# NEVADA DEPRTMENT OF TRANSPORTATION

FFY 2015 RESEARCH PROBLEM STATEMENTS

## I. PROBLEM TITLE:

Development of a New Analytical Procedure for Analysis of Large-Diameter Drilled Shafts Subjected to Lateral Loading in Nevada Soils

## II. PROBLEM DESCRIPTION:

Current widely employed methods for analyzing deep foundations subjected to lateral loading, such as the p-y method, often do not take into account the vertical side shear which develops as lateral movement is induced. While this effect may be negligible for smaller diameter piles/shafts, it can have a significant impact on the response of large diameter foundation elements because the vertical deflection along the outer edges must be greater to accommodate the same level of rotation than would be needed in a smaller foundation. The side shear that occurs under shaft rotation results in a stabilizing moment that helps to reduce the lateral pile deflection. It is especially prominent in drilled shafts which tend to have the potential to develop higher frictional resistance at the soil-shaft interface due the rough nature of cast-in-place concrete. Since the use of large diameter drilled shafts has gained popularity in recent years for projects in Nevada, there is a real potential for significant cost savings if a new method of analysis could be developed in which the practically of the widely-used p-y method could be combined with the accuracy of a robust analysis which can take into account the additional vertical side shear and the resulted extra lateral resistance. Current design approaches, which do not account for the stabilizing moment require much larger shaft diameter for a given target top of the shaft lateral displacement. In addition, the consequence to design when significant difference in stiffness between adjacent layers exists when cliché layers are present needs to be explored.

## III. OBJECTIVE:

The main objective of this study is to develop a method of analyzing laterally loaded large-diameter drilled shafts for soil conditions in Nevada which will allow designers to capture the effect of vertical side shear in lateral analyses of drilled shafts.

## IV. CURRENT PRACTICE and RELATED RESEARCH:

Current practice for design of laterally loaded drilled shafts typically involves the use of the computer program LPILE (Ensoft Inc., 2014). LPILE implements the p-y method by either using internally calculated curves which originate from a number of sources (i.e. Reese, 1986; Reese and Matlock, 1956; American Petroleum Institute, 1993; etc.) or it can accept user-defined curves. Unfortunately, the internally calculated curves are not appropriate for analyses involving large diameter shafts as these empirically derived p-y curves were obtained using laterally loaded piles up to 2 ft in diameter and

none were developed to account for the aforementioned issue concerning vertical side shear.

Recent literature has highlighted how the standard of practice is inadequate for lateral loading analyses of moderate to large-diameter shafts and many authors have proposed their own methods for correcting this problem. Khalili-Tehrani et al. (2014) used the results of three full scale load tests on shafts ranging from 2 to 6 ft in diameter to show that the curves recommended by the American Petroleum Institute (API, 1993) do not agree with back-calculated values for p-y relationships, specifically for larger diameter shafts. Khalili-Tehrani et al. (2014) illustrated that the capacity of fixed-head 6 ft diameter shafts was underestimated by 100% using the API curves when compared to the experimental results. A 60% underestimation was observed for same shafts with free-head conditions.

Another example is the results of six load tests reported by Bhushan and Scheyhing (2002) which indicated similar observations in that the p-y curves calculated in accordance with standard practice yielded unreasonable predictions which required what they termed a "p-y multiplier" of 3 to 8 to convert to acceptable estimates.

While efforts have been made to provide correction factors for p-y curves and even to re-evaluate the commonly used analytical frameworks, there is still insufficient information available in literature to carry out a proper lateral loading analyses of large-diameter drilled shafts. As per the PI's discussions with industry experts in this field, they confirmed the lack of a rigorous practice-oriented tool to analyze large-diameter shafts under lateral loading and emphasized the fact that there is no general consensus on the methodology being used in practice.

## V. RESEARCH METHODOLOGY:

The objectives of the proposed research will be achieved through the following steps:

1) Perform a thorough literature review to identify advantages and drawbacks of existing analytical tools, such as LPILE and CGI-DFSAP (also referred to as SWM6.2), to predict the lateral capacity of large-diameter drilled shafts
2) Collect available lateral load test data conforming to the following criteria:
    a. Some, if not all, of the soils involved are comparable/the same as those found in Nevada
    b. Test shafts are large diameter
    c. The final database must include shafts with a wide range of length to diameter ratios
    d. Head fixity conditions must be known with certainty
3) Develop a new analytical tool and validate it against available full scale load tests. Use the validated tool to perform additional analyses covering a wider range of soil conditions and shaft geometries likely to be encountered in Nevada. It is important to note that, the cemented sandy soils in Las Vegas, colloquially known as caliche, are essential to consider for such a study since they are likely to greatly influence the true lateral capacity of shafts in Southern Nevada.

## VI. IMPLEMENTATION POTENTIAL:

Using the referenced NDOT's Five Stages of Research Deployment, the nature of the proposed research falls under Stage 1, Concept Stage, because the new analytical procedure will be developed based on the collected field data and analysis.

The immediate implementation potential of this work will include the enabling of accurate lateral loading analyses of large diameter drilled shafts in soil conditions common in the state of Nevada. This can truly be immediate since the proposed methodology will provide designers with a practice-oriented tool which will be simple to use in design as the main deliverable of this research. Nevertheless, full adaptation and thus implementation may require additional full scale load tests. Meanwhile, training will be provided to ensure that the intended use of the new analytical tool is properly understood.

## VII. URGENCY AND PAYOFF POTENTIAL:

NDOT current practice is likely resulting in excessive foundation costs when lateral resistance is a controlling factor in the design. Thus, it is urgent that proposed research be carried out as soon as possible so that unnecessary spending may be avoided.

The payoff potential of this work is significant. Again, available literature suggests that lateral capacity may be under-predicted by as much as 100%. Therefore, depending on the overall cost of a foundation, potential savings on a given project are only limited by the size of the foundation in question.

## VIII. ESTIMATED BUDGET:

Approximately $198,500 for two years (2015-2017)

## IX. DATE AND SUBMITTED BY:

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## X. NDOT CHAMPION, COORDINATION AND INVOLVEMENT:

Considering the multidisciplinary nature of this research, the proposal addresses both the geotechnical and the bridge divisions of NDOT. The PI has had several meetings with both divisions (i.e. geotechnical & bridge) to develop this research statement and discussed with members of NDOT including Mr. Mike Griswold, Mr. Abbas Bafghi, Mr. Ron Siegel, and Mr. Michael Taylor. The PI believes Mr. Bafghi from Geotechnical Division and Mr. Michael Taylor from Bridge Division to be NDOT champions in support of this project. The PI anticipates that all input from NDOT required to complete the proposed body of work would be under the review of the geotechnical and bridge divisions through regular progress meetings.