CASE STUDY OF OFFSHORE GEOTECHNICAL INVESTIGATION IMPACT ON FOUNDATION DESIGN

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ABSTRACT: Site specific geotechnical investigations for offshore structures are essential to acquire data that facilitate successful foundation design and installation of the structure. Offshore geotechnical investigation is expensive due to exorbitant day rate of the vessels ranging from one million to 5 million dollars per day. Not only expensive but also availability of specialized vessels in the market is very limited. Site investigations are generally planned at feasibility stage of the project with limited scope and minimum knowledge of the super structural loads and position of the structure. Additional site investigation is envisaged if any change in the platform location or additional design requirements during the detailed design stage. However, most of the projects are proceed to next phases of the design with the feasibility stage geotechnical data. Sometimes this data may not be site specific or inadequate for the design. This paper presents two case studies, one in Indian offshore and other at Arabian Gulf, where the project costs were adversely affected due to inadequate geotechnical data. In case study-1, impact of the limited tests on design and installation is discussed. Importance of site specific geotechnical data on the design and implications on installation are discussed in case study-2. With these case studies, it is concluded that sufficient site specific investigations with adequate physical and chemical tests are essential at different phases of the projects for safe and economical foundation design.

KEYWORDS: offshore geotechnical investigation, pile foundation, carbonate content

1 INTRODUCTION

Design concepts of offshore and onshore are tend to diverge from practice and foundation design system. Even, there is great variation between size of offshore structures and onshore structures, similar type of geotechnical investigations with similar field and laboratory techniques are used (Randolph et al., 2005). However, type of tests and procedures are different from the onshore environment. Compared with onshore investigation, offshore geotechnical survey is most expensive due to exorbitant day rate of the vessels and time consuming in obtaining several permits from maritime authorities and various departments. Hence, geotechnical expertise is essential during planning and execution of the geotechnical investigation.

Knowledge of soil/rock properties is essential for economical and safe design of the offshore structures. A large part of the commercial and operational risk is involved in these works relate to uncertainties about the properties of soils and rocks at the site (Danson and Swan, 2005). It is necessary to perform sufficient investigations to evaluate these risks thoroughly. The geotechnical information needed for a feasibility study or a site selection is different from that of detailed design and installation engineering. However, for most of the projects geotechnical investigation data used for design is carried out at feasibility study stage with very little knowledge of the location, facilities and dimensions of the structures. The installation philosophy which may require additional soil data could not be envisaged at feasibility stage.

Offshore geotechnical investigation includes high cost and more time in mobilization of specialized spread. From this point of view, it would be ideal to have just one stage investigation in which all relevant information is collected. However, many parties are involved in the planning and decision-making process of a site investigation, including the owners and clients, designers, contractors, investigators and surveyors. Rarely has any one person all the experience and expertise needed for planning the optimal program. During design stage, additional characteristics may be found which suggest the need for additional or more detailed investigations.

The requirements of sampling, laboratory testing and analysis methods are different from site to site. With through knowledge of offshore geotechnical engineering, these requirements shall be properly planned in geotechnical investigation scheme to save project cost and time at the later stages.

This paper describes the two case studies where the inadequate geotechnical investigation was lead to uneconomical design and project schedule was adversely affected.

2 CASE STUDY-I: DESIGN AND INSTALLATION OF ANCHOR PILES FOR SINGLE POINT MOORING SYSTEM

For one of the projects in East Coast of India, the detailed feasibility study was carried out for setting up marine facilities like single point mooring system and associated facilities. For this purpose, geotechnical investigation was carried out at pre-feasibility stage. Geotechnical investigation vessel was mobilsed and drilled out six numbers of boreholes up to 50.0m depth. This survey was carried out based on the specifications developed by feasibility study (FEED) consultant. Typical borehole data and chemical properties of the investigation report are presented in Table 1 and 2 respectively.

Table 1 Stratigraphy of borehole as per geotechnical investigation

Stratum	Boring depth, m From	Boring depth, m To	Description
I	0	10.0	Very soft, Calcareous silty CLAY
II	10.0	19.0	Stiff calcareous silty CLAY
III	19.0	31.0	Stiff to very stiff calcareous sandy CLAY
IV	31.0	39.5	Dense to medium dense calcareous SAND
V	39.5	48.0	Stiff to very stiff calcareous sandy CLAY
VI	48.0	59.5	Dense calcareous silty fine SAND

Table 2 Chemical Analysis of the soil

Borehole	Depth, m	pH	Carbonate (%)	Calcium (mg/kg)
A1	5.95	7.33	25.6	436
	19.55	8.56	30.2	1245
A2	1.65	7.96	24.1	781
	26.7	8.69	36.4	941
A3	10.0	8.14	23.5	789
	16.0	7.57	22.7	542
A4	9.25	7.43	26.9	788
	17.5	7.3	31.5	1241
A5	7.85	7.0	28.0	421
A6	4.6	7.44	31.2	562
	21.25	7.61	33.0	489

Based on the geotechnical data available at feasibility stage, initial pile design was carried out and pile diameter and target penetration was arrived as 24 inch and 35.0m respectively. Contract was awarded based on detailed feasibility study with these pile sizes and scope for new/additional geotechnical investigation was not included. After award of the job, during the detail design stages following shortfalls were found in the geotechnical data.

- Standard Penetration Test (SPT) test was carried out as in-situ test at every 3.0m interval. For offshore, standard penetration tests are not recommended, since SPT values are not reliable for offshore condition. Cone Penetration test (CPT) is the most effective and reliable in-situ test for offshore soils. CPT is most widely used for marine engineering applications to extract essential design parameters of the soil. Since SPT data was collected for this project, reliability of the design parameters was questionable.
- From the soil strata, it was noticed that carbonate soils exist beyond 30.0m. However, as per the testing scheme of the geotechnical investigation, carbonate content tests were not included beyond 30.0m. Due to this, carbonate content was not measured during laboratory chemical testing and not reported beyond 30.0m in table 2. Engineering behaviors of the soils could be adversely affected, if carbonate content is greater than 30%. Due to presence of carbonate content, extremely low skin friction is mobilized by driven piles (Kolk, 1999) and also chances of pile buckling during driving through hard carbonate layers. Hence, percentage of carbonate content is important factor in the design of driven piles. Due to unavailability of carbonate content data beyond 30.0m, conservative pile design was carried out with assumption of degraded soil parameters. Conservatively, carbonate content of 90% was considered after 30.0m and as per the method suggested by Kolk (1999), angle of internal friction (ϕ) was reduced by 5 degrees for axial pile capacity estimation. However, during the driving, soil resistance encountered in carbonate sands was higher than silica sands (Rausche, 1999). Hence, angle of internal friction of sand layers was increased by 5 degrees for pile driveability analysis. With this approach, pile length was increased to 45.0m to meet design safety factors and pile wall thickness increased to overcome high driving stresses anticipated during driving. Project cost was escalated by approximately 30% due to increase in material with that of initial FEED design. In addition, extra cost incurred for additional barge time for driving of extra 10.0m pile length. Total increase in project cost due to extra material, fabrication and installation was approximately five times more than cost of new geotechnical investigation.

Proper geotechnical investigation scheme and planning could have been saved the project cost and time. Indeed, the use of good geotechnical knowledge in the planning and execution of investigation could be optimized the design of the foundation.

3 CASE-II: INSTALLATION OF DRIVEN PILES FOR OFFSHORE JACKET STRUCTURE

For the production of gas and development of the field in Arabian Gulf, one of the platforms was designed with typical template type fixed jacket structure. Platform consists of a foundation system with four main piles of 914mm diameter (36") and batter of 1:8 in both directions. The required penetration depth based on the design loads from in-place analysis was 45.0m below the seabed. All the piles were planned to install in three sections (one lead and 2 add-on sections). Geotechnical data used for the design was carried at feasibility stage of the project in the year 2001.

Due to layout and other changes, platform was relocated to 980m away from the initial site where geotechnical investigation was carried out. Geotechnical investigation at new location was not carried out and design was proceed with old geotechnical data. Soil strata used for design are presented in Table.3.

Table 3 Stratigraphy of borehole as per geotechnical investigation

Stratum	Boring Depth (m) From	Boring Depth (m) To	Soil Description
I	0	1.9	Very soft CLAY
II	1.9	2.3	Moderately weak CALCARENITE
III	2.5	4	Medium dense to dense Sand and GRAVEL
IV	4.0	11	Very soft carbonate SILT
V	11	15	Slightly to moderately cemented carbonate SAND
VI	15	20	Slightly cemented carbonate fine SAND
VII	20	28.1	Stiff to very stiff CLAY
VIII	28.1	33	Slightly to moderately cemented weak to very weak CALCARENITE
IX	33	38	Very stiff to Hard CLAY
X	38	50	Very weak to weak CALCARENITE
XI	50	60	Very stiff to hard Carbonate CLAY

As per the strata, numerous carbonate layers are reported at this location. Based on the pile driveability assessment hard driving was anticipated and higher pile wall thickness was adopted. However, during the installation on contrary to prediction, very low blow counts and smooth driving was noticed. Comparisons of predicted and actual blow counts are presented in Figure.1. From the blows counts and stresses observed during driving, it was noticed that soil strength considered for design is lower than actual strength. Comparison of pile axial capacity of actual and predicted is presented in Figure.2. For evaluation of actual field capacity, independent specialist consultant was appointed. Third party was back calculated soil parameters using the recorded blow counts and net striking energies of the hammer. Ultimate axial capacities were evaluated based on back calculated soil parameters according to methods described API RP 2 GEO (2011). Aging effect of both clay and sand was considered in estimating long-term pile capacity. As a result, it was noticed that as-built pile capacity was not meeting API required minimum factor of safety.

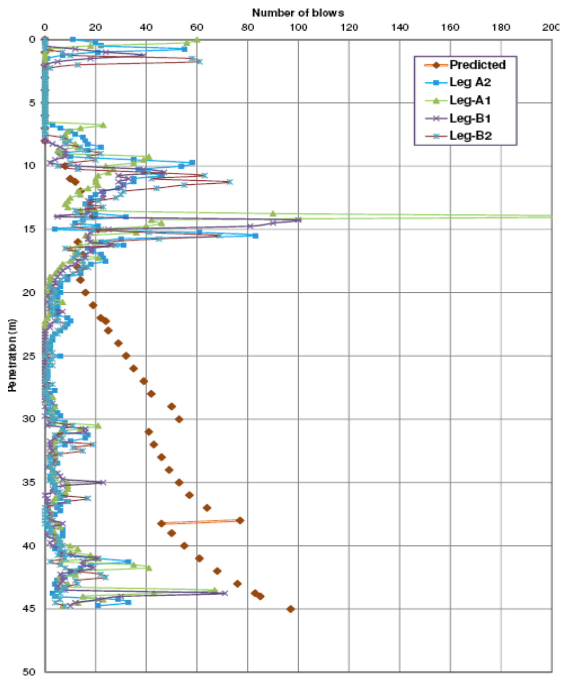

Fig.1 Comparison of predicted and actual blow counts

Additional pile of 13.0m length was recommended to meet axial compression and tensile capacity requirements. Pile monitoring was mobilsed to check actual pile capacity during driving of additional pile length. Due to these additional material and extra barge works, project cost was escalated by 20% approximately. Lack of site specific soil data was lead to uneconomical design and finally project schedules were adversely affected.

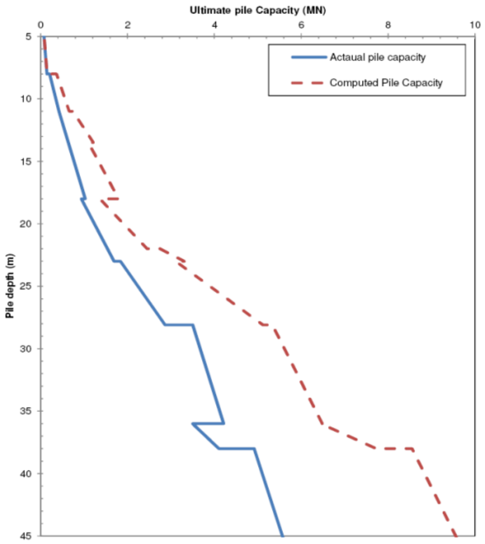

Fig. 2 Comparison of predicted and actual pile axial capacity

4 CONCLUSION

From the above two case studies, it is clear that collection of site specific soil data, execution of required tests and comprehensive geotechnical knowledge are essential for safe and economical design. In early stages of project, frequency of in-situ testing and number of laboratory tests are limited to the information necessary for deciding the feasibility of structure configuration. Additional testing shall be required at the other stages of the project depends on the design requirements. In case of change in platform location during detailed design stage due to changes in field layout or platform properties, site specific geotechnical investigation shall be carried out as a mandatory requirement. It is recommended to perform at least one borehole at the center for well head tower and two to three (center and corners) for process platforms depends on foot print of the jacket. Geophysical data of the field shall be compared with geotechnical data to check the lateral variation of the soil stratum. Geotechnical expertise is required at all stages of investigation like planning, execution and testing to optimize foundation design at later stages. To focus and optimise the geotechnical investigation, it is important to consider the prime design factors in the early investigation program. Site specific and adequate geotechnical investigation data is vital for successful completion of the project within stipulated time and budget.

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