REVIEW OF HISTORICAL JACK-UP RIG SPUDCAN PENETRATION PREDICTIONS IN MALAYSIAN WATERS

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ABSTRACT
This paper presents a summary of the performance of jack-up rig spudcan penetration predictions in Malaysian Waters over the past ten years. Measured spudcan penetrations at maximum preload from 100 jack-up rig emplacements are compared against the corresponding spudcan penetration predictions. The locations of these jack-up rig emplacements are evenly distributed between offshore East and West Malaysia. The spudcan penetration predictions, which originated from third parties and are presented anonymously, consist entirely of Class-A predictions made prior to the jack-up emplacement. A typical spudcan penetration prediction consists of penetrations based on high and low estimates of the soil strength. Both upper and lower bounds of the predicted penetrations are considered in the comparison against actual data. This work is part of an ongoing initiative to further improve jack-up rig spudcan penetration predictions in Malaysian Waters under the PETRONAS Regional Suitability Mapping project launched in 2013.

KEY WORDS: jack-up, spudcan penetration, predicted, measured

INTRODUCTION

Compilations of historical jack-up rig spudcan penetration records at a regional scale are rarely reported in the literature. More often, data from a few selected cases are investigated in detail (e.g. [1, 2]). From the operational perspective of an oil company, it is of interest to take a macro view of the performance of historical jack-up rig spudcan penetration predictions in relation to the field measurements. Inaccurate spudcan penetration predictions can lead to costly stand-by as well as unsafe condition arising from unexpected punch-through. In the absence of a company sanctioned initiative, it is difficult to compile a meaningful database of predicted versus measured spudcan penetrations. PETRONAS Carigali Sdn. Bhd. (PCSB) commissioned the PETRONAS Regional Suitability Mapping (PRSM) project in 2013 to improve on the safety and efficiency of jack-up emplacements in Malaysian Waters. As part of this initiative, measured spudcan penetrations at maximum preload from 100 jack-up rig emplacements are compared against the corresponding spudcan penetration predictions. The spudcan penetration predictions, which originated from third parties and are presented anonymously in this paper, consist entirely of Class-A [3] predictions made prior to the jack-up emplacement.

SELECTED DATABASE

The selection of sites to be included in the database is mainly driven by the completeness of the datasets. The main criterion is that the records of actual spudcan penetration and the corresponding Class-A spudcan penetration predictions must be available before a particular jack-up rig emplacement can be included in the database. As an additional check, the coordinates of the site investigation is verified against the coordinates of the jack-up emplacement. The locations of these jack-up rig emplacements are evenly distributed between offshore East and West Malaysia, as shown in Figure 1.

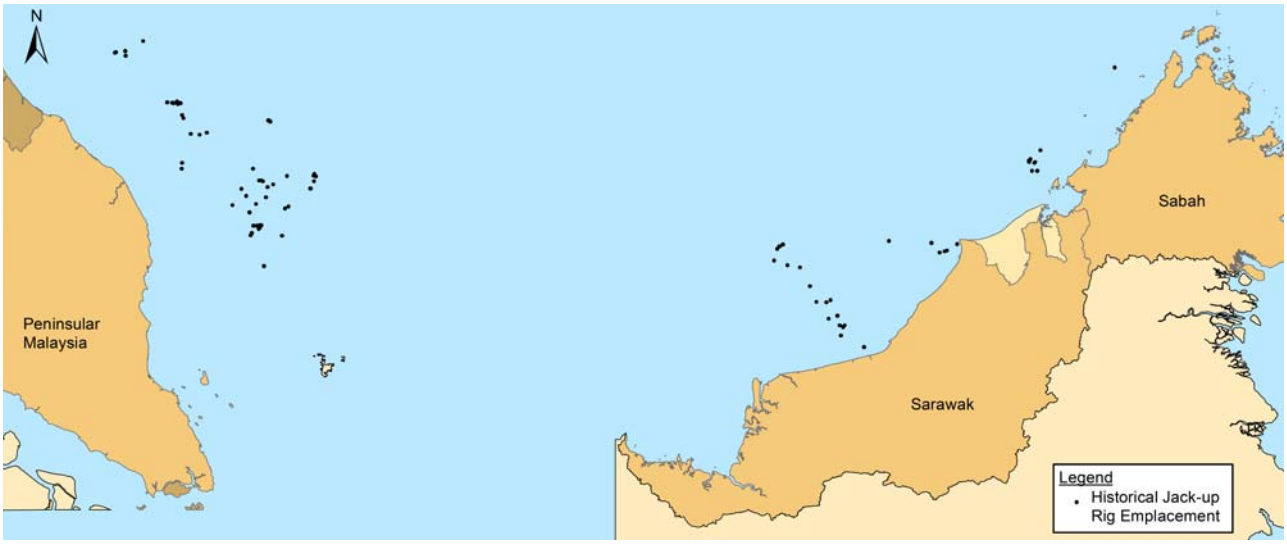

Figure 1: Location map of selected historical jack-up rig emplacements

GENERALIZED SOIL CONDITION

The following discussions of generalized soil conditions are limited to a depth of approximately 50m below seabed. For the purpose of assessing spudcan penetration, the soil condition in this depth range is of primary interest.

Offshore Peninsular Malaysia (PMO)

The soil condition offshore Peninsular Malaysia can be broadly generalized as consisting of a thick layer of clay with the presence of intermediate clay crust. As noted by [4], jack-up drilling units in South East Asia routinely encounter punch-through hazards due to peculiar conditions prevalent on the Sunda Shelf. Zones of stiff desiccated "crustal clays" formed by sub-aerial exposure are often found to be sandwiched between overlying very soft to soft and underlying soft to firm clays offshore Peninsular Malaysia.

Offshore Sarawak (SKO)

The soil condition offshore Sarawak can be generalized as consisting of interlayered clay and sand. No sizeable coral area is observed in oil and gas producing regions offshore Sarawak.

Offshore Sabah (SBO)

Similar to the soil condition offshore Sarawak, the generalized soil profile offshore Sabah consists of interlayered clay and sand. Corals are present at several oil and gas producing regions offshore Sabah. Overconsolidated clays can also be found further north of offshore Sabah.

SPUDCAN DIAMETER AND PRELOAD LEVEL

The independent leg jack-up rigs considered in this study are equipped with spudcans of 12-17m equivalent diameter. The spudcan preload pressure for these rigs ranges from approximately 350 to 500 kPa.

PROCEDURES FOR DATA EXTRACTION

Measured Spudcan Penetration Depth

The measured spudcan penetration depths were mainly extracted from the jack-up rig daily operations summary reports. In a majority of these reports, only spudcan penetration depths corresponding to the maximum preload are indicated for each of the starboard, port and bow legs. Spudcan penetration depths were interpreted as depth below mudline.

Predicted Spudcan Penetration Depth

The spudcan penetration predictions were extracted from the geotechnical engineering reports submitted by third parties. These predictions were all made prior to the rig emplacement and hence are strictly Class-A predictions. In most of these reports, upper and lower bound final spudcan penetration depths are presented and both of these values are extracted for comparison purpose. It is important to note that there exist significant differences in the basis and intent of the upper and lower spudcan penetration curves presented by different parties. The commonly adopted approach is that the upper and lower bound spudcan penetration curves were generated based on consideration of the low and high estimates of the input soil strength profile. In some cases involving marginal punch-through scenarios, the upper bound spudcan penetration value denotes the penetration depth after punching through while the lower bound spudcan penetration value corresponds to the scenario that the spudcan "hang up" without punching through. In some cases, only a single value corresponding to the best estimate of the spudcan penetration at maximum preload is presented in the reports.

RESULTS AND DISCUSSIONS

For each of the records, the predicted spudcan penetration is plotted against the measured spudcan penetration for ease of visualization. For cases in which both upper and lower bound predicted penetration depths were available, a line is used to connect between the two points representing upper and lower bound values. In order to facilitate identification of temporal trends, different symbols and colors were used to denote different time periods. The results for PMO, SKO and SBO are presented in Figure 2, 3 and 4 respectively. Two reference lines indicative of a ±10% band are also included in these figures for comparison purpose.

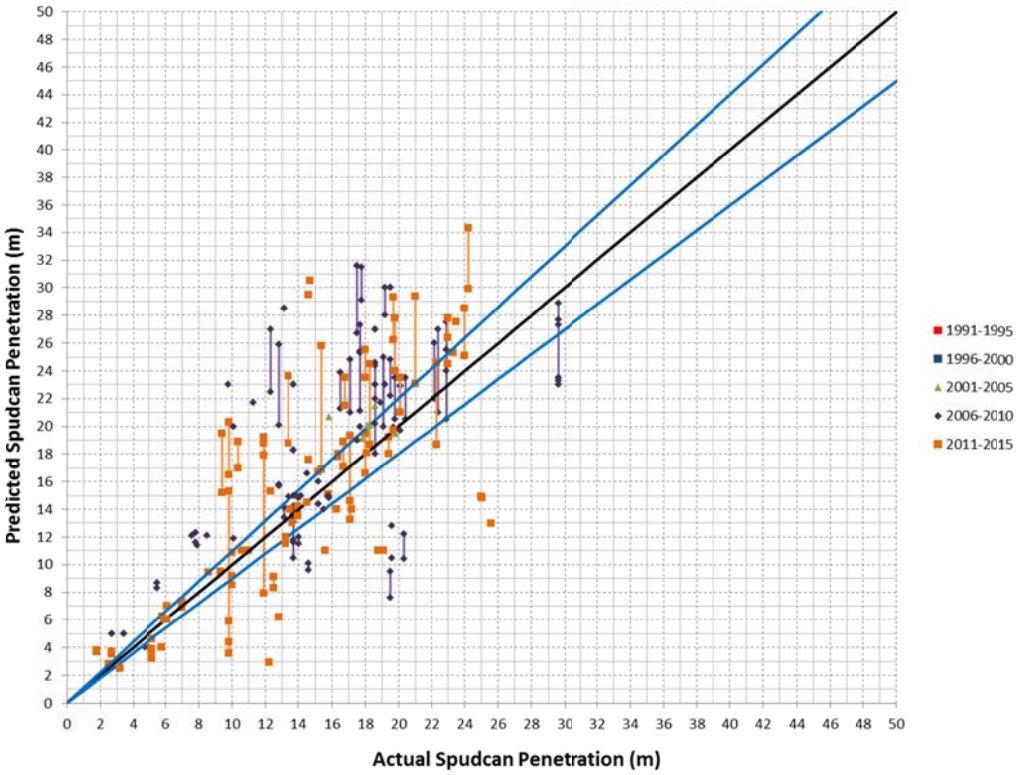

Figure 2: Comparison of predicted and measured spudcan penetration offshore Penisular Malaysia (PMO)

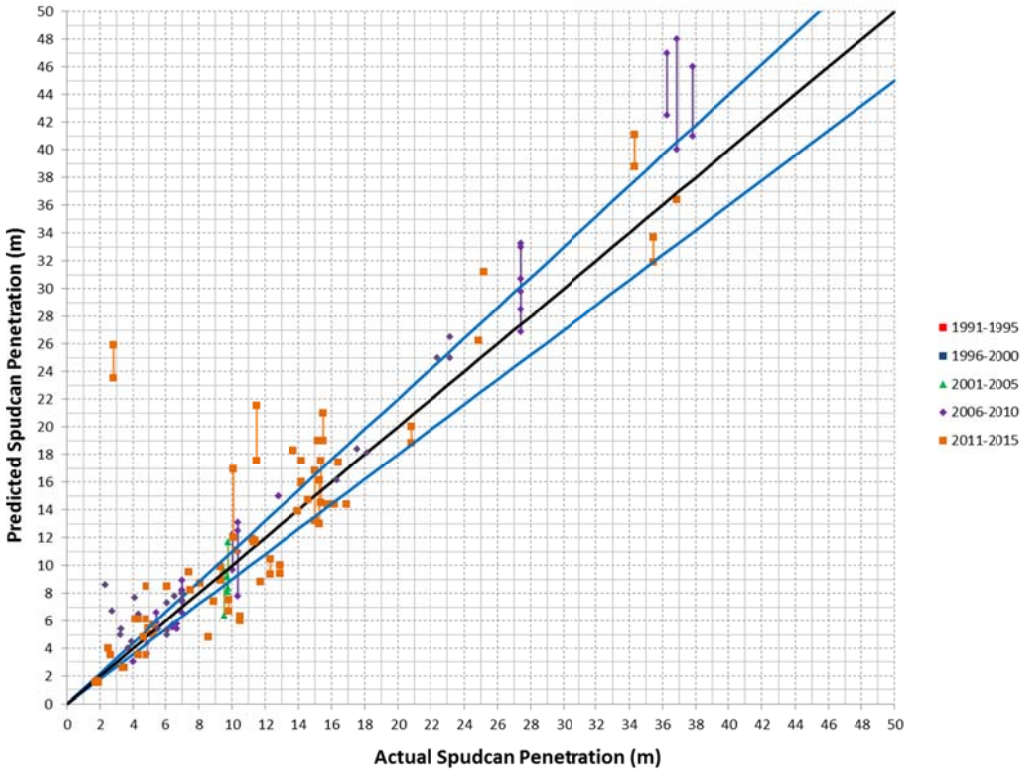

Figure 3: Comparison of predicted and measured spudcan penetration offshore Sarawak (SKO)

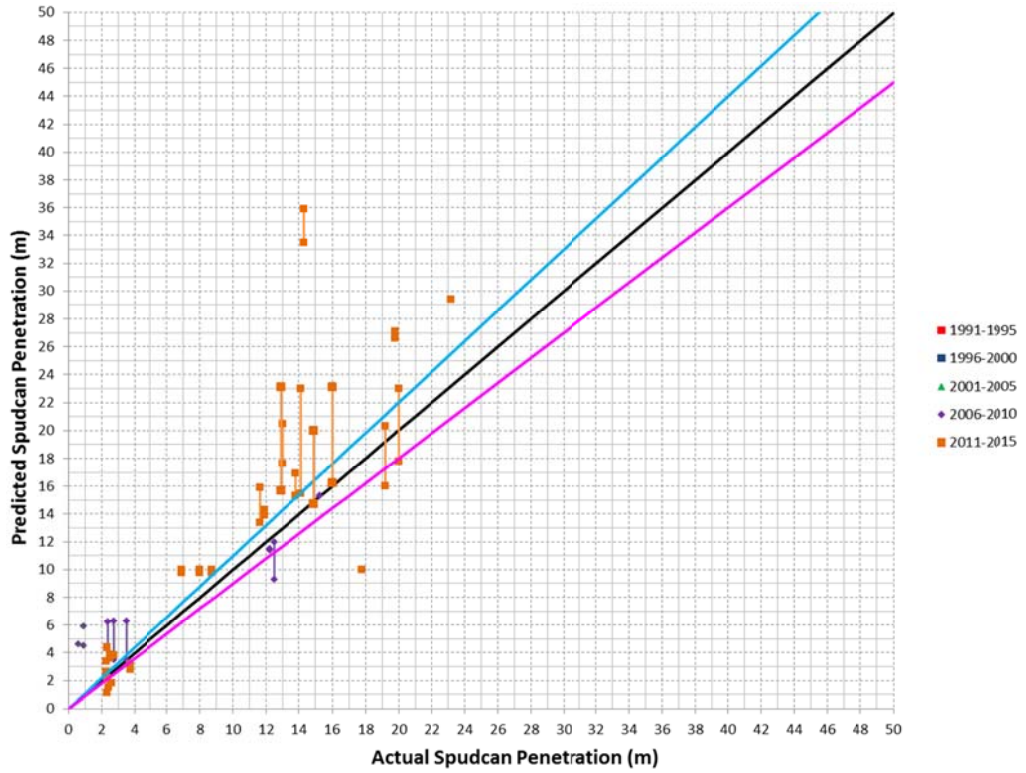

Figure 4: Comparison of predicted and measured spudcan penetration offshore Sabah (SBO)

Offshore Peninsular Malaysia (PMO)
The measured spudcan penetration depth at PMO varies over a very wide range of approximately 2-30m. Locations with very shallow spudcan penetration are associated with the presence of very stiff clay crust (>100 kPa) close to the mudline overlying a stiff clay layer. At several locations at PMO, the trend of increasing undrained shear strength with depth is found to be reversed beyond a certain depth and these locations are typically associated with deeper spudcan penetration and/or rapid leg penetration.

Offshore Sarawak (SKO)
The measured spudcan penetration depth at SKO varies over a very wide range of approximately 2-38m. Locations with very shallow spudcan penetration are associated with the presence of a thick sand layer close to the mudline. Locations with deeper spudcan penetration are associated with the presence of a homogeneous clay layer with a linearly increasing undrained shear strength of which the gradient of strength increase with depth is approximately 1kPa/m.

Offshore Sabah (SBO)
The measured spudcan penetration depth at SBO varies over a wide range of approximately 0.5-23m. Locations with very shallow spudcan penetration are associated with the presence of coral and/or sand close to the mudline. Locations with deeper spudcan penetration are associated with the presence of thick clay layers of very soft to stiff consistency. There are comparatively fewer data points at SBO as compared to PMO and SKO. Although there are overconsolidated clays, jack-up installation in such soil condition has not been reported.

For PMO, SKO and SBO, it can be observed that there are many cases in which both the upper and lower bound predicted spudcan penetration depths are outside of the ±10% band and no clear temporal trends were observed from the datasets. The range bounded by the upper and lower bound predicted spudcan penetration depths are intended to encompass the most likely range of spudcan penetration and should ideally overlap with the target ±10% band. Hence, there are scopes for further improvement to the performance of spudcan penetration predictions in Malaysian Waters.

Overall, it is apparent from this review exercise that the soil condition offshore PMO, SKO and SBO are highly variable. With such high spatial variability, it will be extremely difficult to draw on past experiences without a systematic framework. The insight gleaned from this review of historical jack-up spudcan penetration predictions in Malaysian Waters serve as a motivation to reassess and/or improve on the current practices of planning for a jack-up rig emplacement.

WAY FORWARD

In the context of jack-up operations in Malaysian Waters, the two main objectives of performing a jack-up spudcan penetration analysis are: (1) to estimate the spudcan penetration at full preload and (2) to identify possibility that one or more legs will punch through at leg loads up to full preload. With a reliable spudcan load-penetration prediction, risk associated with issues such as punch-through or deep spudcan penetration can be mitigated at the planning stage. As emphasized in [5], it is important to recognize that spudcan penetration prediction is not entirely deterministic but involves some element of judgment. For example, there are two different methods for assessing the punch-through potential of sand overlying clay soil profiles in SNAME [6] and these methods can result in different outcomes. The load spread method described in the Commentaries to SNAME (2008) further involves a parameter “n” that is suggested to vary between 3 to 5 and hence could lead to significantly different punch-through scenarios when different values of “n” are adopted.

The comparison charts presented in this paper originated from the effort to consolidate and aggregate historical spudcan penetration data. The next phase of work will involve performing detailed back-analysis based on SNAME [6] and ISO19905-1 [7] for selected cases with the aim of identifying root cause of the observed discrepancies and to determine the most applicable engineering procedure for a particular scenario in Malaysian Waters.

CONCLUSIONS

As evident from the data presented in this paper, the final spudcan penetration depths in Malaysian Waters vary over a very wide range. It is further noted that there are many cases in which both the upper and lower bound values of the predicted spudcan penetration depths are outside of the ±10% band around the measured spudcan penetration. The next phase of work will involve performing detailed back-analysis for selected cases with the aim of identifying root cause of the observed discrepancies and to determine the most applicable engineering procedure for a particular scenario in Malaysian Waters.

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