to range from 9-½ to 10 in., which was considered acceptable.

Concrete was tremied into the shaft until the level of the

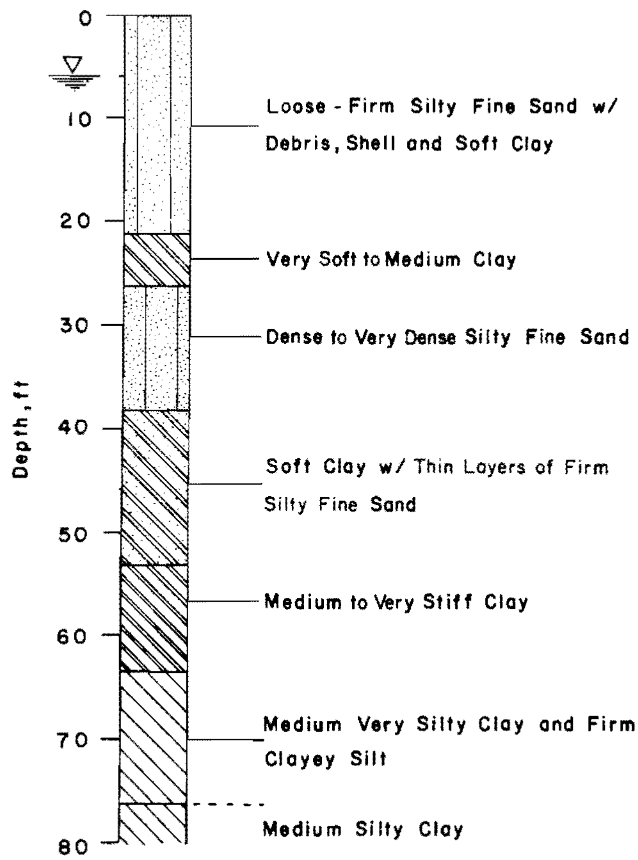

Fig. 1 Soil Profile, Test Site 1

concrete was within a few feet of the top of the shaft. At this time the manifold for the Mustran cells was placed inside the rebar cage and tied to the cage. The vibratory hammer was then connected to the steel casing and the casing was pulled out. The manifold was removed from inside the shaft and more concrete was added to complete the construction.

The next shaft constructed was 36 in. in diameter by 65 ft in length, test shaft G-2. A 48-in.-diameter casing was driven to a depth of 50 ft with a vibratory hammer. A 46-in. auger was then used to excavate the casing to its full depth. Slurry was introduced and a 36-in. auger was then used to excavate the hole to its final depth of 65 ft. After the excavation was at its final depth, a 36-in.-diameter casing was placed in the hole, with the slurry still in the hole. The casing went the full length of the hole.

A reinforcing rebar consisting of eight number 10 bars to 18 ft and four number 10 bars to 60 ft was placed in the hole. This cage was uninstrumented. With the 48-in.-diameter casing still in place, the concrete for this shaft was placed with the aid of a tremie. Slump tests were done and the concrete slump was found to range from 9-½ to 10 in. The 36-in. steel casing was left in place on this shaft, but the 48-in. casing was removed and the slurry was left between the casing and the soil. By the next day the soil at the ground surface had moved inward toward the casing.

The third test shaft, G-3, constructed was 36 in. in diameter by 60 ft in length. A 42-in.-diameter surface casing was driven to a depth of 10 ft. Then a 36-in.-diameter hole was augered, with the use of slurry, to a depth of 35 ft. At this time a 36-in.-diameter casing was screwed in to a depth of 40 ft. The excavation was then continued, with a 34-in. auger and slurry, to a final depth of 60 ft.

A rebar cage, fully instrumented, was lifted by a crane and carefully placed in the hole. Concrete was placed in the shaft with the aid of a tremie. The shaft was filled completely with concrete and the casing was left in place. Slump tests were performed and the concrete slump was found to range from 9-½ to 10 in. The last step was to remove the 42-in. surface casing.

The two 36-in.-diameter test shafts were tested on September 4 and 5, 1980. The instrumented, 36-in.-diameter shaft (G-3) was tested on September 5. As expected, because the casings were left in place, the shafts failed at relatively low loads. In an attempt to increase the load-carrying capacity of the shafts, it had been previously decided to grout around sections of each of the 36-in.-diameter shafts.

The mixture for one cubic yard of grout consisted of 750 lb of sand, 846 lb of cement, 40 lb of water, 27 oz of normal-set water reducer. Water was then added on the job site to get a workable fluid mix. A single-cylinder grout pump was used to inject the grout. Although the grout pressure was not measured, it is assumed that it was low.

In grouting test shaft G-3 with a casing to 40 ft, six grout tubes were jetted into place, three to a depth of 40 ft and three to a depth of 30 ft. Grout was then pumped into the tubes, and pumping was continued as the grout tubes were removed. A total of 8 cu yd of grout were used to grout the shaft from the ground surface to a depth of 40 ft. Assuming that the excavation in the top 40 ft, using the 36-in.-diameter auger, had a diameter of 37 in., the volume of the annular space around the casing was 0.6 cu yd. Therefore, the volume of grout was about 13 times greater than the annular space.

The grouting of the 36-in.-diameter shaft (G-2) with a casing to 65 ft was done by jetting three grout tubes to a depth of 65 ft. Then a total of 6 cu yd of grout was pumped into the grout tubes, pumping was stopped, and the grout tubes were withdrawn. After the grout had been allowed to set, a steel rod was used to learn the extent of the grouting. It was determined that the lower 15 ft of the shaft had been grouted. The volume of the annular space around the casing of the lower 15 ft, using the same assumptions indicated above, was about 0.3 cu ft. Therefore, the volume of grout was about 27 times greater than the annular space.

Results of Load Tests

The results of the load tests are shown in Figs 2, 3, and 4. The quick load method was used in the testing.

A detailed analysis of the load-settlement curves and of the results from the Mustran cell readings was made.

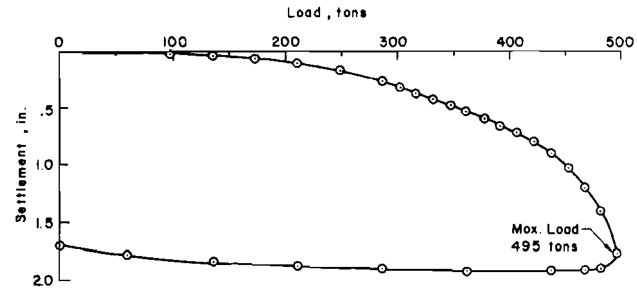

Fig. 2 Load Settlement Curve, Test Shaft G-1

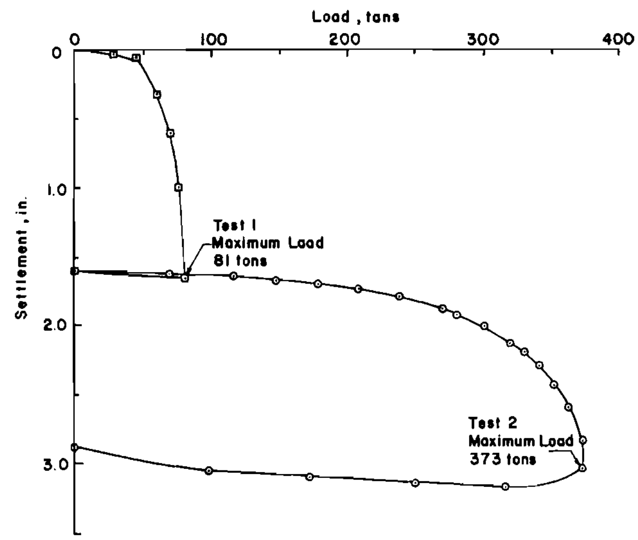

Fig. 3 Load Settlement Curves, Test Shaft G-2

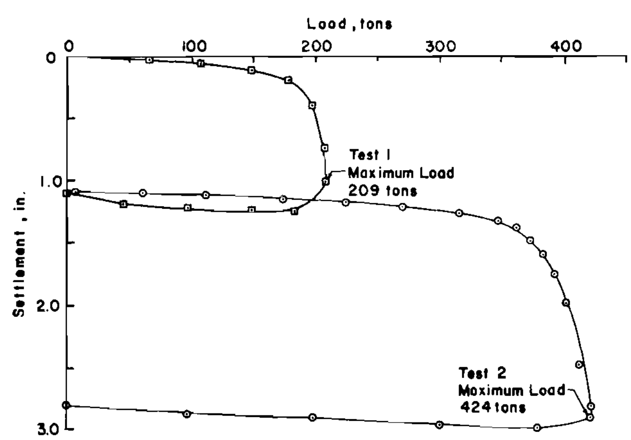

Fig. 4 Load Settlement Curves, Test Shaft G-3

Conclusions

(1) Leaving casing in place when the excavation has been over-drilled dramatically reduced the capacity of a drilled shaft.

(2) The grouting of the annular space between the casing and the excavation caused a significant increase in capacity for these tests.

(3) There is evidence to indicate that increasing the liquidity of fresh concrete (increasing its slump) increases the load transfer in skin friction.

(4) The load transfer in skin friction was a nonlinear function of the downward movement of a drilled shaft.

(5) The maximum load transfer in skin friction occurred at a small downward movement of a drilled shaft.

(6) The maximum load transfer in skin friction for sand increased with depth with almost a linear function.

(7) The maximum end bearing in clay agreed well with bearing capacity theory and required more downward movement than did the maximum skin friction.

(8) The Mustran-cell instrumentation system provided an adequate method of the measurement of axial loads in a drilled shaft.

Recommendations

(1) When a casing has to be left in place, a remedial measure should be taken to insure the integrity of the foundation.

(2) Grouting of the annular space is recommended as a remedial measure when the casing is left in an over-drilled hole.

(3) Any type of remedial measure that is taken should be verified by use of some type of load test.

(4) When fluid concrete (slump 9 to 10 in.) is used in constructing drilled shafts in sand, the following design equation can be used to predict the side resistance:

$$f_s = K_c p_c \tan \phi$$

where

f_s = ultimate unit skin friction,
K_c = lateral pressure of concrete,
P_c = effective overburden pressure of concrete, and
ϕ = effective angle of internal friction of soil.

(5) Internal instrumentation for the measurement of the distribution of axial load with depth should be employed in any future test shafts. Experience has shown that extreme care must be used in the installation and operation of any of the available systems in order to obtain results of the best quality.

KEY WORDS: drilled shaft, axial capacity, steel casing, load test, grouting, vibrating hammer, over-sized excavation

The research reported here was conducted for the Texas State Department of Highways and Public Transportation in cooperation with the U. S. Department of Transportation Federal Highway Administration.

The full text of Research Report 255-1F can be obtained from Mr. Phillip L. Wilson, State Transportation Planning Engineer; Transportation Planning Division, File D-10R; State Department of Highways and Public Transportation; P. O. Box 5051; Austin, Texas 78763.