Effect of Best-estimate Geotechnical p-y Curves on Performance of Offshore Structures

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Executive Summary

Fixed offshore platform pile foundation design and assessment in the Gulf of Mexico (GOM) has been based on API RP 2A (various editions) and API/ISO RP 2GEO, 1st Edition. Over the years, post-hurricane observations of the platform performance in the GOM have shown that these standards tend to underestimate soil stiffness and capacity. This underprediction does not necessarily lead to conservative structural design and assessment. For example, fatigue design requires a realistic estimate of structural dynamics and strength design with a clear definition of structural load path and failure mechanism.

Research work, consisting of small- and large-scale pile tests, laboratory testing, and numerical analyses, has been carried out for years to understand this conservatism and define best-estimate geotechnical criteria, i.e. best-estimate soil lateral reaction for pile foundation design. These efforts culminated in the proposed draft of API/ISO RP 2GEO, 2nd Edition, which systematically re-defines the clay soil lateral reaction formulations for piles under monotonic, cyclic, and fatigue loads.

The goal of this study, sponsored by API SC2, was to perform structural analyses using soil models developed by 2GEO, 1st Edition criteria and 2GEO, 2nd Edition draft criteria to determine the effect of the new clay soil p-y formulations on the structural responses of these platforms. The predicted responses were then compared with measured or observed platform performance in field.

Three (3) featured fixed offshore platforms in the GOM, i.e. a free-standing caisson structure, a jacket type platform, and a tripod platform, were selected as representative structures for the study. The selected platforms are actual platforms in operation in the GOM. The caisson structure and jacket platform were damaged in Hurricanes Andrew and Ike, respectively. Platform vibration of the tripod platform was measured and recorded in the field to verify the tripod structural integrity. All relevant platform design, operation, and maintenance data of these structures are sufficient and available for the study.

Results of the analyses performed in this study demonstrate that structural models using the soil reaction formulations of the proposed 2GEO, 2nd Edition (draft), in combination with the best-estimate soil profiles interpreted based on the standard direct simple shear (DSS) tests, adequately predicted the platform responses observed in hurricanes and in normal sea conditions.

The clay soil p-y reaction formulations (monotonic, cyclic, and fatigue), when used with best-estimate DSS shear strength profiles as proposed in the draft of 2GEO, 2nd Edition, show significant improvement over the formulations in 2GEO, 1st Edition and older RP 2A editions (e.g. the so-called “Matlock curves”), and are endorsed and recommended for pile foundation design and assessment. In particular, the use of the new cyclic p-y curves is recommended for platform structural analysis under extreme environmental conditions.

1 Introduction

1.1 Background

Post-hurricane observations of fixed offshore platform performance in the Gulf of Mexico (GOM) often demonstrate platform structural damage or failure rather than foundation failure. However, platform analysis and assessment by API RP 2A (various editions) and API/ISO RP 2GEO, 1st Edition (Ref. 1, 2) foundation design approach are frequently governed by the foundation capacity and predict failure in the piles rather than the jacket structure.

Subsea wellhead and conductor fatigue design and analysis also predict unrealistic fatigue life expectancy due to the deviated dynamics caused by underestimated soil stiffness near the mudline. These have led to questions of unknown reliability and level of conservatism in the current API recommended pile foundation design approach.

Unrealistic conservatism in pile foundation design may have significant impact on new platform design and existing platform assessment. For new platform design, it may lead to excessively larger, deeper pile design associated with higher cost. Fatigue life can also be miscalculated due to inadequate estimates of platform dynamics (e.g. natural periods). For existing platform assessment, it may lead to misjudgment of platform actual capacity (due to pre-mature foundation failure in analysis) and locations of critical structural components (for platform repair and strengthening).

Research work and studies on fixed offshore platform performance in GOM hurricanes, funded by MMS/BSEE, API, and industries, have been carried out for decades (Ref. 5-12, 14-15, 23-26). A general perception indicates that pile foundations appear to be stronger and stiffer than calculated. Pushover analysis for jacket structures to their ultimate capacities commonly indicates that the foundation governs the capacity of the structural system. However, there are few, if any, observed pile foundation failures that have occurred in these hurricanes.

Discrepancy between predicted and observed performance of platform foundation system may be in part due to:

— underestimation of soil stiffness and capacity on the soil-structure interaction curves, especially the pile foundation soil lateral p-y curves for clays;

— interpretation of geotechnical soil boring and test data;

— loading rate and cyclic effect on pile capacity under short term wave loading conditions;

— aging effect of increased pile capacity for years or decades after installation;

— platform computer modeling inaccuracies and over-simplifications;

— disproportionate redundancies associated with structure components and foundation system in existing design practice;

— incomplete or misguided structural data and information.

Geotechnical research work, consisting of small- and large-scale pile tests, laboratory testing, and numerical analyses, has been performed for years to check the pile foundation design and define the best-estimate geotechnical criteria (Ref. 16-18, 20, 29-33). This culminated in the proposed draft of API/ISO RP 2GEO, 2nd Edition (Ref. 3, Annex D), which systematically re-defined the soil lateral reaction formulations, especially for clays.