Construction Shortfall And Forensic Investigation On Soft Ground

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

Abstract. 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 inappropiate type of ground improvement techiques 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. As forensic investigation works carried out after failure reveals drastic variation in site investigation (SI) data as compared to SI data used to perform the design works. The importance of SI works were not give an adequate attention during the design stage. Some of measures required to be addressed during design stage will be discussed in the paper.

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 adoptation of cross verification of site investigation data, required to be performed. Furthermore, selection of reliable, workable and cost effective solution to be implemented at the site, are vital for any project. Stringent site supervision and quality assurance required to be executed and uphold at all time. With the all mentioned being implemented any potential failures related to construction activities of soft ground can be eliminated.

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 (i.e. data mis-interpretation, lack of supervision during SI carried out, incompetent person to execute the works and location identified for SI works. With all the above mentioned shortfalls, engineers would not able to provide optimise design in which related to cost saving and environmental friendly).

Example case of data mis-interpretation due to lack of supervision.

Serious design error could be related of mis-interpretation to SI works. Site supervisions are important as reported 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 Fig. 1.

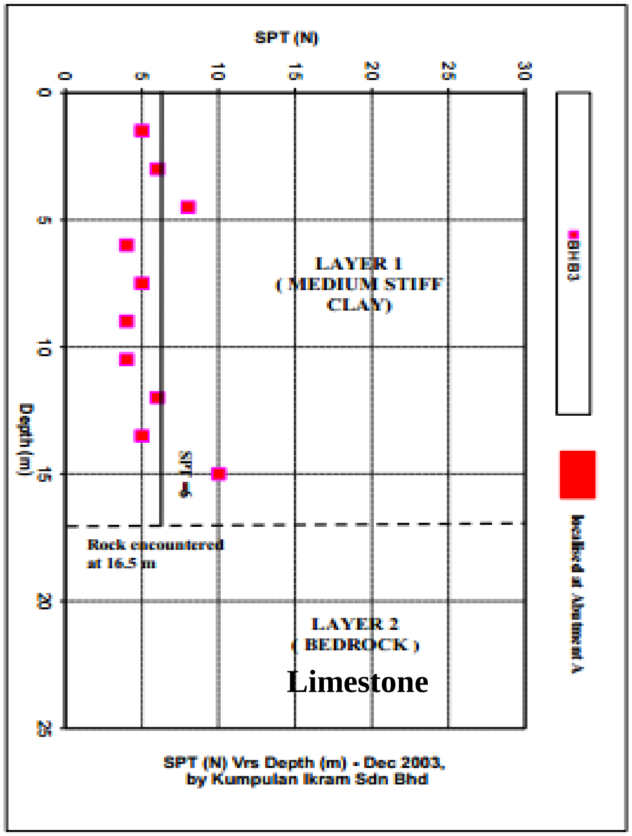

Fig. 1: SPT-Nvalue (Blows/300mm) for Abutment A (SI in 2003).

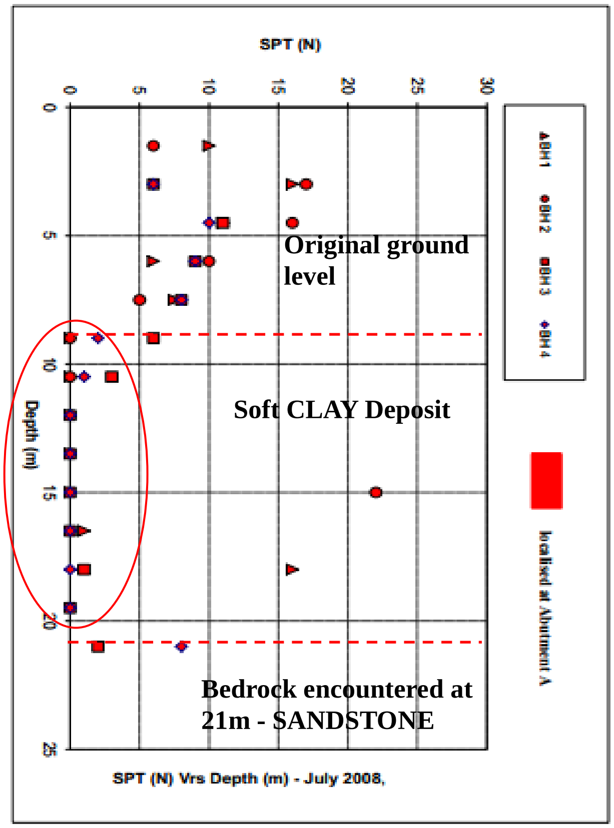

Fig. 2: SPT-Nvalue (Blows/300mm) for Abutment A (SI in 2008).

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 and Fig. 2.

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 Fig. 3 and 4).The bedrock reported in SI 2007 and 2008 were Sandstone. The present of competent geologist and supervisor are critical for the site data verification.

	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		Fill Material
	1.5		16 Stiff	17 Very Stiff	11 Stiff	6 Firm	
	3.0		11 Stiff	16 Very Stiff	9 Stiff	10 Stiff	
OGL ▽	4.5		10 Stiff	10 Stiff	8 Firm	9 Stiff	
	6.0		6 Firm	5 Firm	6 Firm	8 Stiff	Original Ground
	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.

Table 1: SI comparison at Abutment A.

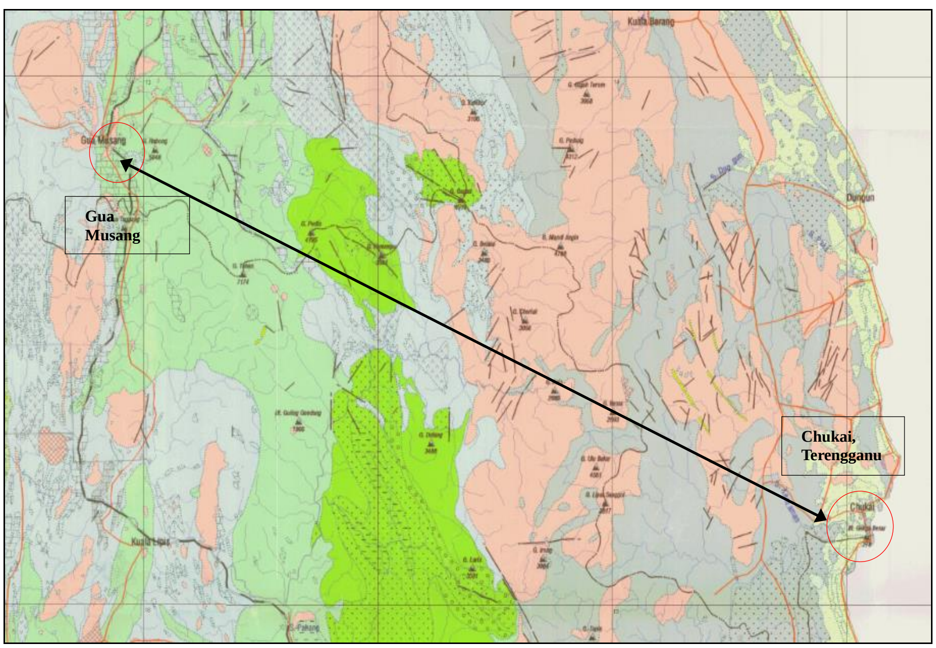

Fig. 3: Geological Map showing site project (Chukai, Terengganu) and Gua Musang (Limestone area).

Fig. 4: Geological Map showing Geological formation of project area.

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-interpretated 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 Fig. 5 and 6).

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 borehole 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 Fig. 7 and 8. The findings are relatively consistent with CPT findings. However, Borehole data were not able to identify the loosely deposited earth. Subsoil stratum obtained from borehole are shown in Fig. 9.

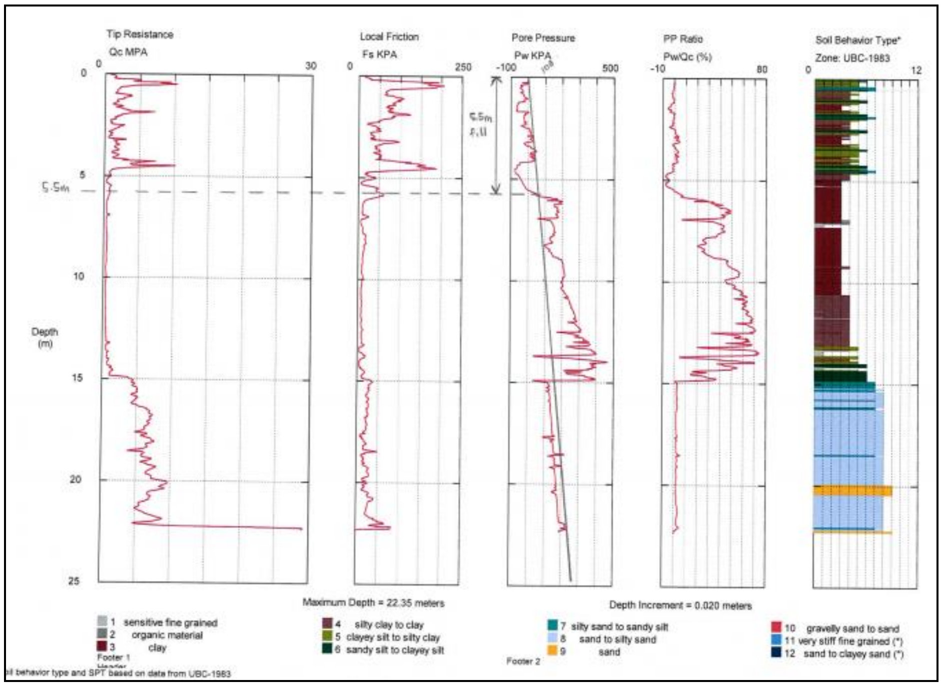

Fig. 5: CPT data from site with pond filling.

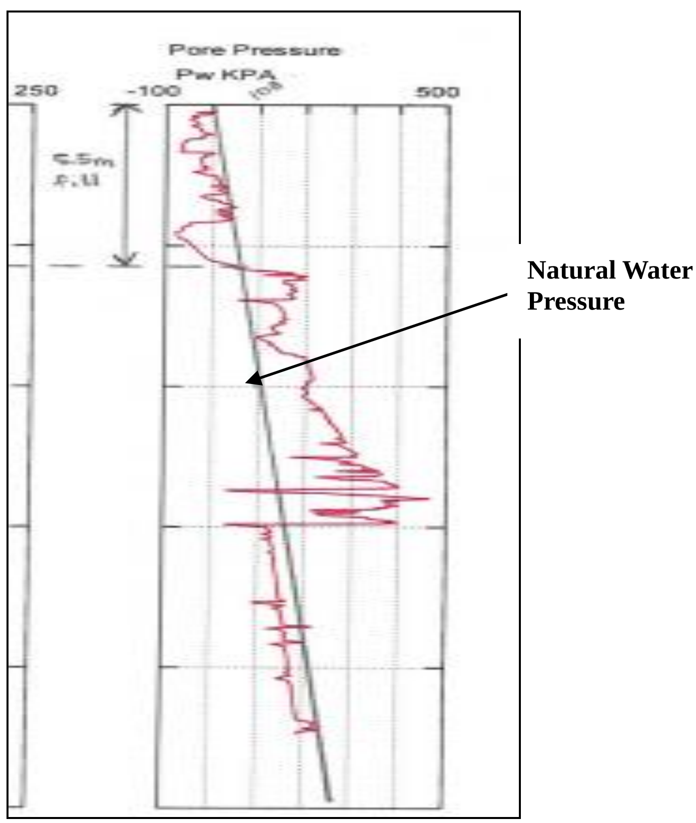

Fig. 6: Pore water pressure reading.

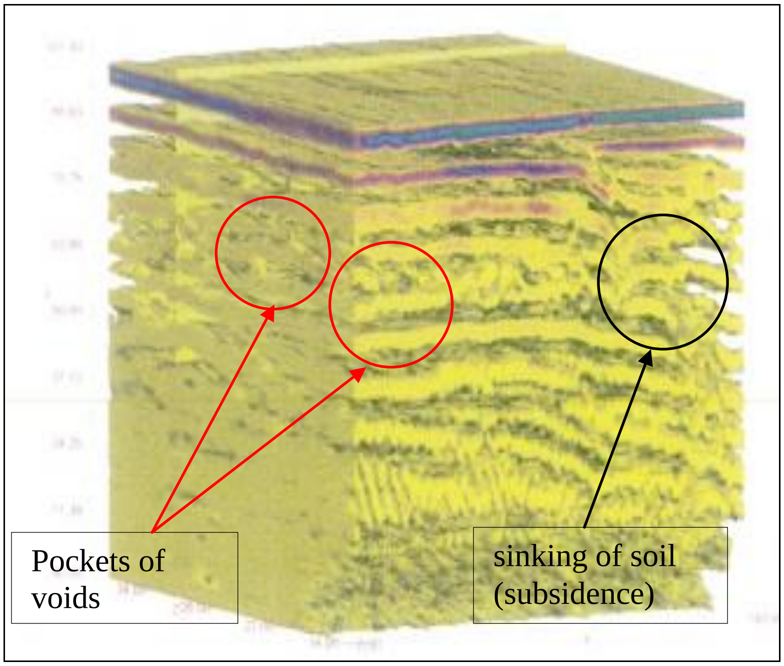

Fig. 7: Localise pocket of voids and subsidence based on GPR scanning.

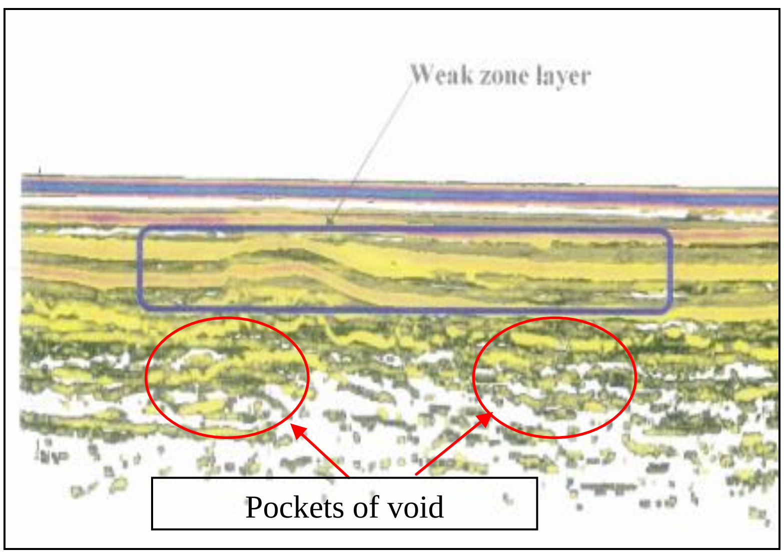

Fig. 8: Localise pocket of voids.

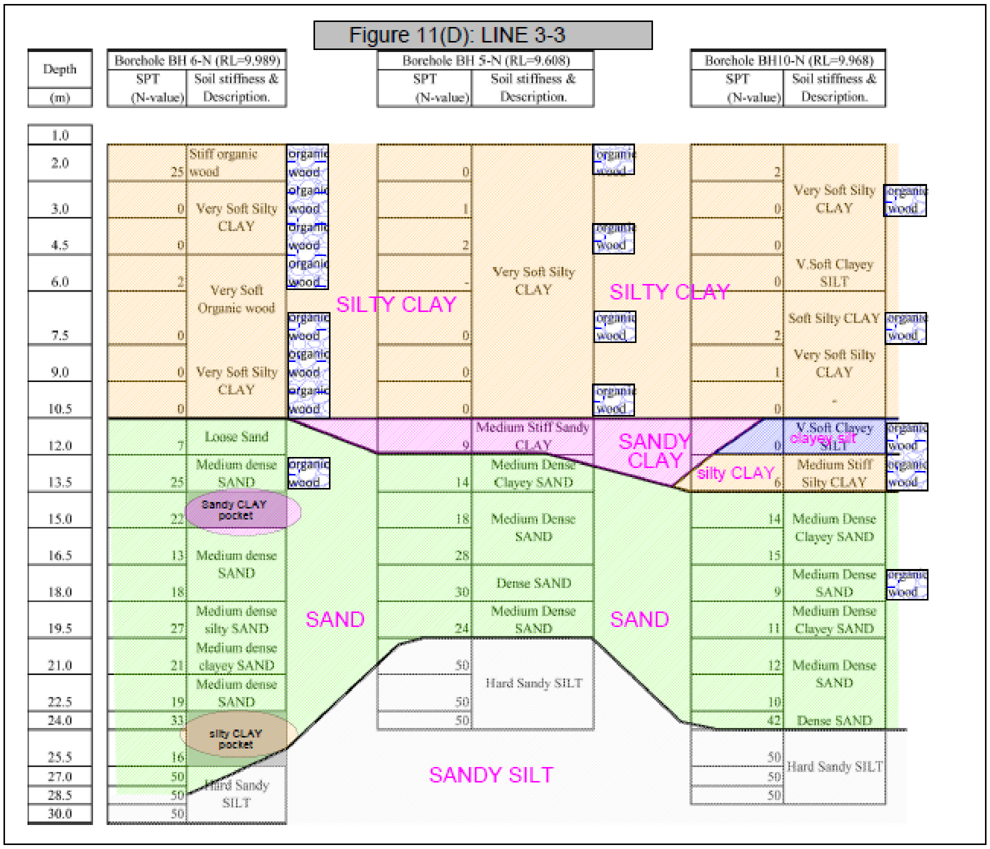

Fig. 9: Subsoil stratum obtain by Borehole.

Recommended methodology for site investigation works.

In order to avoid errors in SI works, following preventive measures are recommended as methodologyof work sequences:-

- Study the site geological and terrain information.
- Avoid wash boring method of drilling, adopt recommended machines as per MS2038:2006 [1].
- Ensure adequate planning were carried out before suitable works being performed.
- Propose adequate numbers of boreholes to cross check the boreholes data, minimum two (2) or three (3) borehole numbers depending on the project area.
- SI supervision recommended by experience geologist.
- Recommended to perform the SI works with cross check using Cone Penetration Test (CPT) or any other method (i.e. seismic survey or resistivity survey).
- Extract adequate soil sample for laboratory testing (i.e. undisturbed and disturbed samples).

- Perform Consolidated Isotropic Undrained Test (CIU) and Unconsolidated Undrained Test (UU) on sample diameter of minimum 50mm. Trimming of samples not recommended.

- Perform and report laboratory test as per British Standard [2] (BS5930:1999) and Malaysia Standard (MS2038:2006) [1].

- Ensure the completed SI report together with laboratory test results are prepared and endorsed by professional engineer.

Discussion

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 Cu=15 kPa is suggested for treatment with stone column [3] and [4].

   - Although there have been few situations where softer soils have been succesfully improved [5].

   - For very soft Clay with Cu between 4~15 kPa, soil with very low cohesion have relatively low radial support given to the stone columns by soil [6].

ii. Soil plasticity index.

   - The plasticity index (Ip) of soil reflects the potential for volumn change, UK national Building Council (NHBC, 1998) suggests that stone columns not recommended to be used when Ip > 40% [3].

   - However, only few succesfully cases where high plasticity soils has been improved using stone column.

iii. Soil Permeability.

   - The major difficulties in forming uncontiminated 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 [6].

iv. Ground settlement.

   - With reference to the research work by Hughes and Withers [7] 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. Thorburn 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 [6].

The risk and project delivery responsibility for designing and constructing stone columns in ground weaker that 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 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.

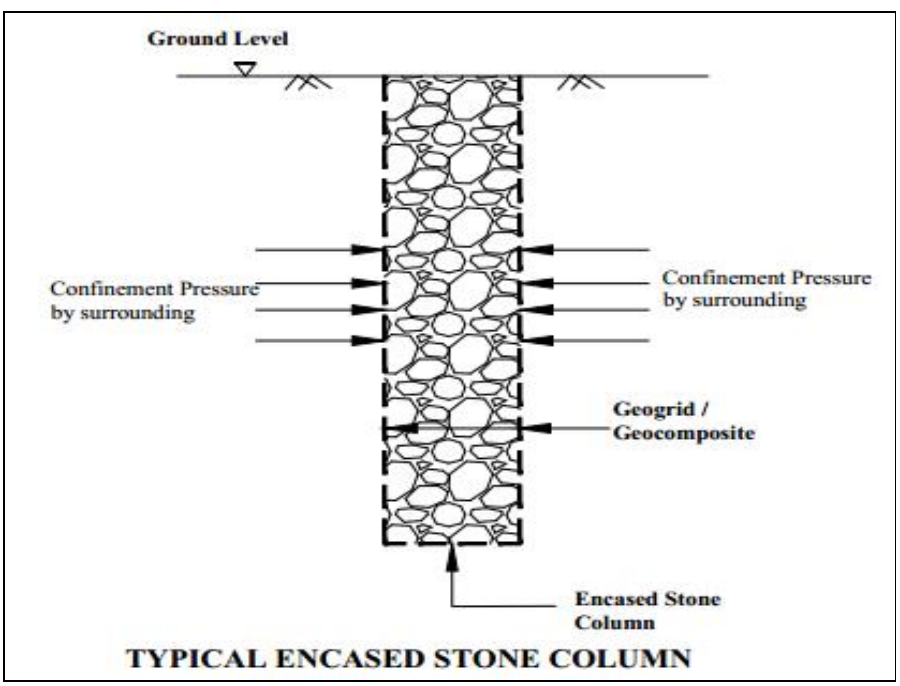

Plate C: Illustration of encased (reinforced) stone column.

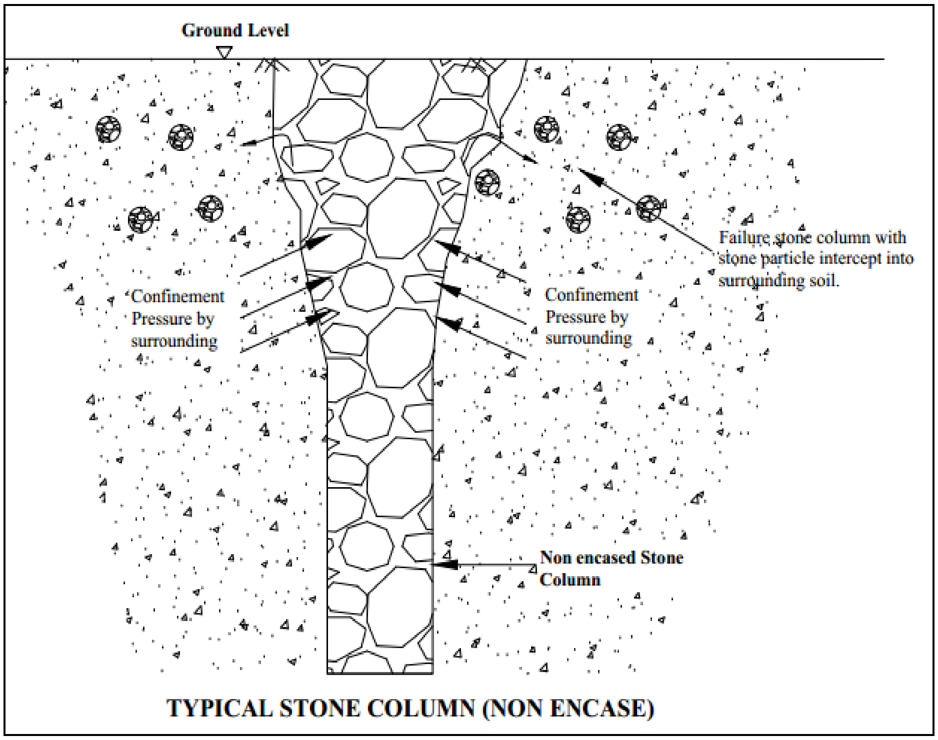

Plate D: Image showing decintigrade of stone column in soft ground due to lack confinement strength of surrounding soil.

Conclusion

With the above shortfalls and errors in SI works, private and government institution undergoes tremendous financial losses in term of project delivery, reliability and safe performance of the project. Repair and maintenance cost are expensive in the long term due to design failure cause by error and mis-interpretated SI data. Spending more attention on SI works by engaging qualified personals and by performing adequate sampling, million of ringgits can be saved. To start out with, training for engineers recommended to be conducted by key authorities such as Jabatan kerja Raya (JKR), Jabatan Mineral Geosains (JMG) and Board of Engineers (BEM).

References

[1] Malaysian Standard MS 2038 (2006), "Site investigation – Code of Practice", Department of Standards Malaysia.

[2] British Standards BS5930 (1999), "Code of Practice for Site Investigations", British Standard Institutions.

[3] Cabe. Bryan A. 2007, Ground Improvement Using The Vibro-Stone Column Technique, Department of Civil Engineering, National University of Ireland, Galwa.

[4] Davies M.C.R, Francois Schlosser (1997). Ground Improvement Geosystem: Densification and reinforcement.

[5] 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.

[6] Thorburn, S. 1975. Building structures supported by stabilized ground. Geotecnique 25(1): 83–94.

[7] 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.

[8] 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.

[9] GEOGUIDE 2, “Guide to site investigation”, Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong.

[10] Carter M. and Bently S.P. (1991), “Correlations of Soil Properties”, Pentech Press.

[11] Day R.W. (1999), “Forensic Geotechnical and Foundation Engineering” 2nd Edition, Mc Graw Hill.

[12] GEOGUIDE 6 (2002), “Guide to Reinforced Fill Structure and Slope Design”, Geotechnical Eng. Off., Civil Eng. Dept., Special Administrative Region, Hong Kong.

[13] Guo W.D. (2013), “Theory and Practice of Pile Foundations”, CRC Press Taylor & Francis Group.

[14] Head K.H. (1981), “Manual of Soil Laboratory Testing. Volume 2: Permeability, Shear Strength and Compressibility”, Pentec Press.

[15] Look B.G. (2007), “Handbook of Geotechnical Investigation and Design Tables”, Taylor & Francis.

[16] Price D.G. (2009), “Engineering Geology Principles and Practice” Edited and Compiled by M.H. De Freitas, Springer-Verlag Berlin Heidelberg.

[17] S.K. Garg (2001), “Soil Mechanics and Foundation Engineering (in S.I. Units)” 4th Revised Edition, Khanna Publishers.

[18] Tomlinson M.J. (2001), “Foundation Design and Construction” 7th Edition, Pearson Education Limited.