Quantification of Remeasurable Hard Strata in Pipeline Projects Using SPT before Trenching

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***Abstract*—**During the project life cycle, some quantities are not measureable exactly or reliably beforehand to tender. These quantities are termed as re-measurable quantities, which while execution of the project should measure on the case-by-case basis. Usually these re-measureable items/ quantities will be given with an assumed base-total quantity on tender documents for the bidding purpose. One such quantity is the Hard Strata found under the soil bed at locations where the propose project to be executed.

Here, a successful practical methodology adopted for finding the re-measurable hard strata quantity before trench excavation for the pipeline project for the Kuwait Oil Company's (KOC) Major Project EF1701, a 40" Gas Pipeline from Point 'A' located at North Kuwait to Mina Al Ahmadi Refinery located at South Kuwait, about 142km distance is given.

In this methodology, the site soil stratification, the hard strata, is determined using an in-situ test the Standard Penetration Test (SPT) with the criteria adopted from the KOC Standard for Geotechnical Investigation (Onshore). A generalized computation has been developed based on the SPT blow nos. got for 75mm penetration of the split spoon barrel in the bore-holes done for every 200 meter length along the pipeline centerline route. The required width and depth of the trench are fixed measurements according to the pipeline diameter to be placed with 1 meter soil cover from ground level to the crown of pipe. Only the effective depth of the hard stratum varies at the 200m interval bore-hole SPT conducted values and hence the average effective depth of hard stratum between the two bore-holes SPT conducted is calculated. Thus the total volume of the hard strata along the pipeline can be determined before the excavation of trench for the pipeline. A few assumptions are made in order to generalize the spreadsheet computation.

The data collected from 382Nos. bore-holes with SPTs carried out along the hard-stratum suspected portions along the pipeline right-of-way spanning altogether 78km, during the KOC's Major Project EF1701 is taken as an example to demonstrate in this paper. The same data has been considered for the Fiber Optic Cable (FOC) trench taken along the side of the pipeline trench with 5m distance apart, with less trench width and depth. The distance between the bore-holes can be reduced according to the site and the accuracy of the quantity calculation requirements.

***Keywords*—** SPT, Borehole, Pen Mark, Penetration

I. Introduction

SITE investigation and estimation of soil characteristics are essential parts of a geotechnical design process.

Geotechnical engineers must determine the average values and variability of soil properties. As stated by Mair and Wood (1987), in –situ testing is becoming increasingly important in geotechnical engineering, as simple laboratory tests may not be reliable while more sophisticated laboratory testing can be time consuming and costly. One of in-situ testing methods is the Standard Penetration Test (SPT). SPT is used to identify soil type and stratigraphy along with being a relative measure of strength.

SPT, developed in the United States , is a well-established method of investigating soil properties such as bearing capacity, liquefaction,…. etc. As many forms of tests are in use worldwide, standardization is essential in order to facilitate the comparison of results from different investigations, even at the same site (Thorburn, 1986). The quality of the test depends on several factors, including the actual energy delivered to the head of the drill rod, the dynamic properties of the drill rod, the properties of the soil, the method of drilling and the stability of the borehole.

According to the unavailability of equipment and also financial and time limitations in a project, in many cases various types of relationships may be needed to estimate the geotechnical parameters from the values extracted from the in-situ tests. One of these important parameters is bearing capacity of the soil which could be estimated from in –situ test such as standard penetration.

The present study area, project pipeline Kuwait, investigated, for the first time, to estimate site characterization of the site that can be used as potential input for designing structures by planner, civil and geotechnical engineers. In the present study, we have analyzed site responses of boreholes at different locations in project pipeline.

II. Background

SPT was introduced in the USA in 1902 by the Raymond Pile Company. The earliest reference to an SPT procedure appears in a paper by Terzaghi in 1947. The test was not standardized in the USA until 1958. It is currently covered by ASTM D1586-99 and by many other standards around the world (Robertson, 2006).

The Standard Penetration Test consists of driving the standard split barrel sampler a distance of 460 mm into the soil at the bottom of the boring, counting the number of blows to drive the sampler the last two 150 mm distances (to obtain the N number) using 63. 5 kg driving hammer falling free

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from a height of 760 mm (Bowles, 1977) The boring log shows refusal if 50 blows are obtained for a 300 mm increment or 10 successive drops produce no advance. SPT data have been used in correlations for unit weight, relative density, angle of internal friction and unconfined compressive strength (Kuihawy and Mayne, 1990).

Schmertman (1979) provided valuable insight into the mechanics of the Standard Penetration Test. Schmertman (1979) illustrated that the standard Penetration Test is a combination of dynamic end bearing and side resistance must be overcome in order for sampling barrel or split spoon to advance into the ground. By comparison with parallel results from a mechanical friction cone, Schmertman was able to demonstrate the contribution of side resistance and end resistance to the advance of the spoon was a function of soil type.

Zekkos et al. (2004) studied the reliability of shallow foundation design using SPT test. The results of reliability analysis show that the factor of safety approach can provide an impression of degree of conservatism that is often unrealistic. The reliability based approach provide rational design criteria, accounting for all key sources of uncertainty in the foundation of engineering process and thus should be the basis of design.

Lutenegger (2008) showed that the SPT provides three numbers that can be used to evaluate soil properties through an analysis to illustrate how the incremental blow counts may be used to obtain more information from the test.

Hooshmand et al.(2011) used SPT to investigate the strength and deformation characteristics of Tabriz marls and their stress-strain behavior were investigated by a various in-situ and laboratory tests. In order to study deformation behavior of these marls, various experiments were used such as the pressure meter test, Plate Loading Test (PLT) , seismic wave velocity test, uniaxial compression test and Standard Penetration Test (SPT).

Obeifuna and Adamu (2012) presented an assessment of the geological and geotechnical parameters in Wuro Bayare area of northeastern Nigeria. The results indicated that soils are poorly to well-sorted, soils have moderate to high plasticity, slight dry strength and are easily friable. From geotechnical analysis results, recommendations for erosion control were given, such as; construction of drainages, grouting concrete rip-raps and afforestation.

III. Criteria

As per the KOC standard for Geotechnical Investigation (Onshore) KOC-C-003 as per attachment (1) , the hard stratum is defined as natural or artificial material including rock, which cannot be penetrated except by the use of chiseling techniques, rotary drilling, blasting or powered breaking tools.

The following conditions apply as per the Clause 3.1.5 of KOC-C-003:

1. The above definition shall apply during boring using 150 or 200mm diameter boring equipment, provided that the boring rig involved is in good working order and is fully manned.
2. Under the above stated condition (1), if the boring cannot be able to proceed at a rate greater than 0.5meter per hour through the hard stratum being penetrated.
3. Under the above stated condition (1), 100mm diameter undisturbed sample tubes cannot be able to drive more than 300mm.
4. Under the above stated condition (2), a Standard Penetration Test (SPT) shows a resistance in excess of 35 blows per 75mm penetration of the split spoon barrel.

The general and the above conditions draw backs are:

a. Nobody can able to ascertain hard stratum by its look, texture & color.
b. No equipment available to scan.
c. Condition (1) depends upon the person handling, the type of machine and the machine power; which is inconsistent.
d. Conditions (2) & (3) are still inconsistent, as it depends upon the machine and difficult to ascertain a fixed depth where it started becoming a hard stratum.

Condition (4) is a consistent way, since it gives internationally accepted test method SPT blow-values carried out during borehole tests and the correct depth, which is utilized for the hard stratum datum assessment

IV. Methodology

A survey shall be conducted either by the Contractor or KOC approved third party laboratory or agency, from the permanent control points/ bench marks provided, to the pipeline right-of-way (ROW) using either Total Station or GPS instrument. The chainage marker boards shall be place at about 20m distance from the center-line of the pipeline route established. These marker boards shall be established from the starting point to the end-point of the proposed pipeline route and shall kept undisturbed/ protected up to the completion of the project. The suitable coordinates either in UTM Zone 38 WGS84 or UTM Zone 38 International Spheroid can be adopted according to the project requirement.

Then, boreholes with the SPTs shall be conducted along the pipeline center-line route established, by a KOC approved third party laboratory or agency or Contractor, at an intervals of 200meter minimum along the hard-strata suspected areas with location corresponds to the chainage marker boards established. Each borehole is named with an identifying number. The SPT is carried out in each borehole, starting from the depth of 0.5m in order to get clear from the top soil. Then two seating blows applied for the penetration of 75mm depth each by the split spoon/ barrel; consequently another four 7mm penetration blows will be counted separately. In between if at any penetration level 35 or more than 35 No. of blows reached the SPT stop, since the KOC-C-003 criteria being achieved. If not, the SPT continues from 1.0m, 1.5, 2.0 etc. from every further 0.5m depth up to 3m or 3.5m as decided in minimum to the project required trench depth plus about 0.8 to 1m further depth of borehole.

The related Borehole Log and the Pen-mark Penetration Table is prepared (please see the specimens attached for the samples taken in the 'Results and Discussion' section). The activity continues with the other borehole along the pipeline route as decided.

From the depth of the hard-stratum starting, the effective depth is calculated from the fixed project pipeline depth. Since the width of the pipeline trench is fixed and the length in between the boreholes is also known, the volume of the hard strata can be calculated by taking the average depth of hard strata between the two boreholes.

Some assumptions are made in view of practicability, which are:

a. The No. of blows for the initial two 75mm penetrations (seating blows) will not be taken into account.
b. If 35 and more No. of blows got at the start of the SPT on the initial level itself, then the effective depth of hard strata will be counted from the ground level (GL).
c. The effective depth shall be calculated up to the fixed pipeline trench formation level required.
d. If the hard stratum starting level comes below the fixed pipeline trench formation level, then the effective depth will be taken as zero.
e. The width of the pipeline trench shall be fixed according to the pipeline project requirement.

V. Site Description And Map

The State of Kuwait situated in northeastern edges of the Arabian Peninsula at the tip of the Persian Gulf. It lies between Latitudes 28O and 31O N; Longitudes 46O and 49O E. In the UTM coordinates, it lies in Zone 38 and extension.

The country is generally low lying, with the highest point being 306m (1,004 ft) above sea level and the flat – sandy desert covers most of the land. The oil fields are located in deserts, where the ground water table is much below the ground level and stratified layers of hard strata soil occurs. The world's second largest Greater Burgan oil field is situated in the southeast of Kuwait; wherein the subject methodology of determining the hard strata quantity carried-out project had taken place.

The project 40" diameter gas pipeline starts from the location named Point 'A' north of Kuwait and ends up in Mina Al Ahmadi Refinery at south of Kuwait with total 142km length of pipeline as per attachment (2).

VI. Results And Discussion

In the KOC's Major Project (EF1701) 40" Gas Pipeline from NK to MAA, three series (i.e. at three portions along the pipeline route) of boreholes with SPTs carried out on an average distance of 200m. 1st portion from chainage 10+250.000 to 52+400.000, 42.15km with 211Nos. boreholes; 2nd portion from chainage 53+100.000 to 67+000.000, 13.9km with 71Nos. boreholes and 3rd portion from chainage 111+400.000 to 132+900.000, 21.5km with 100Nos. boreholes.

A. *Results*

Case-by-case 5 typical samples are taken from the 1st portion of hard strata quantities evaluated in order to discuss the methodology and the results arrived.

For this project pipeline trench cross-section is fixed as: Width = 1.420m & Depth = 2.200m.

Sample case 1: From Borehole A34 (10+250.000) to Borehole A33 (10+450.000) as per attachment (3).

In A34 Borehole Log, it can be seen more than 35Nos. of blows (50Nos.) got at the 4th set of 75mm penetration from initial/ first SPT (i.e. SPT-1), where the required criteria for hard strata has been met. Hence, from the corresponding Pen-mark Penetration Table it can be seen the hard stratum starting depth from ground level (GL) is 0.5 + 0.075 + 0.075 + 0.075 = 0.725m. Since at the 4th set of 75mm penetration reached the required criteria for hard stratum, its penetration starting-point is taken for the start of hard stratum level. Therefore, the effective depth of hard stratum is 2.200 - 0.725 = 1.475m.

Similarly, In A33 Borehole Log, it can be seen at 5th set of 75mm penetration from SPT-1 met the required criteria. Hence from corresponding Pen-mark Penetration Table, the hard stratum starting depth from GL is 0.5 + (0.075 x 4) = 0.800m. Therefore, the effective depth of hard stratum is 2.200 – 0.800 = 1.400m.

Hence, the average effective depth is (1.475 + 1.400) / 2 = 1.4375m. Since we know the length between the boreholes from the chainage, i.e. A33 – A34 = 10450.000 – 10250.000 = 200.000m; and the width is fixed 1.420m, the volume of hard stratum will be calculated as:

Length x Width x Average Depth = 200 x 1.42 x 1.4375 = 408.25m3

Sample case 2: From Borehole A33 (10+450.000) to Borehole A32 (10+650.000) as per attachment (4).

In A33 borehole, from previous sample case 1, it is already described the effective depth of hard stratum is 1.400m

In A32 Borehole Log & the corresponding Pen-mark Penetration Table, it can be seen that hard stratum criteria has not been reached at any of the penetration levels. Hence, the effective depth of hard stratum is zero (0.000m).

Hence, the average effective depth is (1.400 + 0.000) / 2 = 0.700m. The distance between the boreholes, i.e. A32 – A33 = 10650.000 – 10450.000 = 200.000m. Width = 1.420m. Therefore, hard stratum volume is 200 x 1.42 x 0.70 = 198.800m3.

Sample case 3: From Borehole A32 (10+650.000) to Borehole A31 (10+850.000) as per attachment (5).

In A32 borehole, from previous sample case 2, it is already described the effective depth of hard stratum is 0.000m

A31 Borehole Log & the corresponding Pen-mark Penetration Table, it can be seen that the hard stratum criteria has been reached at 4th set of 75mm penetration from SPT-5. Hence, the starting depth of hard stratum from GL is 2.500 +

(0.075 x 3) = 2.725m, which is below to the trench formation level fixed i.e. 2.200m. Therefore the effective depth of hard stratum is zero (0.000m) as per the assumption taken.

Hence, the volume of hard stratum for this portion is zero [200 x 1.42 x 0.000 = 0.000m3]

Sample case 4: From Borehole A29 (11+250.000) to Borehole A28 (11+450.000) as per attachment (6).

In A29 Borehole Log & the corresponding Pen-mark Penetration Table it can be seen that the hard stratum criteriahas been reached at 3rd set of 75mm penetration from SPT-3. Hence, the starting depth of hard stratum from GL is 1.500 + (0.075 x 4) = 1.800m. Hence, the effective depth of hard stratum is 2.200 – 1.800 = 0.400m.

In A28 Borehole Log & the corresponding Pen-mark Penetration Table, it can be seen that the hard stratum criteria has been reached at the initial level, at the start of the SPT-1 itself and hence, the hard stratum starting level will be counted from the GL as per the assumption taken, i.e. zero level (0.000m). Therefore the effective depth of hard stratum is 2.200 – 0.000 = 2.200m

Hence, the average effective depth is (0.400 + 2.200) / 2 = 1.300m. The distance between the boreholes, i.e. A28 – A29 = 11450.000 – 11250.000 = 200.000m. Width = 1.420m. Therefore, hard stratum volume is 200 x 1.42 x 1.30 = 369.200m3

Sample case 5: From Borehole A21 (12+850.000) to Borehole A20 (13+050.000) as per attachment (7).

In A21 Borehole Log & the corresponding Pen-mark Penetration Table, it can be seen that the hard stratum criteria has been reached at the initial level, at the start of the SPT-1 itself and hence, the hard stratum starting level will be counted from the GL as per the assumption taken, i.e. zero level (0.000m). Therefore the effective depth of hard stratum is 2.200 – 0.000 = 2.200m.

Similarly, in A20 Borehole Log & the corresponding Pen-mark Penetration Table, it can be understood the effective depth of hard stratum is 2.200m.

Hence, the average effective depth is (2.200 + 2.200) / 2 = 2.200m. The distance between boreholes, i.e. A20 – A21 = 13050.000 – 12850.000 = 200.000m. Width = 1.420m. Therefore, hard stratum volume is 200 x 1.42 x 2.20 = 624.800m3, which is the section full volume.

B. Spread-sheet computation

All the data collected is entered into a formulated spread-sheet as shown on attachment (8). The boreholes designations and the initial 'from' & 'to' chainages of the boreholes are entered in their respective columns on the spread-sheet. After that, 'to' chainages of the boreholes should be entered since the 'from' chainages are automatically (formulated cells) populated in the spread-sheet. The hard stratum starting depth from ground level for the 'from' & 'to' boreholes shall be calculated from the respective Laboratory prepared Borehole Log and the Pen-mark Penetration Table and entered into the respective columns of the spread-sheet. The rest of the columns are been formulated to give the results up to the volume of that section. All the section volumes are added up automatically to give the grand total at the end of the spread-sheet.

The portions where there Main Road Crossings using the methods Horizontal Directional Drilling (HDD) and Micro Tunneling (MT) met with hard stratum, were calculated separately and entered into the spread-sheet at their respective chainage position columns.

Further columns can be added for the site verification checks to be carried-out during the actual excavation carry out.

VII. Improvisation

During SPT conducting, there may be chances to have small stand-alone boulders or other artificial blocks to come across the penetration path of the split spoon/ barrel sampler. This can be seen by the sudden big difference on the No. of blows recorded. In order to avoid or improve on these cases, the following assumptions can be included –

(a) If soft stratum found below the hard stratum with a difference of 5 No. of blows or less, then the effective height will be taken from the initial hard stratum found.

(b) If soft stratum found below the hard stratum with the difference of more than 5 No. of blows, then it will be discarded.

Sometimes the hard stratum starting level will come below to the project trench formation level. For example, please see figure (1) & (2) below, let the starting depth of hard stratum at borehole A be 1.00m from the ground level (G.L) and that at borehole B is 2.80m, which is below the pipeline trench formation level of 2.20m. Let the red marked curved line will be the original hard strata profile at site.

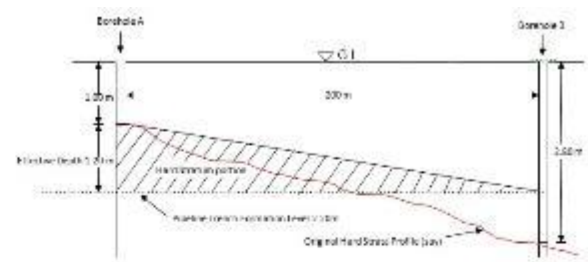

Figure (1)

In fig. (1), by the method adopted, the effective depth of hard stratum at borehole B will be zero. Hence, the cross sectional area (slant lines marked/ shaded) will be more; wherein the chances of hard stratum occurrence is less.

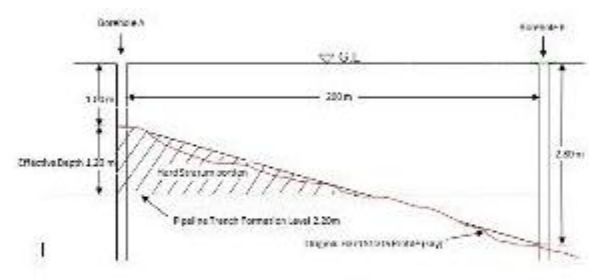

Figure (2)

In fig. (2), if the actual depth of the start of hard stratum is considered at borehole B, then the cross sectional area (slant lines marked/ shaded) will be comparatively less; wherein the chances of hard stratum occurrence is more

Therefore for this SPTs should be conducted further below the project pipeline trench formation level as decided based on the accuracy required and improvisation can be made by giving conditions for this.

VIII. Discussion

The site verifications were carried-out during the project execution stage with the plus (+) or minus (-) quantities on the suspected portions, agreed between the Contractor and the Company authorized representatives. The variations came below 10% of the estimated total volume and hence the accuracy of the methodology was more than 90%.

IX. Conclusion

The methodology adopted in EF1701 project is found practicable with an accuracy of about more than 90% as evident from the site verifications done while executing the trench excavations on the concerned hard starta areas along the pipeline route. Improvisations can be made as described above from the lessons learned from the project. The following merits foresight by adopting this methodology:

1. A reliable quantity for hard strata is obtained before the actual excavation of the pipeline trench
2. A baseline quantity or depth will be available to verify at site while the excavation of trench for the pipeline takes place.
3. Later disputes with Contractor can be avoided.
4. A well-defined procedure can be developed which can put in to the contract documents.

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