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A meaningful correlation between shallow seismic refraction data to borehole data in site investigation work

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Abstract: In site investigation work the subsurface characteristic is mainly determined from boreholes data such as the bore log, standard penetration test and other suitable test. Surface geophysical survey including seismic refraction has been routinely used to compliment the borehole data. In many small scale site investigation boreholes are made mainly using the wash boring method and are normally very shallow. The standard penetration test value N = 50 is used to end the borehole and it occurs normally within the weathered zone or above the bedrock surface. The seismic work determines the depth and characteristic of the bedrock as well as the strata above the bedrock. The seismic refraction data is compared to the boring data and often used to extrapolate the subsurface condition between the boreholes. Correlation of seismic refraction data to wash boring data is often difficult because the wash boring bore log description is mainly grain sized based and not lithological based. Comparison to both the bore log and the standard penetration test values allows a better correlation. In addition, at the shallower level the Mackintosh probe test value and the water table has been used. The two sites studied show that comparison of the seismic refraction data to an integrated data gives a more meaningful and useful correlation.

Abstrak: Dalam kerja penyiasatan tapak ciri ciri subpermukaan biasanya di tentukan dari data lubang bor termasuk log lubang bor, ujian tusukan piawai atau dari ujian ujian lain yang bersesuaian. Survei geofizik permukaan termasuk seismos biasan selalu di gunakan bersama dengan lubang bor. Dalam penyiasatan tapak skala kecil pengrudian biasanya mengunakan kaedah pemboran basuhan dan hujung lubang bor biasanya cetek sahaja. Nilai ujian tusukan piawai N = 50 digunakan mengakhiri pemboran dan biasanya ia berada di zon luluhawa dan di atas paras batudasar. Kerja seismos biasan menentukan kedalaman batudasar dan ciri strata di dari batudasar. Data seismos di bandingkan kapada data lubang bor dan biasanya di gunakan bagi menganggarkan ciri subpermukaan antara lubang bor. Pengkaitan antara data seismos kapada data lubang bor dari pemboran basuhan sahaja biasanya sukar kerana penerangan log lubang bor dari kaedah ini adalah berdasarkan kapada saiz butiran dan bukan litologi. Perbandingan data seismos kapada data lubang bor bersama nilai ujian tusukan piawai memberikan perkaitan yang lebih baik. Pada kedalaman cetek perbandingan juga di buat kapada uji prob Mackintosh dan aras air tanah. Kajian di dua tapak menunjukan perbandingan data seismos kepada data bersepadu lubang bor dapat memberikan perhubungan yang lebih bermakna dan berguna.

INTRODUCTION

In site investigation work for infrastructure such as for housing development, road, water tank site and others, the subsurface characteristic is mainly determined from borehole data such as the bore log, cores, disturbed and undisturbed samples, and down hole analysis. Surface seismic refraction survey which determine the subsurface characteristic from measurements on the surface (Samsudin and Ahmad Nizam, 2001), however, has been used as a rapid tool to determine the characteristic of the subsurface and has been routinely used to supplement the borehole data. In some cases the seismic work are carried out as the first phase of the site investigation work and used to plan for the boring program.

In many small scale site investigation boring program, beside the description of the drilled material (bore log), the result of the standard penetration test (SPT) and the Mackintosh probe test are used as the quantitative measure of the subsurface characteristic. Borehole and Mackintosh probe information are point information and the coverage of the boreholes within the investigated area are often sparse generally due to cost constrain. Therefore, the seismic refraction survey, which provides data along a profile, can be used to correlate the subsurface characteristic between boreholes besides providing data rapidly at a relatively low cost. However, correlation between borehole data (the SPT value and bore log) to the seismic data is sometime difficult. This paper present result from two areas in which the SPT, Mackintosh probe blow value, bore log and seismic data have been obtained. These data combined provides better correlation so that the seismic velocity values obtained from the shallow seismic refraction survey can be of quantitative value thus enhancing the use

of the seismic refraction work.

THE STUDY AREA

The two areas studied are Shah Alam, and Sungai Buloh, Selangor. The Shah Alam site covers an area of about 200 meters by 50 meters (Fig. 1) while the Sungai Buloh site covers an area of about 200 meters by 400 meters.

The Shah Alam site is a very flat area. The site is bordered by a steep down slope on one of its long side. The ground level difference is about 3.5 meters. On this lower level at about 20 meters away from the border is the north-south railway track. Away from the railway track the ground slopes to a lower level. The other long side borders a main road. The short sides both border a main road and a laterite road respectively. An eleven-story multi purpose building has been proposed on this site.

The Sungai Buloh site is an undulating area (Fig. 2). A small part of the site has been used as fill area and the remaining is basically a grassland and shrub land. A small stream runs through the area. A mixed development of high and low-rise building has been proposed for this area. The area is bordered by building or areas being developed for building.

GEOLOGY

In both of the sites no rock outcrop can be found. For the Shah Alam site a road cut near the area indicates that the area is probably underlain by sedimentary rock. Across the main road bordering the long side of the site a trench of about 3–4 meters deep indicates that the material is weathering product of sedimentary rock. Relic of bedding plane and fracture system can still be observed.

In the Sungai Buloh site the rock underlying the areas may be a mixture of sedimentary and igneous rock. The sedimentary is inferred from the excavation work at about 500 meters away from the site. However, two of the boreholes end on granite rock. It is probable that a sedimentary rock is intruded by a younger intrusion that is the granite, while being overlained by alluvial and weathering material. The alluvial material including river terraces can be observed along the stream bank and cutting.

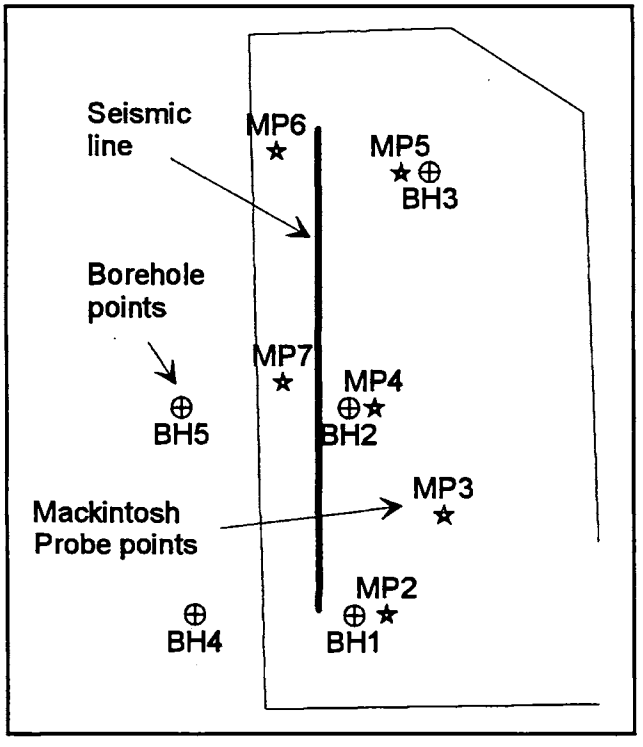

Figure 1. Shah Alam site showing location of the boreholes and the Mackintosh probe points with respect to the seismic line (110 meters). The horizontal axis scale is twice the vertical axis scale.

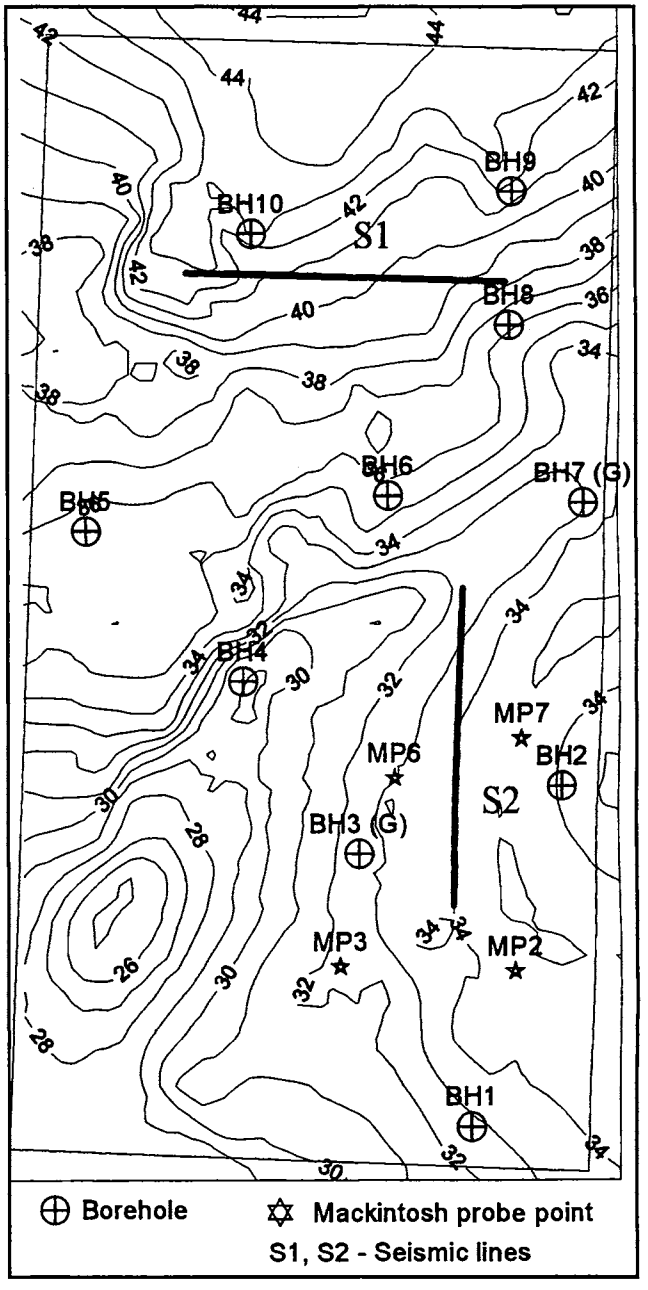

Figure 2. Map of Sungai Buloh site showing the location of the boreholes and Mackintosh probe points used in the study.

INVESTIGATION METHOD

In carrying out site investigation some of the data acquired include bore log, standard penetration test (SPT) value generally known as N value and Mackintosh probe values given as number of blows per distance. In many of the small-scale site investigation work, the seismic refraction survey is carried out in addition to these tests as done in these two sites.

Boring

The boring has been carried out using a multi speed-boring machine with mast. Wash boring method was used with water as flushing medium to advance the borehole. The fragments of material brought to the surface by the flushed water are used to determine the type of material being penetrated. Samplings are also carried out at regular depth interval.

Five boreholes have been made within the Shah Alam site. The boreholes within the site area are BH1, BH2 and BH3 are aligned along the elongation of the site (Fig. 1). The other two boreholes are on the railway track platform. Two example of the bore log data from BH2 (Fig. 3) and BH3 (Fig. 4) are given. The SPT test result are also given for all the five boreholes. A number of the Mackintosh probe test has been carried out and the result from the points near the bore holes and seismic line are used in this study.

The Sungei Buloh site map shows the contour lines, location of the seismic lines; SPT points and the Mackintosh probe points. In the Sungai Buloh site ten boreholes have been sunk named BH1 to BH10. They are quite evenly placed within the site. Two of the boreholes, which end on granite rock, are BH7 and BH3.

Standard Penetration Test (SPT)

SPT was carried out at an interval of 1.5 meters during the drilling by driving a 50 mm diameter split spoon hammer into the subsurface. This is done using a 65 kg hammer falling freely over a height of 760 mm. The number of blows for the initial 150 mm was recorded as seating blow. The number of blow for the following 300 mm penetration was recorded as the N value (or the blow count) of the strata penetrated. The number of blows is recorded for every 75 mm penetration throughout the 450 mm penetration.

Mackintosh Probing Test

The standard JKR probing equipment and procedure has been used. The test is carried out by dropping a 5 kg hammer from a height of 300 millimetres on to a standard penetrating rod set, placed on the ground. This is termed as a blow. The strength of the ground is measured by the resistance of penetration as given by the number of blows to penetrate the ground to a length of 300 millimeters. The probing exercise is terminated when the number of blows reaches 400 for any 300 millimetres penetration length or less. In both sites the Mackintosh probing test points are evenly distributed over the entire area. Only Mackintosh probe points near the borehole and the seismic lines are used in this study.

Seismic Refraction Survey

The seismic refraction survey has been carried out using a 24-channel seismograph and 5 meters geophone spacing. A 14-pound hammer has been used as the vibration source. With 24 geophones at 5 meters interval, a seismic spread is 115 meters long. Within this 115 meters spread, five-impact point has been used. This is sufficient to enable fairly accurate velocity determination along the spread and depth calculation at every geophone points. In the Shah Alam site seismic data has been obtained on one seismic spread while the Sungai Buloh site, on two seismic spreads. Procedure like the plus-minus and delay time method (Redpath, 1973) can be used to interpret the seismic refraction data.

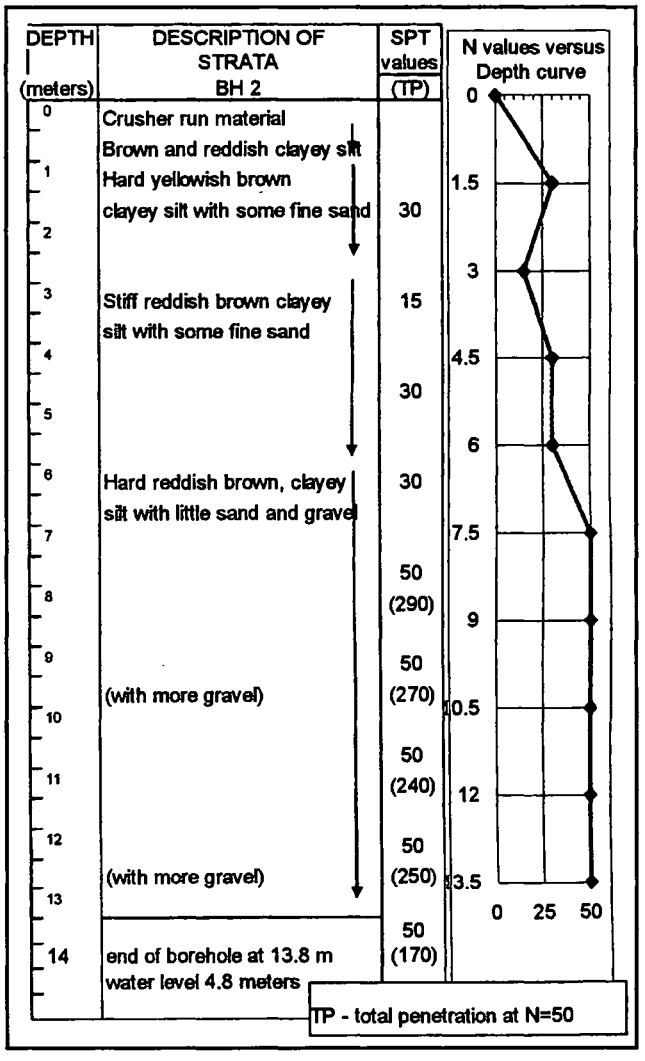

Figure 3. Bore log for BH2 from Shah Alam site. It has description of the bored material and the SPT value.

PLACEMENT SEISMIC LINES

In both of the site the boring has been done first. The seismic survey has been carried out to help solve some specific interpretative problem related to the borehole data. In the Shah Alam area the seismic line was placed along the alignment of the three within site boreholes. One of the problem here is that the SPT values before reaching N = 50 in BH3 are relatively low compared to the values in other boreholes. The seismic survey is an attempt to help identify this anomaly. Another problem at this site is that the SPT N = 50 value is reached at a relatively shallow depth and this depth is just slightly below the railway level platform. Furthermore the bedrock information is not available from the borehole and has been determined using the seismic method. The additional seismic data can help in determining the type and depth of piling to be applied to build the eleven storey high building.

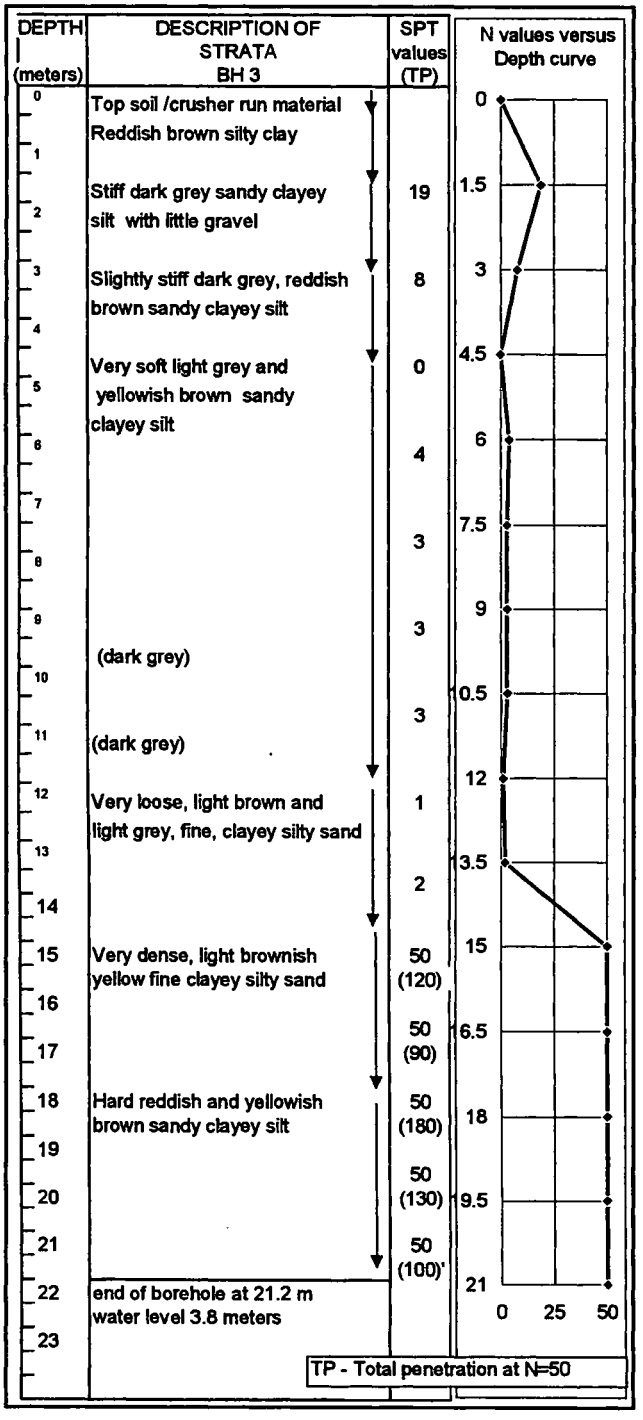

Figure 4. Bore log for BH3 Shah Alam site giving the description and the SPT value.

In the Sungai Buloh site one of the seismic line (S2) has been placed between the boreholes with granite show (BH3 and BH7) and near BH2 and BH6 for comparison with the SPT test. One of the problems here is to determine weather the granite extends between the boreholes, as it appears to form a subsurface ridge. A number of Mackintosh probing points are also near this seismic line. This will be discussed in this paper. The other seismic line (S1) has been placed near BH 8, BH 10 and BH 9.

FIELD DATA AND RESULTS

Shah Alam Site

A typical bore log includes information on the depth of borehole, description of the material at various depths, sample identification at various depth and legend (BSI 1981). Included in the bore log is the SPT result. The number of blow is shown at six 75 mm interval. The first two 75 mm intervals are the seating blow while the next four 75 mm intervals will contain the no of blows for each interval. The total number of blows for these four 75 mm interval gives the SPT N value. These are also given in graphic form as seen in Figures 3 and 4. However, the figures given only contain part of the bore log information. The Mackintosh probe number of blow values is given at every depth interval of 300 mm. They are given both as numbers and graph of number of blows verses depth as given in Figure 5. The SPT N values are given in Figure 6 while velocity profile obtained from the seismic refraction survey is given in Figure 7.

Sungai Buloh site

The Mackintosh probe result for the test near the seismic lines is given in Figure 8. Only four points are near enough to be correlated to the seismic data.

The SPT values carried out at the four boreholes BH2, BH3, BH6 and BH7 are given in Figure 9. The granites are found at the end of boreholes BH3 and BH7. No granite rock is found in other boreholes.

The seismic velocity profile along seismic spread S2 is given in Figure 10. Borehole BH2 and BH3 are marked on the profile however they are about 30 meters away from the boreholes. BH6 and BH 7 are about 30 meters away from the start of the seismic spread (0 meters). The profile joining BH3 and BH7 (borehole which ends on granite) is at about 50 meters distance along the seismic line.

DISCUSSION OF THE RESULTS

Boring Data

In the wash boring method the material broken up at the end of the drill rod is flushed up to the surface through the borehole by water pumped down the hollow drill rod. The material brought out with the flushed water is continuously checked. It provides an indication of the material been drilled. This, however, may not be representative of the character and actual nature of the strata being penetrated. Besides being broken, crushed and mixed this flushed materials also can contain material from the wall of the borehole along the passageway of the flush material. The description of the bore log as seen from Figure 1 and 2 does not specify the true nature of the subsurface instead basically only classify it into grain size based character such as silt, clay and sand. Additional description includes stiffness, loose, dense and hard. Another part of the description is colour. These descriptions are mainly for loose material or highly weathered materials. Due to this problem, the properties are determined using the standard penetration test (SPT), which has been done at a regular interval of 1.5 meters.

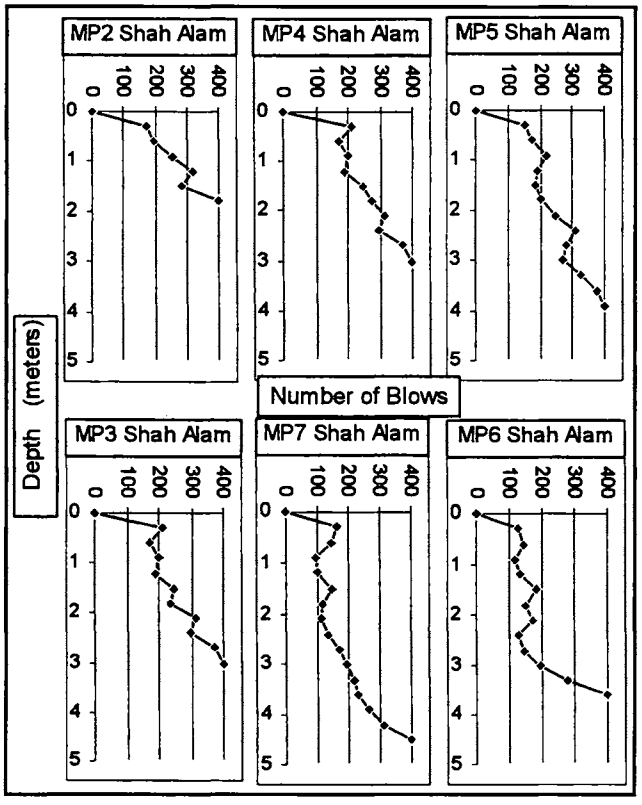

Figure 5. Shah Alam Mackintosh probing test value versus depth for test points near BH1 (MP2 and 3), BH2 (MP4 and 7) and BH3 (MP5 and 6).

Shah Alam Site

Bore Log Description And SPT Values

Generally the uppermost layer with thickness of less than 0.3 meters is referred to as top soil, clayey with sand

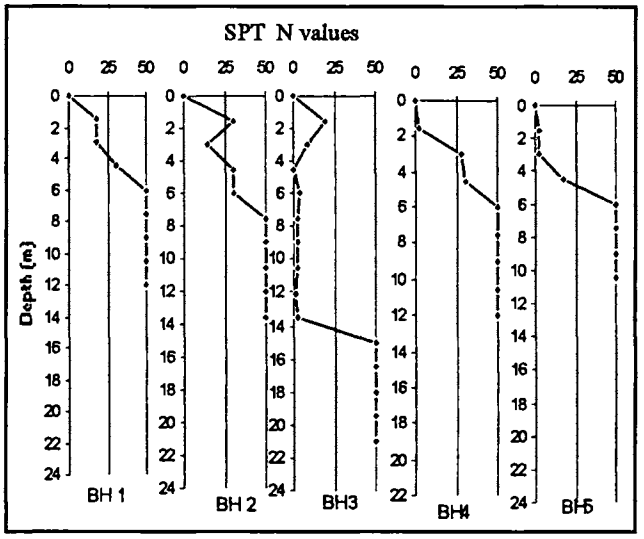

Figure 6. SPT N values for boreholes at Shah Alam site. Note relatively low N values and deeper N = 50 value at BH3.

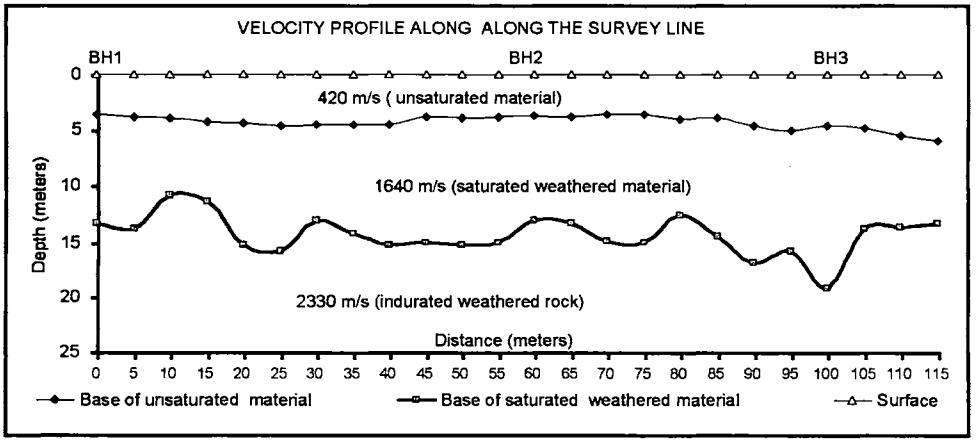

Figure 7. Velocity profile from the seismic refraction data for Shah Alam site. Note a deepening of the indurated material at about 100 meters distance.

and silt and contain crusher run material. This layer with the crusher run material is thicker in BH3 extending to 1.1 meters. The next stratum is described as various type of silt in BH2, BH3 and BH5 to a depth (end of borehole) of 14, 10.5 and 1.5 meters respectively. A sandy layer follows this for BH1, BH3, BH4 and BH5 to a depth of 12, 18, 12 and 12 meters respectively. These are the ends of the boreholes except for BH3, which has a silty strata extending to the end of the borehole at 21 meters depth.

The SPT values generally increases gradually with depth to N = 50 at about 4.5 to 6 meters depth (Fig. 6). A marked contrast occurs at BH 3 where the value first increases to N > 25 at 1.5 meters and decreases to about N = 5 at depth of 4.5 meters. This low N values continues until a depth of 13.5 meters and increases sharply to N = 50 at 15 meters. This is indicative of an extreme change in properties in the subsurface but this change is not obvious in the bore log description.

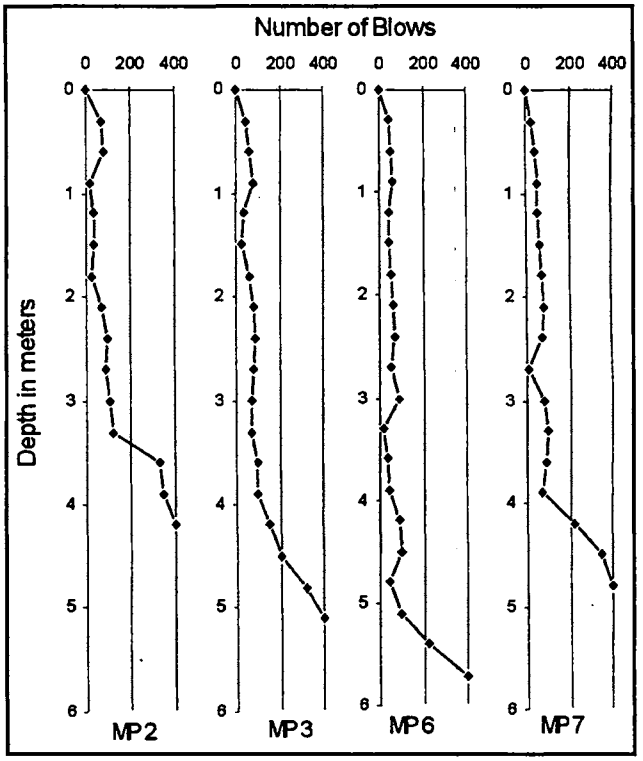

Figure 8. Mackintosh probing test value versus depth for test points near seismic line S2 in the Sungai Buloh site.

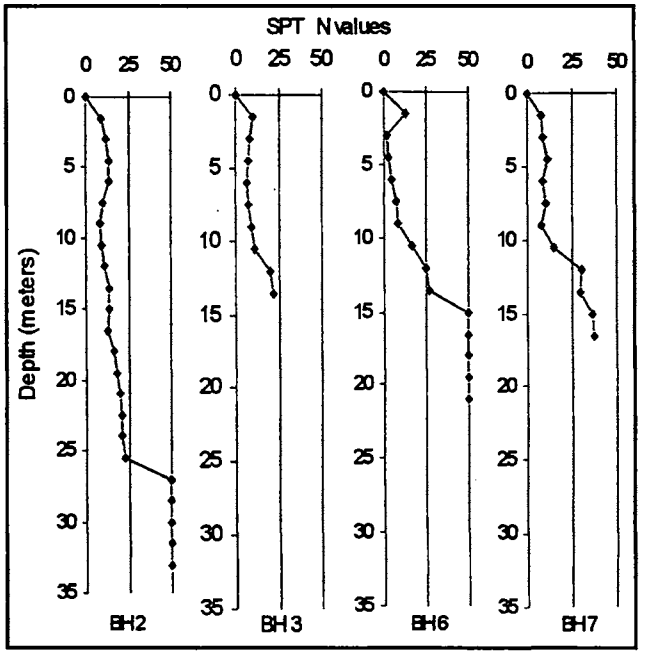

Figure 9. SPT N values for boreholes at Sungai Buloh site. End of BH3 and BH7 is granite.

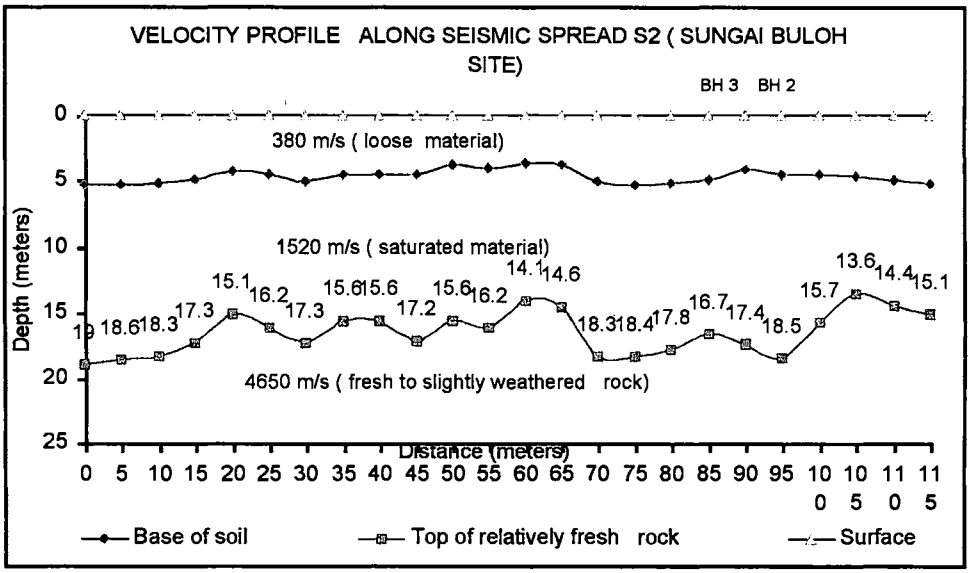

Figure 10. Velocity profile along S2 (Sungai Buloh site). BH2 and BH3 are about 30 meters away from the seismic spread. The profile joining BH3 to BH7 passes at about 50 meter point.

The Mackintosh Probe Test

The Mackintosh probe reaches a depth of 3 to 5 meters. The result indicates a general increase of the numbers of blows to the limiting value of 400 with depth. Points MP2 and MP3 which are near the borehole BH1 give the shallowest end depth of about 3 meters. The end depth deepens to 4–4.5 metres at MP7 and MP6 near BH2 and at MP4 and MP5 near BH3.

A comparison of these Mackintosh probe values to the description of the bore log does not indicate any marked change in material or strata at the depth of the limiting value of 400 blows per 300 mm length. Similarly a comparison to the SPT values also does no indicate any comparable event in both the SPT value and bore log.

The seismic velocity profile

The seismic data indicates clearly that the subsurface can be divided into three velocity layers. The top layer has a velocity of 420 meters per second and the depth of its base is about 4 to 5 meters. Underlying this is a 1640 meter per sec layer with a variable bottom of 10 to 18 meters depth. Below this is a 2330 meter per second layer.

A velocity of 400 meters per second suggests a loose uncompacted material normally dry or unsaturated. The velocity of 1,640 meters per second is normally highly weathered material but probably fully saturated. The velocity of water is about 1,500 meters per second. The water table observed in the boreholes ranges from 3 to 5 meters depth. The velocity of 2,330 meters per second is generally associated to a rather indurated material such as fractured rock with slight weathering. An obvious feature at the interface between the 1,640 and 2,330 meters per second layers is an obvious deepening (depression) at about 100 meters distance along the seismic profile. This deepening is aligned to BH3 where the SPT values are low throughout the borehole. It is likely that a fracture system passes through these two points as a fracture zone lowers the seismic velocity thus producing the depression.

A comparison of the seismic data to the Mackintosh probe result shows that the change in velocity at this depth is complimented by ending of the Mackintosh probe test. A comparison to the SPT N value at this depth indicates that these materials have SPT N values less than 30.

The second seismic layer is mainly in the silty or sandy strata. The SPT N = 50 values starts within this layer. The base of this second seismic layer is thus at a deeper depth than the SPT N = 50 value.

Discussion On The Shah Alam Site

Comparison of the four different data sets indicates that the seismic refraction data can be (i) compared directly to the Mackintosh probe test where the low velocity layer is equivalent to the layer where the Mackintosh probe test is less than 400 blows per 300 millimeters. (ii) this layer also gives SPT N value of less than 30 (iii) that the SPT N = 50 do not define the bedrock or consolidated rock and occurs within the 1640 meters per second layer and (iv) comparison to the water table suggest that the top seismic layer is probably closely associated to the boundary of saturated and unsaturated materials. In addition generally the description of the wash boring flushed material reflect more on the grain size rather than the lithology of the subsurface. Therefore comparison of the seismic refraction result, which is based largely on velocity differences reflecting a change in the physical character, to the grain size based description of the wash boring data do not give accurate comparison. But, the comparison to the Mackintosh probe and SPT values gives positive results. Another advantage of carrying out the seismic refraction in this type of site investigation is it determines the depth of the bedrock, which is not encountered in the standard penetration test. This is useful as an aid to determine the end of the pile.

The Sungai Buloh Site

Bore Log Description And SPT Values

Compared to the Shah Alam site the boreholes here are deeper (e.g. BH2 – 33 meters and BH7 – 18.5 meters). The top 1.5 meters is described as brownish silt soil. Underlying this is either sand with gravel and clay and generally described as medium dense or silt also with sand and gravel and describes as stiff or medium stiff. In some of the boreholes gravel with silt and clay have also been described. The lack of clay suggests that these are terrace deposit materials where the fine particles had been transported away. In BH3 and BH7 which end within weathered granite (described from core), the material overlying is described as sand with some gravel and traces of clay which is probably still the terrace deposit. BH6 which is near BH7 (about 30 meters away) has the N = 50 in dense sand with gravel and traces of clay.

No SPT value has been obtained in the weathered granite as coring was done. In BH2 and BH6 the SPT N values are generally low. They are normally less than 25, however the increase from N = 25 to N = 50 value occurs suddenly and within the next 1.5 meters interval. The penetration at each of the N = 50 values are very small at less than 10 cm indicating a resistant strata.

The Mackintosh Probe Test

The Mackintosh probe blow value reaches 400 at about 5 meters deep. The ground water level is at about 3–3.5 meters. Although BH2 is deeper and is at a relatively lower topography than the others the end is reached at a shallower depth.

A comparison of these Mackintosh probe value to the bore log does not show any drastic change in material at each of the probe end. They occur within the sand or the silt layer. The SPT value at this depth also does not show any noticeable change in value.

The Seismic Velocity Profile

The seismic data indicates that the subsurface can be divided into a three-velocity layer. The top layer has a relatively low velocity of about 380 meters per second. The velocity of air is about 345 meters per second. The base of this layer is at about 4–5 meters. The second layer has a velocity of 1,520 meters per second. This appears to be within range of velocity of water and therefore the layer is most likely to be a saturated sandy or silty terrace deposit. The bottom layer has a relatively large velocity of 4,650 meters per second. Velocity of granite is greater than 3,000 meters per second. The seismic profile indicates that the top of the 4,650 meter per second layer is undulating but it is at about 15–17 meters depth between 20 to 70 meters of the seismic spread. This is flanked by a deeper surface reaching to greater than 18 meters depth.

A comparison of the seismic data to the Mackintosh probe value indicates that the change in seismic velocity values at the 5 meters depth is complimented by the Mackintosh probe value reaching 400 blows. The bore log and the SPT values do not show any noticeable change at this depth.

The depth of the second seismic interface at about 15 to 16 meters appears to correspond closely to the granite depth at boreholes BH3 and BH7. As bedrock is reached here, no further standard penetration test has been carried out on these two boreholes. The standard penetration test for the other two neighbouring boreholes at all the five N = 50 has little penetration (less than 10 cm). The material at these N = 50 layers are gravelly sand with little clay. This is probably still the terrace deposit. Therefore, the seismic data exclude the possibility that the granite identified at BH3 and BH7 is core boulders.

Discussion On the Sungai Buloh Site

As in the Shah Alam site the seismic first interface is closely associated to the end of the Mackintosh probe blow value of 400 at about 5 meters depth. The SPT value here is less than 15. The SPT value for the layer overlying the granite is less than 30. This layer is the saturated alluvial/ terrace deposit. In the other two boreholes a sudden change from low (below 30) to N = 50 occur near the end of the boreholes.

While the Mackintosh value has close correlation to the seismic velocity interface, the SPT value does not have a very clear correlation to the seismic interpretation. But the second seismic layer has an upper strata with SPT value up to 30 and a lower layer SPT value greater than 30.

The bore log description also does not show a clear correlation to the seismic velocity profile. Nevertheless, the seismic data correlates well with the depth of the granite identified in BH3 and BH7 and this indicates that the granite at the end of the borehole is not a core boulder. The granite forms ridge like topography that is shallowing in some places and deepening at other places.

DISCUSSION AND SUMMARY

In small-scale site or soil investigation work where the drilling program is carried out using wash boring method seismic refraction survey is an essential compliment to determine the subsurface characteristic. Using the wash boring method the hard layer is determined using the standard penetration test value N = 50. In this test when N = 50 is encountered five times continuously the boring is stopped. But this hard layer is not necessarily the bedrock. As in the case of the Shah Alam site, the end of the pile needs to be deeper than this hard layer but above the bedrock. Thus the seismic refraction work, which enables determination of the bedrock, is an essential compliment. Furthermore as in the Sungai Buloh site the seismic refraction survey exclude the possibility of a core bolder that ends the borehole.

In the seismic refraction, the velocity subsurface division does not provide the subsurface with quantitative data directly. The comparison to the SPT, bore log and Mackintosh values allows the seismic result to be equated to the quantitative values. The Mackintosh probe blow value of less than 400 is comparable directly to the velocity layer of less than 500 meters per second. In the absent of the Mackintosh probe test this velocity value can replace the test. The SPT values of less than N = 30 correspond to the second velocity layer. A velocity of 500 to 1,650 meters per second can represent this SPT values. The SPT test, however gives a more detail variation along the borehole than the surface seismic refraction survey. The SPT value N = 50 is within the same velocity layer. In the absent of the SPT test this velocity range can be used as a guide to the quantitative value needed. Further study and refinement of the correlation of this seismic velocity range to the SPT value should make the seismic refraction data a more useful tool for the shallow site investigation work.

ACKNOWLEDGMENT

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