International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

Site Investigation Techniques for Ground Improvement.

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Abstract*: *The paper explains a brief about the different methods which are currently being used for the purpose of Geotechnical Site Investigation. Further, a descriptive literature review has been done of about the use of different geotechnical site investigation methods in ground improvement. Six different studies have been considered with different purposes, methods and assumptions. The first study deals with the static probing method used to determine the load bearing capacity using the resistance parameter obtained from the test. The second study signifies the use of CPT for determination of liquefaction hazard induced due to an earthquake. The third study gives us a good distinction between the SBP and CPT on the basis of case studies at different locations. The fourth study is about the use of different geophysical exploration used at an earthquake affected site in Sikkim region of India. The fifth study emphasizes the use of geophysical exploration for evaluation of soil profile. The last study is about development for a new method for data interpretation from a boring log.
Keywords: Probe method, Borehole method, Geophysical exploration, CPT, DMT, MASW, GPR, and ERI

I. INTRODUCTION

Geotechnical site investigations are usually carried out to determine the specific properties of soil, which will further aid us in modelling the soil data, designing foundations, structure and also make many facts about the sub-surface clearer to us. Site investigation can be broadly classified into two categories Lab Test (In this type of investigation soil samples are collected from the site and then transported to the lab for the further test procedure) and In-situ Test(In this type of test the soil is tested on the site itself). In this work, we will be taking a close look at the In-Situ methods of Geotechnical Investigation. In-Situ testing can be further classified into three sub group namely Borehole Methods, Probe Methods, and Geophysical Exploration.

A. Probe Methods

The Probe methods are also called as Direct Push Methods as the test instruments are directly pushed into the ground to get theessential information about the ground. DMT, SBP, CPT, SCPT, SDMT are some of the methods for the Probe testing. The only difference between a CPT and SCPT or between DMT and SDMT is just that CPT and DMT are normal tests while SCPT and SDMT also check for the seismic effects. Thus, the combination proves to be a tool of great value. We need to understand one thing that the ground is complex material and there are many variables of uncertainties associated with it. Hence, no single test is ever sufficient to determine the characteristics of the soil. We often have to perform different tests for the exact same parameter. This is because of the uncertainties involved which always push us to look for a range of answers which could be right.

CPT or the Cone Penetration Test was developed in early 1930 in Holland and is also known as the Dutch Cone test. They usually range from $10cm^2$ to $15cm^2$ in cross sectional area i.e. approximately 3.6 to 4.4cmin diameter. The assembly consists of a Cone at one end, from this end the cone is pushed into the ground. The cone is followed by Friction sleeve. Some instruments have a pore pressure filter embedded into it at different positions to measure the pore pressure u_1, u_2 and u_3. The u_2 is the most preferred type. As said earlier that we deal with a lot of uncertainties and thus there are always some corrections that we need to apply to the results obtained from this test. The modern-day technique has the cone penetrometer attached in a truck which goes over the ideal location and inserts the penetrometer in the soil. A computer system is attached to Penetrometer basically measuring the resistance met by the instrument and thereby giving us the material properties. It can be used at sites susceptible to Liquefaction.

The DMT or Flat Dilatometer Test. It was used in Italy and is now being used worldwide. Its assembly contains a steel blade which holds an expandable circular steel membrane. The diameter of the membrane is 0.6cm and width is 0.95cm. In this method, thrust is being measured at the test depths. The test depths maybe at a spacing of 20 cm. The measurements are done by inflating the membrane and making two readings: (i) the pressure required to just begin to move the membrane against the soil "lift off", and (ii)

the pressure, required to move the center of the membrane 1.1 mm against the soil. Data interpretation is done from the above parameter and can be used in determining soil properties.

B. Geophysical Methods

Geophysical methods can sometimes be invasive or non-invasive in nature. These methods can be broadly classified as wave propagation methods, resistivity methods and case studies. We will be studying Wave propagation method in depth. Basically, waves propagate in two ways they are Body waves (these are the ones which travel into the soil) and Surface waves (these are the ones which travel along the surface of the soil). We need to understand some common term in the context of waves, which are like wavelength, frequency, amplitude, etc. Further, these mechanical waves are also classified as compression waves – These waves are like sound waves propagates with compaction and rarefaction, shear waves – these waves tend to move normal to the soil skeleton, surface waves(love waves) – mostly are parallel to medium and Rayleigh waves – both horizontal and vertical motion, waves tend to move cyclically.

There is also a method that involves boreholes in it which is sort of an invasive method. This method makes use of Geophones to transmit signals. Many invasive methods are there to investigate soil e.g. the cross hole, Downhole, P-S suspension, Direct push cross hole. Surface waves, these waves also have three different types namely spectral analysis of surface waves, multi-channel analysis of surface waves and micrometric array. Wave generation is mostly accomplished using vertical vibration. These vibrations can be sourced from a hammer, drop weight, vibrator, rolling bulldozer. With varying frequency and wave-length we can figure out many different properties from the soil during the test.

After the test, we get many shear wave velocity profiles which we can use for data interpretation. We have to be very cautious with the data interpretation as there are many uncertainties involved in the test which can be accomplished by the use of automatic inversion to make the results more accurate.

C. Borehole Methods

Boring is yet another type of invasive method used in the sampling of rocks. Common methods for advancing bore holes are Auger boring, auger & shell boring, wash boring, percussion boring and rotary drilling. In accordance with the type, size and weight of the structure the spacing of boring and number of bore holes can be selected. The depth of boring is also an important aspect which is governed by the type of proposed structure. A record of boring operations has to be maintained which is a typical report called as "boring log"(Venkatramaiah, 2017).

II. LITERATURE REVIEW

A. Study showing use of different probing methods.

The precision in measurement and reliability of results related to static probing test are very efficient and of an epitome importance in the design procedure. Continues research is being carried out in the direction of the static probing method which is thereby inducing much more reliability and accuracy in the probing method of site investigation(Kozłowski & Niemczynski, 2016). The author used all the static probing methods to estimate the load bearing capacity of ground. He further states that the results obtained from the penetrations tests are the basic parameter to derive the load carrying capacity of pile foundation. The results obtained from the probing test were used to determine the load bearing capacity which was evaluated using different methods like Dynamic load test, EUROCODE 7, Bustamante and Gianeselli, and PN-83B-02482. The calculations from all mentioned test have been compared with the values obtained from the archival engineering and geological test using the method given in PN-83B-02482. The extent of suitability of different methods of site investigation has been summarized in the paper.

Table 1. Shows extent of suitability (A-high, B-medium, C-Low)(Kozłowski and Niemczynski 2016)

Test	Soil type	Geological profile	u	∅	Su	ID	c_v	k	G_o	σ_h	OCR	σ-ε
CPT	B	A	-	C	B	A/B	-	-	B	B/C	B	-
SCPT	A	A	A	B	B	A/B	A/B	B	B	B/C	B	C
DMT	B	A	C	B	B	C	-	-	B	B	B	C
FVT	B	C	-	-	-	-	-	-	-	-	C	B
SPT	A	B	-	C	C	B	-	-	C	-	C	-
DP	C	B	-	C	C	B	-	-	C	-	C	-

The results of the tests show bearing capacity estimated from different test using he data obtained from probing method was very similar. Also, the probing methods are now being used worldwide and follow pretty much same standards. There are many facts which make this test better than other site investigation test like it gives a continuous ground profile characteristic, it is conducted in natural state thereby giving more accurate results as the sample is not moved anywhere from the site. Thus, the method of probing will be the most trusted method in the field of site investigation(Kozłowski & Niemczynski, 2016).

B. Study showing use of probing methods in liquefaction analysis.

Liquefaction is a consequence which is induced by an earthquake. Liquefaction is the phenomenon in which total stress becomes equal to the pore water pressure thereby resulting in the effective stress to be zero. This condition leads the soil to be loosely packed and does not have any shear strength(Sarah & Soebowo, 2013). The event of liquefaction leads to lateral spreading, settlement, and loss of load bearing capacity of soil causing building instability. The Yogykarta earthquake of a magnitude of 6.2 occurred on May 27, 2006 which induced the phenomenon of liquefaction at many places. Liquefaction occurred near the Opak fault area. A series of cone penetration test and drilling was done to carry out a geotechnical investigation. Analysis of liquefaction potential was done using CPT data with Robertson and Wride (1989) method. Results of the analysis proved that there were potential Settlement and Liquefaction. The settlement was also observed from 0.2-12.98cm. The results confirmed the occurrence of liquefaction which was also supported by sand boils, lateral spreading, sand covered dug wells and settlement. Liquefaction caused a lot of damage to infrastructure during the Yogyakarta earthquake in 2006. CPT was carried out to analyze the effect of liquefaction and its distribution pattern. It also highlighted that there was an alluvial and lahar layer for a depth of 20-200m and water tables are shallow. Hence, probing methods prove to be very useful in areas susceptible to an earthquake to overcome the losses which may be caused under the action of potential liquefaction.(Sarah & Soebowo, 2013).

C. Comparative study between CPT and SBP (Probing methods).

The CPT is an easy, inexpensive and accurate test but does involve certain uncertainties whereas the SBP have vice-versa performance history(Ghafghazi & Shuttle, Dawn, 2008). The paper compares the estimates of the in-situ state parameters of soil obtained by CPT and SBP. In cohesionless soils the relative density is a very important aspect which cannot be determined by any of the above tests as it's difficult to find the max and min void ratio values. CPT was performed at 38 different locations at an interval of 1-2m whereas SBP was done at 16 locations. The type of soil which was under test was Erksak sand. After the tests, the results of CPT test showed a slight inconsistency in a range of 0.026 to 0.065 and the inconsistency range for SBP was 0 to 0.05. Although the value may be small in SBP as compared to that of CPT it does not mean a lot variance. CPT is very easy to perform but have to take considerable care while making data interpretations. On the other hand, SBP is tedious to perform but the analysis is a lot straight forward. Therefore, the conclusion for the above experiment is that both the test proved to be very good in terms of achieving results and that also at a very acceptable consistency level. And the difference between results may just be because of difference in geometry corrections applied to correct consequences of restrained pressuremeter length.(Ghafghazi & Shuttle, Dawn, 2008).

D. Study focusing on different geophysical tests.

In 2011 earthquake of magnitude Mw 6.9 hit Sikkim, one of the north-eastern states of India. A detailed geotechnical investigation was undertaken at the site affected by the impact which included a distressed pavement, a school building and secretariat building. Field observation and surface wave testing was done with MASW and GPR(Anbazhagan and Murali Krishna 2012). The distressed pavement was located at 1km away from Tashi view point towards Ganeshtok. The MASW test showed that the layer of soil between the base hard rock and road pavement experienced loss of strength due to cyclic loading which was the major cause of the pavement distress. The conclusion was made using the test data from the MASW test which showed 350m/s shear wave velocity near the pavement and just 200m/s shear wave velocity in the layer below pavement.The pavement was placed on a natural slope which also encountered slope failure due to cyclic mobility and resulted in slip movement. The above analysis was also cross checked with a GPR radargram which gave similar results. The school building was located near the Upper Dzonga region in North Sikkim here settlement and tilting was observed. During the investigation, it was confirmed the school building was standing over a lake which was filled for construction purpose. The MASW showed very low shear wave velocity below the school building and from the GPR radargram it was confirmed that there was presence of loose soil at 5m depth below the school building. Boreholes was also drilled and sample was collected which was further tested in lab. The soil was found to be of SP (poorly graded sand) type. The subsequent settlement was a result of liquefaction. The secretariat building was constructed according to the seismic code hence

the five storey building survived the earthquake but a major damage was encountered to the structural members. According to the MASW test it was observed that for the first 3m depth below the building gave very low shear wave velocity of magnitude 180m/s which was followed by a medium dense soil layer giving shear wave velocity 320m/s and then the bed rock. Similar result was from the GPR radargram which is presence of loose soil.(Anbazhagan and Murali Krishna 2012).

E. Comparative study between geophysical method, boreholes and CPT.

For design and construction of any structure we have to get a sound knowledge of the engineering properties of the ground(Groves, Cascante, Dundas, & Chatterji, 2011). In this work, different types of geophysical explorations were used to determine the properties of soil. Mainly MASW, ERI and SR was performed and compared. Further, the results obtained from the geophysical test were cross checked with results from boreholes and cone penetration test. Three geophysical test used namely electric resistivity imaging, seismic refraction and multi-channel analysis of surface waves gave accurate results about the ground stratigraphy. The ERI method proved to be the most effective as it gave the perfect depth of the glacial till ranging from 4.6 to10.7m across the site. The SR results overestimated the depth of glacial till by up to 4m. The MASW results were less accurate as compared to ERI but it was successful in identifying the three distinct layers of soil. On comparing the results from the geophysical test to the results from boreholes and CPT it was found that the results were more or similar.

F. Comparative study of oriented core and imaging method of borehole data interpretation.

The presentwork focuses on the merits and demerits of data collection associated with boreholes by the imaging technique over the traditional oriented core technique. Case studies were done to compare traditional method and imaging method of data collection. Borehole tele-viewer was first developed by Mobil in the 1960s. Over the course of time, this technique was mostly used by the petroleum and mining industry. With the passing decade, the technology has encountered massive changes and recently is used across many engineering fields, including geotechnical engineering. An extensive research was carried out using case studies from Papua New Guinea exhibiting low rock strength and faults another from Australia exhibiting high strength granite-hamitite.

Table 2. Issue with collection of structural data from boreholes. (Weir, 2015)

Issue	Relative Importance to hard rock	Oriented Core (OC)	Borehole Imaging using ATV/OTV
Core Loss	High	Issue	No Issue
Accuracy of Measurement	High	Issue	No Issue
Inexperience Handling	Medium	Issue	Issue
Lack of continuity of coverage	Medium	Issue	No Issue
Reference line error	Medium	Issue	No Issue
Orientation bias – hole parallel	Low	Issue	Issue
Orientation bias – hole normal	Low	No Issue	Minor Issue
Classification	Medium	No Issue	Minor Issue
Magnetic effects	Low	No Issue	Issue
Image artifacts	Low	No Issue	Minor Issue
Defect visibility	Low	No Issue	Minor Issue
Depth of defect	Low	Minor Issue	Minor Issue
Time effort of data collection	Low	Minor Issue	No Issue
Data volume	Low	Issue	No Issue

ATV: Acoustic tele-viewer; OTV: Optical Tele viewer(Weir, 2015)

From the case studies undertaken at different sites we can comment that the imaging technique can have many advantages over the traditional oriented core method of data interpretation. But, the use of imaging method of data interpretation is associated with some limitation such as linear sampling technique and the continuity and large-scale shape of structures cannot be assessed.

III. CONCLUSION

The findings from the above literature review can be concluded as geotechnical site investigation is a very useful in assessing the ground conditions. Different methods are available for the purpose of ground investigation. The probing method of ground investigation can provide us with continues ground profile. Further, the test results obtained are more accurate as compared to that of boreholes methods as soil is tested in its natural state. It also helps in identifying true characteristics of soil such as strength and deformation parameter. The actual reflection of ground geology also helps in cost optimization of projects keeping in mind structural stability. But still the probe methods are invasive method and do tend to disturb the soil and data obtained contains uncertainties. One of the above studies is related to the comparison between two probe methods which signifies that there can be substantial difference between same type pf test also. Further, data interpretation from such test requires skills as the only parameter we get from such test is the resistance experienced by the probe from which we deduce the soil properties. These types of test can be not only being used to determine soil properties but also to check whether the soil is liquefiable or not under cyclic loading conditions induced due to earthquakes. The geophysical exploration is one the most modern technique of which is used in the field of site investigation. These methods are non-invasive and do not disturb the soil skeleton under any circumstances hence, the results from this test are the most accurate. The performance of the test is a bit tedious task as it requires a lot of precautions to be undertaken to obtain precise results.Future scope for these geophysical tests will be to introduce the test like response analysis and dynamic test to combine together and give even more precise results. Boring method is an old method od site investigation and involves soil sample to be replaced from the site to laboratory for testing. During this transit period soil may undergo certain changes and the results obtained would not be that accurate. Therefore, new methods like imaging technique which is discussed in the literature should be developed for a more precise understanding of soil properties. A comparative study between all the techniques is also represented in this work through which it is clear that using any technique you can get more or less similar results. Hence, no such claim can be made whether which of the methods is better.

Finally, new techniques such as geophysical exploration of ground investigation should not be allowed to out-date the old techniqueslike boreholes. Instead, a combination of test should be performed to be more accurate with the results.

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