ANALYSIS OF DRILLED-SHAFT FOUNDATIONS FOR OVERHEAD-SIGN STRUCTURES

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SUMMARY REPORT 244-2F(S)

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Research Report 244-2F concerns the design of drilled-shaft foundations for use with Overhead Sign Bridges. Design procedures for single- and double-shaft systems are presented, with attention given to the effects of soil-structure and structure-structure interaction. Design charts formulated by the Texas State Department of Highways and Public Transportation were checked and found to be adequate for design within stated conditions. Alternate methods of design for unusual cases are advanced for both single- and double-shaft systems.

The results of two field tests on uninstrumented shafts are presented and comparisons to predicted results are made. The observed results indicated that the computer-based analysis gave conservative results.

The aims of the research study were two-fold: to investigate the adequacy of available methods of analysis and design and to compare the single- and double-shaft systems from the standpoints of performance and economy.

Introduction

Since the inception of the Federal Interstate Highway System in the 1950's, the number of miles of divided, multi-lane, limited access roadway in use has continued to increase yearly. Among the needs that arose with this highway system was one for a sign system that is easily legible and understandable to the motorist, and the development of the overhead sign has provided an acceptable solution to this problem. Spanning the full width of the roadway, this system quickly provides directional information in an unambiguous form; the proper lane for a given destination can be easily marked overhead. The structural problem of the sign support has been solved by the use of steel trusses with spans of up to 150 feet (45.7 m). The structure must carry the dead load of the signs, lighting, and truss, as well as the live loadings from wind, snow, and ice. The loads are transmitted through vertical support towers to the foundation, which typically consists of one or more drilled shafts. The report presents methods of analysis and design for both single- and double-shaft systems, and an economic comparison is made.

Foundation Configuration

The design of the foundations can be grouped into two main categories, i.e., single-shaft and double-shaft. In this sytem, each foundation shaft must primarily resist axial forces of a compressive or tensile nature in combination with a horizontal component. Relatively speaking, shaft moments caused by the horizontal shears are small.

The single-shaft-foundation system is subjected to a different loading condition. For the structure with supports at each end, the vertical loads due to dead load as well as the horizontal shears are practically the same as in the double-shaft system. However, the moments produced by the horizontal loads are no longer transmitted as axial forces; they are transmitted to the shafts as moments and must be resisted by the shafts in bending. The cantilever-type structure is subjected to torsion along with shear and moment. The cantilever design is not discussed in the report.

Methods of Analysis and Design

The processes of analysis and design of systems using drilled shaft foundations are continually being refined. Newer and more capable methods of computation have allowed the use of systems of analysis and design heretofore unavailable. A problem can now be solved not only by the use of differential equations but also by the use of nondimensional coefficients or computer-based finite difference methods. The desired accuracy of the model used for solution of the problem at hand will determine which method of analysis is selected.

The use of computers has encouraged the development of simplified design charts. While these charts are, of practical necessity, restrictive in their application, they can be utilized by the engineer in everyday practice. Under the proper circumstance they can be used for an adequate and quick solution to a given problem. If the situation is too complex, the charts may still be used to give an idea of an appropriate starting point for a computer-based solution. Such computer-based solutions allow a higher degree of freedom in modelling to match the complexities encountered in more difficult problems.

Two general methods of analysis and design are studied in Research Report 244-2F: the direct use of computer programs that employ finite-difference techniques to solve the differential equations that define the interaction of the foundation with the supporting soil, and the use of charts and diagrams that were prepared by the SDHPT and that were developed by use of the computer programs.

Field Experiments

In December 1978 and January 1979, two sets of drilled-shaft foundations were made available by SDHPT for testing. The shafts were located on the western section of IH 410 in San Antonio. They had been in use as foundations for an overhead-sign structure that spanned the southbound lane. The existing signing and supports were to be moved to another position and the shaft foundations removed to allow the construction of a new access roadway. The major portions of the shafts were to remain in the ground with only the top several feet being removed and the holes backfilled. Because the shafts were of no further use, testing to failure was permissible.

The aims of the testing program in San Antonio were as follows: to obtain data by which the analytical procedures could be evaluated, to obtain a direct indication of the strength of a drilled shaft in a typical installation, and to obtain physical evidence concerning the interaction of a drilled shaft with the supporting soil.

The soil at the sites consisted of overconsolidated clays with the undrained shear strength, measured by unconsolidated-undrained triaxial tests, ranging from 650 lb/sq ft at the ground surface to 1400 lb/sq ft at a depth of 15.5 ft. There was a sharp increase in the shear strength below that point. The water table was deep.

The shafts for both sites were straight-sided 30-inch-diameter shafts spaced 6.0 feet center to center. The lengths were specified on the original plans to be 17 feet at sites 1 and 2. However, there was no way to verify the embedment. The ground surface around the shaft heads varied from being almost level with the shaft head to being as much as 6 to 8 inches below the shaft head. At both sites, minor excavation was performed between shafts to allow room for the jacking system.

The loading sequence consisted basically of loading the shaft to a pre-determined level, unloading, and then reloading to the same level. After a series of load cycles, the load was increased to a higher level and a new series of load cycles performed at this new load. Measurements of deflection and slope were made at given increments of load during the loading process. The rate of unloading was not controllable and no effort was made to measure deflections during unloading.

Curves showing groundline deflections versus lateral load were obtained for the four drilled shafts at the two sites. Short-term loading was employed at test site 1 and both short-term loading and cyclic loading were used at test site 2. The maximum loads ranged from about 60 kips to just over 70 kips, and the curves showing load versus deflection were strongly nonlinear. The maximum groundline deflections ranged from 3 to 4 in.

The computer program for the analysis of laterally loaded piles was used to develop load-deflection curves to compare with the results from the experiments. Test results indicate that theories in use are correct. The pattern of reduction in soil capacity noted is the same as that observed in earlier testing programs. The capacities predicted by the computer analysis and the capacities observed indicate that the method of analysis used will give conservative results. Observed shaft capacity would also indicate that a reserve strength is available to resist possible overload.

The charts developed by the SDHPT also gave values that were in good agreement with the results of the tests.

Comparison of Single- and Double-Shaft Systems

Although many factors will enter into the design process and many decisions will be subjective in nature, an attempt was made to judge the final design only by the criterion of cost. For each of the design methods a solution was proposed. The final step of the process was the economic comparison of the solutions that were obtained.

The physical example that was selected was for the overhead signs at the San Antonio site. The details of the loading are not given here.

It was assumed that each system that was designed was comparable to all the others with respect to factors such as site suitability, ease of construction, and time of construction. Subjective judgments must be made regarding these factors, particularly with respect to the latter two. The three factors noted above were assumed equal for each design in order to make the economic comparison. The physical requirements and price for each solution are summarized in Table 1. The price given is based upon SDHPT average low bids compiled for the twelve-month period ending in February 1980. The price quoted was $74.84 per linear foot for a 30-inch-diameter drilled shaft and was based upon a total bid quantity of 60,774 linear feet.

Table 1 indicates that the cost of the single-shaft system is around one-half the cost of the double-shaft system. If the desired design solution is to be based upon such a simplified cost comparison the single-shaft system would be chosen.

In many cases, the decision on foundation type to be used can be based largely on economic consideration. However, the possibility exists that other conditions may influence or even dominate this selection. In every instance the economic analysis must, therefore, be viewed in light of additional variables that are not directly convertible to dollar quantities.

TABLE 1. COMPARISONS OF SINGLE- AND DOUBLE-SHAFT SYSTEMS

System	Method of Design	Shaft Size and Length	Total Cost, U.S. Dollars
Single Shaft	SDHPT		
	Charts	2 @ 30″ ϕ × 18′	$ 2,694.24
	Computer	2 @ 30″ ϕ × 25′	3,742.00
Double Shaft	SDHPT		
	Charts	4 @ 30″ ϕ × 19′	5,687.84
	Computer	4 @ 30″ ϕ × 16′	4,789.76

Conclusions

The traditional form of foundation for the overhead sign structure has been a double-shaft system. The loadings, shear, moment, and axial thrust, have been resisted largely by the axial resistances of the soil-shaft system in either compression or tension. This system tends to be inefficient in comparison to the single-shaft system for most uses and its application should be restricted to special cases.

The use of single shafts to resist shear, moment, and axial thrust has been suggested. The proper design of such a system leads to the most efficient use of the system materials; the large axial thrusts of the double-shaft system are greatly reduced and at the same time the shaft's capacity for bending is much more fully utilized.

A simplified cost comparison has been made and presented for a typical design problem. The single-shaft system was comparatively cheaper than the double-shaft system. Variables exist that can complicate and influence the design in such a manner that cost figures alone cannot be the sole criteria for system selection.

Results of a test run in San Antonio indicate that current theories of soil-shaft behavior under loading are correct. The predicted behaviors were conservative in comparison to the observed behaviors, indicating that design procedures based upon the theories involved will yield a safe solution.

KEY WORDS: drilled shafts, lateral loads, soil-structure interaction, design procedures, uninstrumented shaft testing, group shafts, design aids

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 244-2F 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.