

Construction Shortfall and Forensic Investigation on Soft Ground

M Saravanan¹ and B N Ibrahim¹

¹Nexus EC Sdn Bhd, Kuala Lumpur, Malaysia

E-mail: vanan.nexus@gmail.com

Abstract. Recently, numerous construction activities performed on soft ground have undergone various kind of failures. Some of the failures were due to lack of understanding the nature of soft ground, inadequate site investigation data, adaptation of inappropriate type of ground improvement techniques or foundation system. Couple with inadequate desk study carried out to the historical condition of the site, chronological of activities carried out within the site prior to construction. Hence coordinated approach required to be executed for field investigation works with proper supervision would be the key to prevent any design or construction related failure in the future. This paper addresses some of shortfalls related to design and construction failures in soft ground.

Keywords: Site investigation, soft clay, stone column, ground improvement, forensic investigation.

1. Introduction

Carrying out project on soft ground requires careful measures to be undertaken systematic, namely:-

- Site selection, existing condition and historical even occurred at the site.
- Planning for adequate site investigation with suitable adaptation of cross verification of site investigation data.
- Selection of reliable, workable and cost effective solution to be implemented at the site.
- Stringent site supervision and quality assurance required to be executed.

With the above being implemented any potential failures related to construction activities of soft ground can be eliminated.

2. Shortfall Related To Site Investigate (SI) Work Carried Out

Selection of site for development in many situation could not be avoided. The wide corridor of soft clay deposit along Malaysian coastal line could not be avoided from development. In the event the site is located within soft clay deposit zone, careful planning measure for site investigation works required to be carried out. Some of the shortfalls or errors identified while handling site investigation (SI) works are:-

- Data mis-interpretation.
- Lack of supervision during site investigation carried out.
- Incompetent person to execute the works.
- Location identified for SI works.



With all the above mentioned shortfalls, engineers would not able to provide optimize design in which related to cost saving (economical) and environmental friendly.

3. Example Case Of Data Mis-Interpretation Due To Lack Of Supervision

Serious design error could be related mis-interpretation to SI works. Site supervisions are important as report in this example of 5m high embankment failures. The design of 5m high embankment were carried out on ground reported to be Medium Stiff CLAY / SILT without any indication of Soft CLAY/SILT deposit. The SI works performed in 2003 reported field data as shown in Figure 1.0.

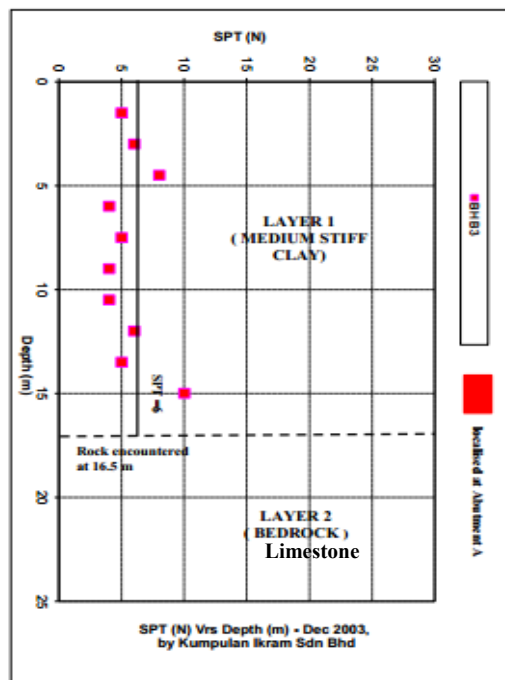


Figure 1.0. SPT-Nvalue (Blows/300mm) for Abutment A (SI in 2003).

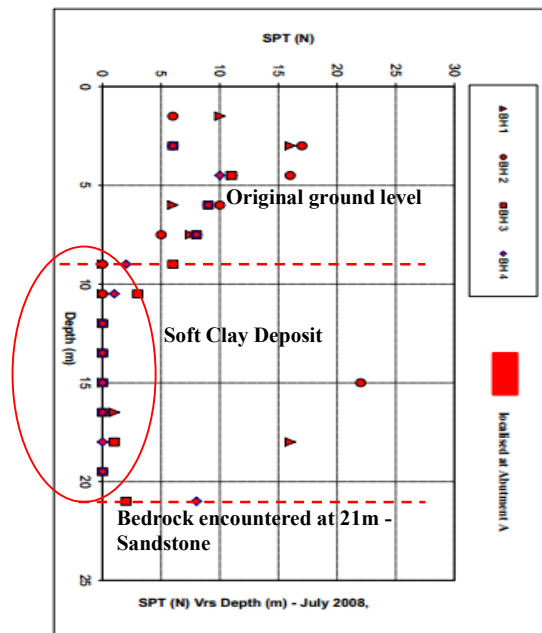


Figure 2.0. SPT-Nvalue (Blows/300mm) for Abutment A (SI in 2008).

The SI works performed were not cross check with the site geology. During the forensic investigation after failure, eleven (11) number of boreholes were carried out which are three (3) numbers (in year 2007) and eight (8) numbers (in year 2008) were performed. The new SI reported the presents of very soft ~ soft CLAY deposit as shown in Table 1.0 and Figure 2.0.

Table 1.0. SI comparison at Abutment A.

Date	12/10/2003-13/10/2003	8/5/2008 - 10/5/2008	11/5/2008 - 12/5/2008	22/4/2008-25/4/2008	26/4/2008-28/4/2008
Year	2003	2008	2008	2008	2008
Borehole	BHB3	BH1	BH2	BH3	BH4
Location/Depth (m)	On ground level	At 5.5m embankment fill (at non failed side of embankment)	At 5.5m embankment fill (at non failed side of embankment)	At 5.5m embankment fill (at non failed side of embankment)	At 5.5m embankment fill (at non failed side of embankment)
0		10 Stiff	6 Firm	6 Firm	
1.5		16 Stiff	17 Very Stiff	11 Stiff	6 Firm
3.0		11 Stiff	16 Very Stiff	9 Stiff	10 Stiff
4.5		10 Stiff	10 Stiff	8 Firm	9 Stiff
6.0		6 Firm	5 Firm	6 Firm	8 Stiff
7.5	5 Firm	0 Very Soft	0 Very Soft	3 Soft	2 Very Soft
9.0	6 Firm	0 Very Soft	0 Very Soft	0 Very Soft	1 Very Soft
10.5	8 Stiff	0 Very Soft	0 Very Soft	0 Very Soft	0 Very Soft
12.0	4 Soft	0 Very Soft	0 Very Soft	0 Very Soft	0 Very Soft
13.5	5 Firm	0 Very Soft	22 Very Stiff	0 Very Soft	0 Very Soft
15.0	4 Soft	1 Very Soft	50 Hard	1 Very Soft	0 Very Soft
16.5	4 Soft	16 Very Stiff	Rock-Sandstone	0 Very Soft	0 Very Soft
18.0	6 Firm	50 Hard		2 Very Soft	0 Very Soft
19.5	5 Firm	Rock-Sandstone		Rock-Sand stone	8 Stiff
21.0	10 Stiff				Rock-Sand stone
22.5	Rock-Limestone				

* OGL – Assume original ground level.

The bedrock encountered and reported to be Sandstone and Limestone. Cross comparison with Geological Map of Malaysia the area reported to be Quaternary Marine and Continental deposit. The area were not likely to have Limestone as bedrock formation. The nearest Limestone found to be at

Gua Musang about 160 ~ 175km away (refer Figure 3.0 and 4.0). The bedrock reported in SI 2007 and 2008 were Sandstone. The present of competent geologist and supervisor are critical for the site data verification.

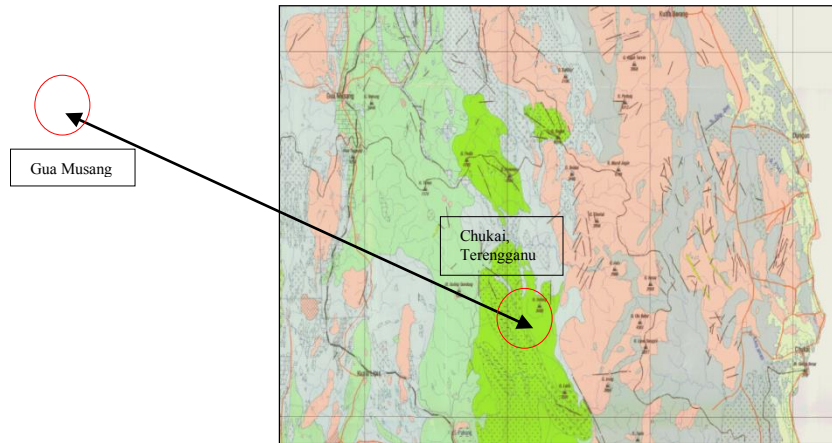


Figure 3.0. Geological Map showing site project (Chukai, Terengganu) and Gua Musang (Limestone area).

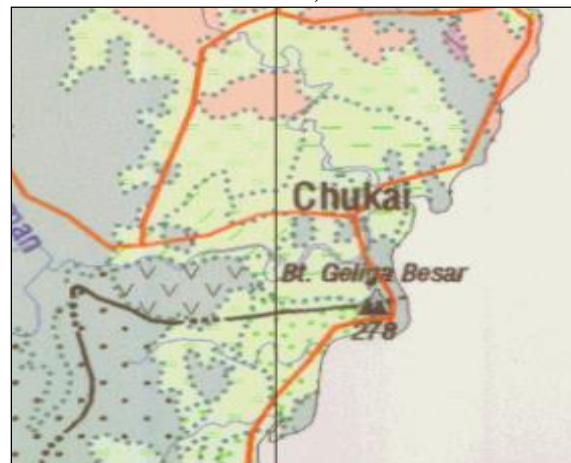


Figure 4.0. Geological Map showing Geological formation of project area.

4. Cross comparison with Standard Penetration Test (SPT), Cone Penetration Test (CPT) and Ground Penetration Radar (GPR).

Performing site investigation works using only SPT and insitu sampling will not be adequate enough to interpret the actual ground condition in area with soft CLAY deposit. Example on how data can be mis-interpreted if comparison were not made with other form of site investigation works. Three (3) types of SI data were cross compared, namely:-

- Boreholes with Standard Penetration Test (SPT).
- Cone Penetration Test (CPT).
- Ground Penetration Radar (GPR).

Boreholes (BH) only indicate the subsoil stiffness (SPT value) without indicate the other parameters which related to historical condition of the site. Whereas the CPT data were able to expose the presents material such as loosely deposited material which is not the original soil of the site. Example the

filling over of old pond or river. This formation contains lot of voids that creates negative pore pressures (much lesser than natural water pressure with depth – refer Figure 5.0 and 6.0).

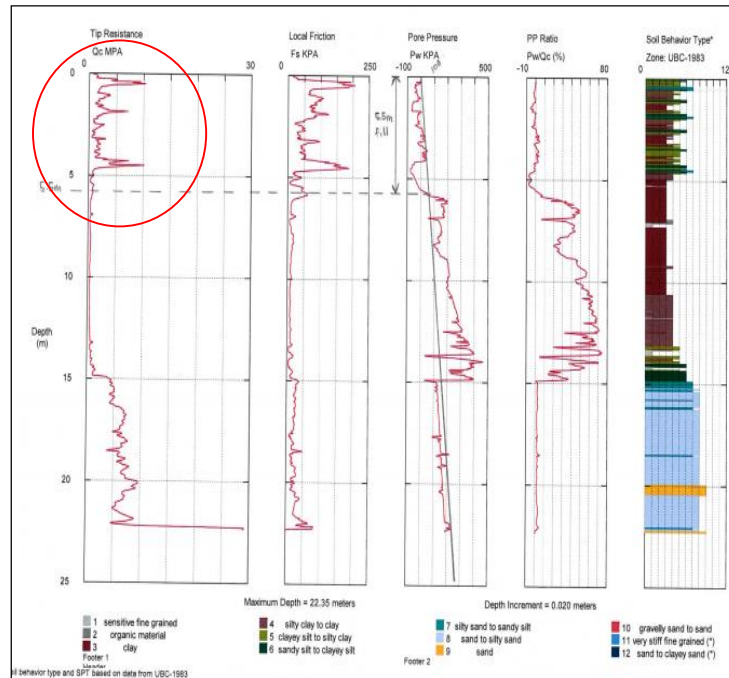


Figure 5.0. CPT data from site with pond filling.

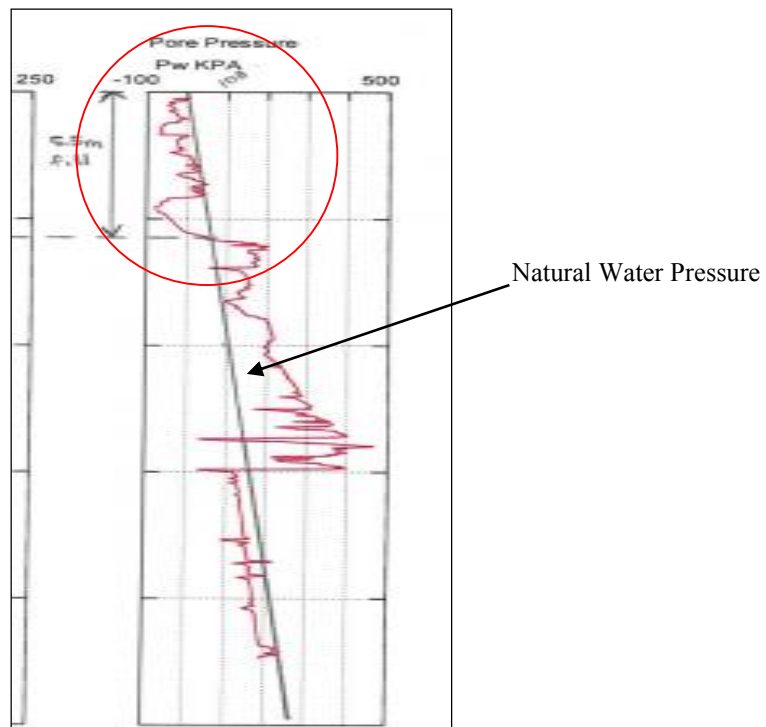


Figure 6.0. Pore water pressure reading.

Hence, as reported in the CPT data, this site consist of material most likely to be loosely deposited earth (transported and dumped) into natural pond. Presents of pond and historical closure of ponds could have direct consequences to the type of foundation to be adopted. Performing CPT test can be very useful to provide vital information to supplement boreholes data. Further cross comparison can also be made using Ground Penetration Radar (GPR). The performed GPR reported pockets of voids and also signs of ground subsidence as shown in Figure 7.0 and 8.0. The findings are relatively consistent with CPT findings. However, Boreholes data were not able to identify the loosely deposited earth. Subsoil stratum obtained from boreholes are shown in Figure 9.0.

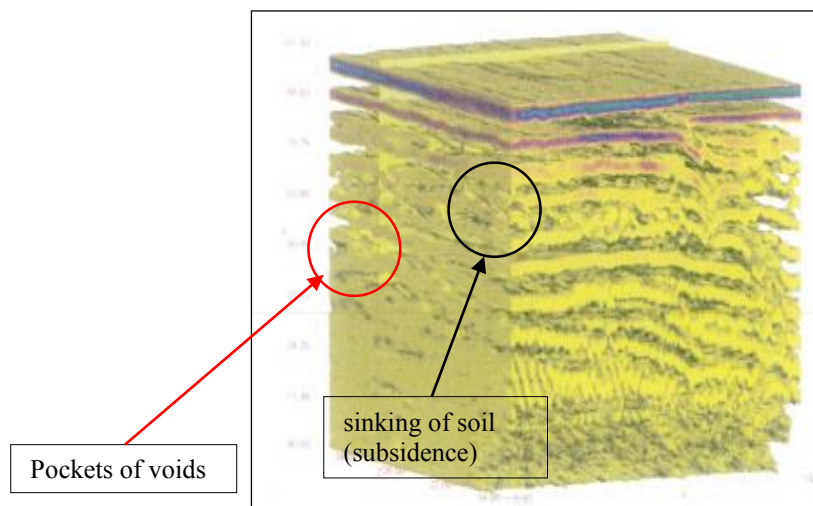


Figure 7.0. Localise pocket of voids and subsidence based on GPR scanning.

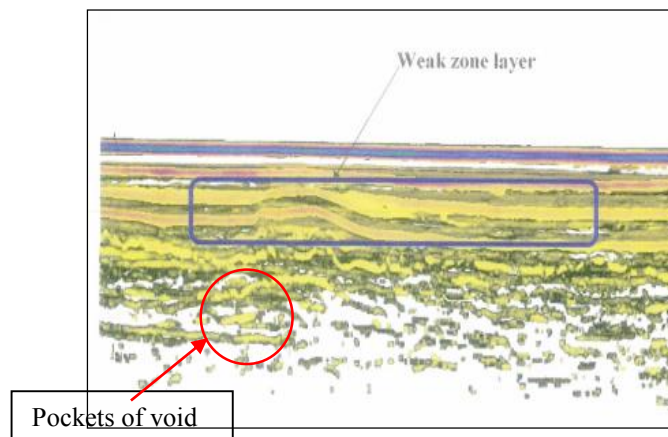


Figure 8.0. Localise pocket of voids.

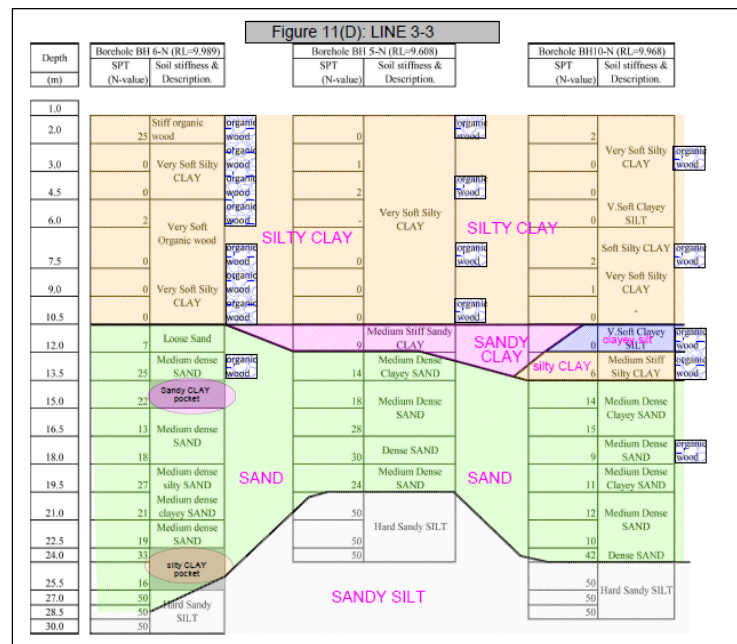


Figure 9.0. Subsoil stratum obtain by Borehole.

5. Conclusion

Performing adequate SI works are major way forward in preventing design failures especially on soft ground. Understanding why failures in soft ground occurs and not repeating the past mistake could also be useful on soft ground engineering. Example, some of key factors that many engineers overlook during stone column design are (refer **Plate A ~ D**):-

- i. Due to shear strength.
 - The recommended lower limit to the undrained strength of $C_u=15$ kPa is suggested for treatment with stone column (Bryan, 2007) and (MCR Davies, 1997).
 - Although there have been few situations where softer soils have been successfully improved (Raju et al., 2004).
 - For very soft Clay with C_u between 4~15 kPa, soil with very low cohesion have relatively low radial support given to the stone columns by soil (Thornburn, 1975).
- ii. Soil plasticity index.
 - The plasticity index (I_p) of soil reflects the potential for volume change, UK national Building Council (NHBC, 1998) suggests that stone columns not recommended to be used when $I_p > 40\%$ (Bryan, 2007).
 - However, only few successfully cases where high plasticity soils has been improved using stone column.
- iii. Soil Permeability.
 - The major difficulties in forming uncontaminated stone columns in very soft soils are due to radial displacement seriously distorts and remoulds the surrounding soil inducing excess pore water pressure which cannot dissipate rapidly even in a laminated soil because the distortions destroy the natural horizontal drainage laminae (Thornburn S, 1975).
- iv. Ground settlement.
 - With reference to the research work by Hughes and Withers (1941) indicates that the ultimate stress in the stone columns were obtained only when the vertical displacement of stone column was 58% of the column diameter. Field test results examined by S. Thornburn on full size stone columns indicates that the vertical displacement of the top of stone

columns at failure were only of the order of 10~15% of the diameter of stone columns (Thornburn, 1975).



Plate A



Plate B

Plate A and B: Photo showing failed stone column (non reinforced stone column) and column being clogged with soft Clay and preventing the pore water discharge during consolidation process and the infill material decentigrate.

The risk and project delivery responsibility for designing and constructing stone columns in ground weaker than the listed above, should not be shouldered by client and consultants. Consultant should not recommend the usage of stone column in such ground condition. Alternatively, instead of stone column, designer / consultant shall recommend more reliable ground improvement work (i.e. Pre-fabricated vertical drain or Encased stone column or pile foundation).

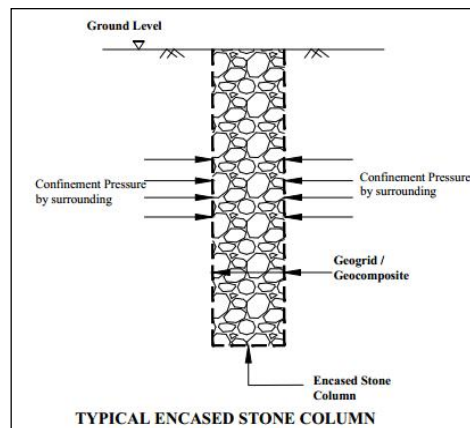


Plate C. Illustration of encased (reinforced) stone column.

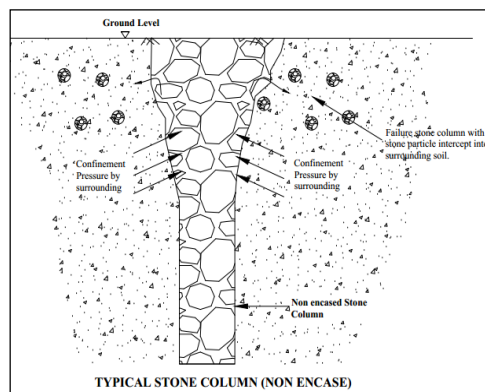


Plate D. Image showing decintigrate of stone column in soft ground due to lack confinement strength of surrounding soil.

References

- [1] British Standards BS5930 1999 Code of Practice for Site Investigations. British Standard Institutions.
- [2] Davies M C R, Francois S 1997 Ground Improvement Geosystem: Densification and reinforcement.
- [3] Cabe B A 2007 Ground Improvement Using The Vibro-Stone Column Technique. Department of Civil Engineering, National University of Ireland, Galwa.
- [4] Hughes J M O, Withers N J and Greenwood D A 1975 A field trial of the reinforcing effect of a stone column in soil. *Geotechnique*. **25**(1) 31-44.
- [5] Krishna H, Raju V R and Wegner R 2004 Ground Improvement using Vibro Replacement in Asia 1994 to 2004 : A 10 Year Review. Proc., 5thInt. Conf. on Ground Improvement Techniques., Kuala Lumpur, Malaysia.
- [6] Raju V R 2002 Vibra replacement for high earth embankments and bridge abutment slopes in Putrajaya, Malaysia. International Conference on Ground Improvement Techniques, Malaysia. 607-614.
- [7] Thorburn S 1975 Building structures supported by stabilized ground. *Geotechnique* **25**(1) 83-94.