TECHNICAL NOTE

The misuse of SPTs in fine soils and the implications of Eurocode 7

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The standard penetration test (SPT) is one of the most commonly used insitu tests to determine density and subsequently the insitu strength of granular soils for use in bearing capacity analysis.

Due to its simplicity and cost effectiveness the use of the SPT as part of insitu testing for ground investigations of fine soils has become common practice in the UK. Several researchers, (Stroud 1974; Stroud & Butler 1975; Charles 2005; Tomlinson 2001) state that an approximation for the undrained shear strength and the coefficient of volume compressibility can be obtained from a standard penetration test N value correlated to the plasticity index of the soil.

Consequently, it has become common to multiply the SPT N value by a factor of five (Charles 2005) to provide a very approximate value of undrained shear strength. While this correlation is widely used in geotechnical engineering the geographical spread of the data from which the correlation was derived is significantly limited as the research is predominantly English based.

However, the use of the multiplying factor of five has now become standard in the geotechnical industry throughout the UK. The use of this rule of thumb may partly explain why to date the use of alternate sampling has been regarded as the general site investigation methodology.

Research carried out by Reid (2009) has revealed that there is little if any relationship between SPT N values and the undrained shear strength or the coefficient of volume compressibility for fine soils within the geographical area of South Lanarkshire. Consequently the continued use of historical empirical correlations is questioned.

Historical empirical correlations

In 1974 Stroud published findings that the SPT was a reliable test that could provide a means of estimating insitu properties of clay. Stroud investigated the relationship between SPT N value and undrained shear strength (c) and found a "simple correlation" of the form

$$c = f_1 x N$$

where f_1 is an independent multiplication factor (Stroud 1974, p374). The f_1 values were found to range from 3.1 to 7.6kN/m^2 and were plotted against plasticity index (see Figure 1). Stroud also investigated the relationship between SPT N value and the coefficient of volume compressibility (mv) and found a direct relationship of

$$mv = 1/(f_2 x N)$$

where f_2 is an independent multiplication factor. The f_2 values were found to range from 350 to 800kN/m^2 and were plotted against plasticity index (see Figure 2), and a "best fit" correlation of f_2 = 440kN/m^2 was found to apply. Both the f_1 and f_2 values were found to increase with decreasing plasticity index.

A lack of statistical analysis is noted throughout the paper with no mention of a correlation coefficient for the relationship between f_1 and f_2 with plasticity index. Furthermore, the best fitting trend lines are not defined in terms of their type and function. In addition, the paper does not state if corrections were applied to the N values.

A year later Stroud & Butler (1975) examined relationships between SPT N values with undrained shear strength and the coefficient of volume compressibility of glacial materials.

The f_1 values were found to range from 4.4 to 7.0kN/m^2 with f_2 values ranging from 350 to 750kN/m^2. The f_1 and f_2 values were found to increase with decreasing plasticity index. The f_1 and f_2 values were plotted against plasticity index along with the previous cases provided by Stroud (1974) and similar charts were produced. Again there is a lack of statistical analysis and provision of details.

Limited information is available on the correlation between the coefficient of volume compressibility and SPT N value. An f_2 value of 450kN/m^2 was recommended for materials of medium plasticity and 600kN/m^2 for materials with a plasticity index of <20%.

A literature review encompassing data obtained from the UK (Stroud & Butler), the US (Sowers), Singapore (Kar Winn) and Turkey (Sivrikaya & Togrol) was undertaken by Reid to obtain an overview of the current information within the knowledge base regarding the correlation of SPT N values, undrained shear strength and coefficient of volume compressibility.

The determination of undrained shear strength of fine grained soils by means of SPT and its application in Turkey is discussed by Sivrikaya & Togrol (2006). Unlike previous authors this paper examines relationships between SPT N values and undrained shear strength from

Table 1: Comparison of studies with f_1 values

Author	Soil Type	f_1 range	f_1 average
Sowers	Highly plastic clay	7.1 to 16.5	-
	Medium plastic clay	4.7 to 9.5	-
	Low plastic clay and plastic silts	2.4 to 4.7	-
Stroud	35<IP<65	4 to 5	-
	IP<20	>6	-
Sivrikaya & E Togrol	Fine-grained soil	2 to 17.5	6.09
	CH	2.25 to 17.5	7.52
	Clay	2.12 to 17.5	6.38
	CL	2.12 to 13	4.98
	ML	2.68 to 6.67	4.22
	MH	2 to 6.88	3.8

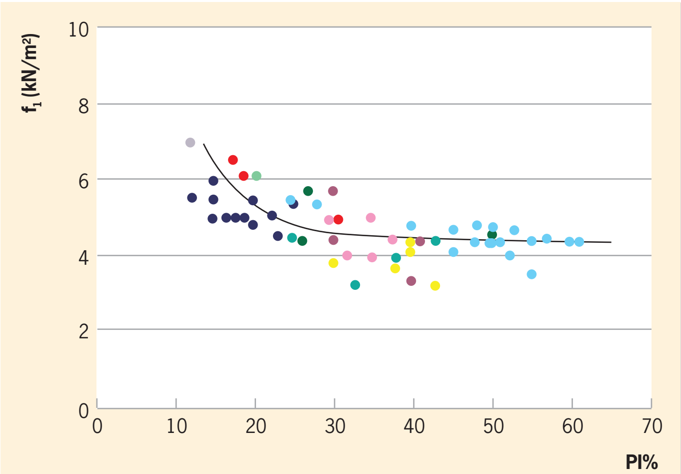

Figure 1: f_1 plotted against plasticity index (Stroud & Butler 1975, p128)

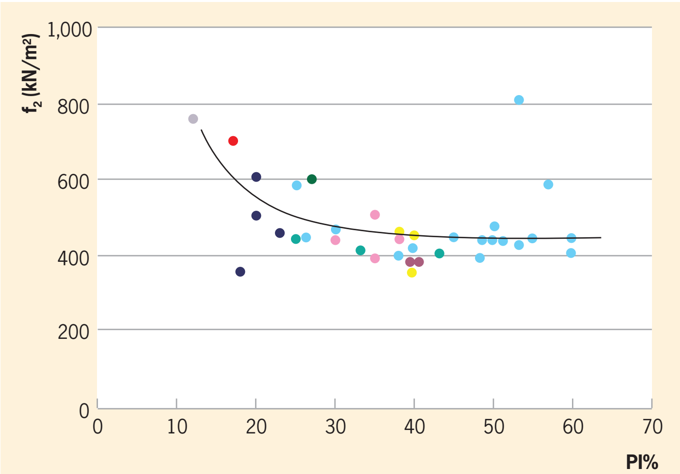

Figure 2: f_2 plotted against plasticity index (Stroud & Butler 1975, p129)

a statistical point of view, taking account of test types and SPT corrections.

The authors indicate that the use of the current correlations without making corrections to the "field" N values can lead to "erroneous results and designs" (Sivrikaya & Togrol 2006, p54). In addition the authors make mention that no statistical analysis has taken place to establish the significance of the correlations previously published.

Sivrikaya & Togrol's analysis of the relation between SPT N values and undrained shear strength highlights that, in most cases, f_1 increases with an increase in plasticity of clay supporting the findings by Sowers (Sowers 1979 after Sivrikaya & Togrol 2006) but opposing the findings by Stroud (1974). The comparison of studies in Table 1 displays the similarities and differences of the value of f_1 in relation to soil type.

The findings by Sivrikaya & Togrol show that the correlation between SPT N value and undrained shear strength are of medium significance and can be used in relation to soil type for the "preliminary" design stage only.

Limited information is available on correlations between the coefficient of volume compressibility and SPT N value. In addition, the correlations all too often refer to unconfined compressive strength (Terzaghi & Peck, 1948) as opposed to undrained shear strength and do not differentiate between uncorrected and corrected N values.

Furthermore, the f_1 values are noted to vary between 2 to 17.5 and the correlations differ with respect to the factor f_1 as to whether or not it will increase or decrease with decreasing plasticity index (Stroud & Butler 1975; Sowers 1979 after Sivrikaya & Togrol 2006). Moreover, the lack of statistical information and correlation coefficients within most of the literature means the significance of the correlations cannot be determined.

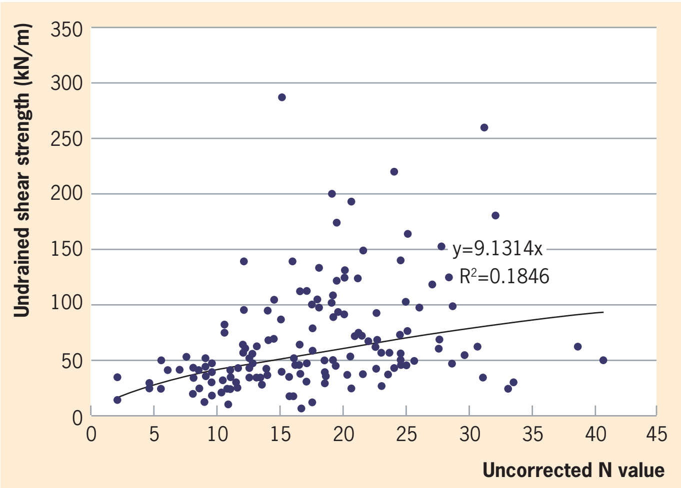

Figure 3: Uncorrected N value versus undrained shear strength

Comparisons and differences in the correlations

The historical correlations:

- do not differentiate between uncorrected and corrected N values
- all too often refer to unconfined compressive strength as opposed to undrained shear strength
- do not show statistical analyses to substantiate the published associations
- consider the correlations sufficient to provide reliable results notwithstanding that the database is limited geographically
- differ with respect to the factor f_1 as to whether or not it will increase or decrease with decreasing plasticity index.

The correlations by Sivrikaya & Togrol:

- do differentiate between uncorrected and corrected N values
- do relate the uncorrected and corrected N values to undrained shear strength
- do provide statistical analysis to support their findings
- do agree with the work of Sowers that the value of f_1 increases with an increasing plasticity index
- recommend the use of the correlations for "preliminary" design work only.

Given the lack of statistical information and correlation coefficients within most of the literature the significance of the correlations must be questioned.

Results

The statistical analysis undertaken of ground investigation data held by South Lanarkshire Council used multiplying factors A_1 and A_2. The factors used were required to change the corresponding uncorrected SPT N value into an undrained shear strength and coefficient of volume compressibility respectively.

The known values were obtained from triaxial and oedometer tests carried out on undisturbed samples obtained by a U100 sampler (following the procedure of Stroud & Butler).

The A_1 and A_2 multiplying factors do not equate directly to the factors f_1 and f_2 as described by Stroud & Butler (1975) as these latter values are linked directly to the individual plasticity index of each sample. In contrast Reid formed three individual datasets comprising low, intermediate and high to extremely high plasticity values respectively with a further dataset comprising all three datasets.

The descriptive statistical analysis undertaken of the undrained shear strength datasets found the mean of A_1 to be approximately 4. This mean value is similar to the mean f_1 values of 5 and 5.5 provided by Stroud & Butler (1975) and Sivrikaya & Togrol (2006) respectively.

However, as the A_1 values were found to range from 0.18 to 19.30, further analysis was undertaken to determine whether or not actual correlations or an association could be found between the parameters.

The relationship between uncorrected N value and undrained shear strength is illustrated in Figure 3. Hypothesis testing indicates that there is little, if any, correlation of significance between these two parameters. The R^2 value of less than 0.2 indicates that there is no significant association between the uncorrected N value and undrained shear strength.

The descriptive statistical analysis undertaken of the coefficient of volume compressibility datasets found the mean value for the multiplier A_2 to be approximately 500, again comparing favourably »

» with the average value of 450 published by Stroud & Butler.

However, as the A_2 values were found to range from 175 to 1,370, further analysis was carried out to determine whether or not actual correlations or associations could be found between the parameters. With an R^2 value of 0.2018, no significant association could be found between uncorrected N value and the coefficient of volume compressibility, as indicated by Figure 4.

The use of hypothesis testing and correlation coefficients to analyse the data for the South Lanarkshire Council area found that the majority of relationships between the various parameters are of little or no significance.

The associations that are of low or moderate significance only apply to soil groups of specific plasticity and as such negate the application of the correlation to this geographical area. A further shortened check on "corrected" N values yielded findings with lower R^2 values to those discussed above.

Conclusion from the review on SPT applicability

The use of such rules of thumb without a full understanding of their relationships in terms of significance and underlying experimental error will lead to the incorrect application of these multiplying factors. The use of such values may lead to erroneous design values when compared to laboratory values obtained.

The findings confirm the guidance given in Eurocode 7 that the use of the SPT should be restricted to a "qualitative evaluation of the soil profile" as there is "no general agreement on the use of SPT results in clayey soil" (British Standard 2007a, p50); the SPT is mainly used for the determination of strength properties in coarse soils.

Moreover, "if an empirical relationship is used in the analysis, it shall be clearly established that it is relevant for the prevailing ground condition" (British Standard 2010, p23). Consequently, in September 2009 South Lanarkshire Council instituted a continuous sampling methodology for future ground investigation works.

The implications of Eurocode 7

The use of continuous sampling allows undisturbed samples of fine soils to be obtained by U100 sampling via the standard shell and auger soil rig. Triaxial tests can be carried out on the undisturbed samples and the resultant values of undrained shear strength used to classify the strength of soil in terms of BS EN ISO 14688-2:2004 (2007b).

Standard interpretative practice of South Lanarkshire Council is to plot all data onto Excel spreadsheets and charts to view the data and determine if any correlations can be found, for example increasing undrained shear strength with depth. This statistical practice is reinforced by Eurocode 7 as a means to demonstrate how one obtains the characteristic value of the site and subsequently the design value (a cautious estimate of the characteristic value).

Experience within South Lanarkshire has shown that determining the characteristic value can be difficult. Typical data (Figure 5) illustrates the lack of correlation between undrained shear strength and depth. This is not unusual and indeed a site displaying a significant association between undrained shear strength and depth has yet to be found.

For sites with this type of data, with a range of undrained shear strengths at the same horizon, the key question is how to arrive at a suitable characteristic value: too low a value could negate the development of the site while too high a value could result in overestimated bearing capacities. Eurocode 7 does provide some help in as much as local knowledge or judgement can be used. However, while this may be feasible for Category 1 developments it is unlikely to meet the test of Category 2 or 3 developments.

Of greater concern is that, as Eurocode 7 is now "live", guidance within BS EN ISO 22475-1:2006 (2007c), Table 2 (column 9 and 10, row 12) discloses that undisturbed samples of fine soils obtained by a shell and auger U100 sampler will only meet the specification of Category C or at best Category B, equivalent to soil quality class 4 or at best class 3.

The view is that undisturbed samples obtained from Category C have been altered and must be regarded as disturbed samples. Consequently such samples are unsuitable for testing for shear strength or for compressibility (class 1) as provided in BS EN 1997-2:2007.

However, according to paragraph 6.4.2.6.3 of the BS EN ISO 22475-1:2006 (2007c, p.25) "Thick-walled open-tube samplers are mostly suitable for stiff and dense soils and for soils containing coarse particles (see line 2 of Table 3).

"For soil types that are difficult to sample, sample-retaining or closure devices are necessary." Furthermore, according to

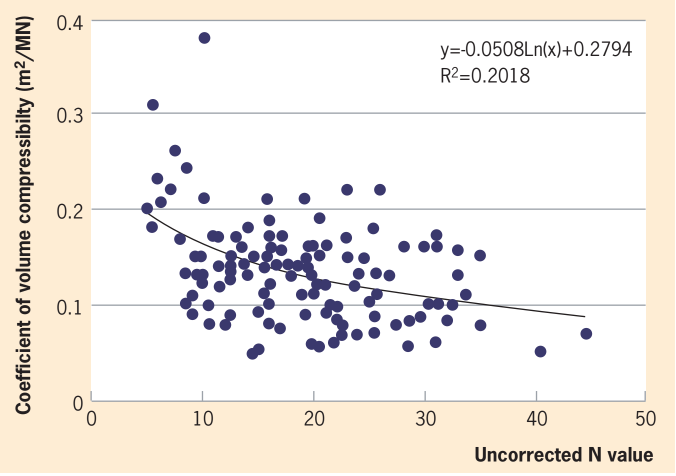

Figure 4: Uncorrected N value versus the coefficient of volume compressibility

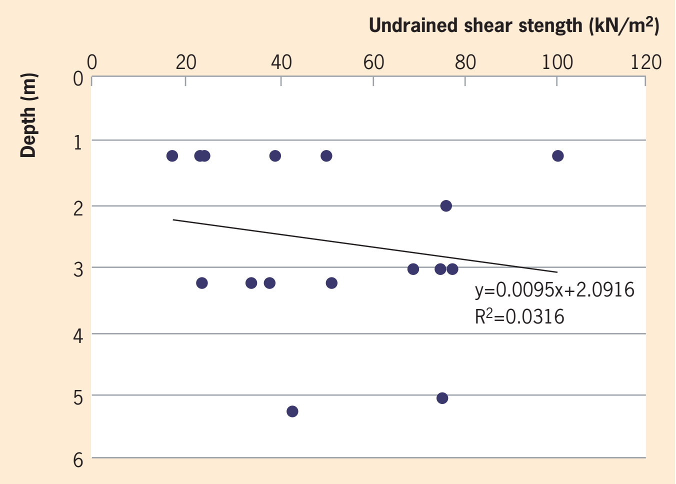

Figure 5: Typical undrained shear strength versus depth

paragraph 6.4.2.6.4: "The thick-walled open-tube sampler is usually regarded as a category B sampling method."

It is also to be noted from Table 3 that open-tube thick-walled samplers are suitable for category B class 3, but may be suitable for category A class 2, if soil conditions are favourable.

The table also states that open-tube thick-walled and thin-walled samplers are unsuitable for use in "firm cohesive" soils. There appears to be some confusion in the terminology used in columns 5 and 6 of Table 3 in that it is unclear if the phrase "firm cohesive" used in column 5 relates to strength whereas it is clear that "firm" used in column 6 refers to consistency.

If column 5 refers to strength then it is apparent that open-tube thick walled and thin walled samplers are only suitable for soils with an undrained strength less than medium with soils of greater undrained strength requiring investigation by rotary cored wireline drilling or similar.

Notwithstanding the foregoing, it is evident that the open-tube thick-walled sampling will not provide class 1 samples and as such it would seem, at least from a Scottish point of view, that rotary cored wireline drilling could become the "standard" replacement for the shell and auger rig to provide samples suitable for strength and compressibility testing.

However, again there is conflict with BS EN ISO 22475-1:2006 as, according to Part 2 (2007a, p75), class 2 samples can be used for strength tests etc. Indeed, for certain soil or special purposes, shear strength tests can be carried out on reconstituted or remoulded specimens (2007a, p74).

Baldwin & Gosling (2009) provide an insight into the implications that BS EN ISO 22475-1:2006 will have for geotechnical sampling in the UK. To comply with the new guidance engineers should specify thin-wall samplers to ensure class 1 samples are obtained during the ground investigation.

According to the article by Baldwin and Gosling (*GE*, March 2010) the development of a thin-wall open drive tube sampler that complies with the requirements stated in BS EN ISO 22475-1:2006 is now available on a commercial basis. Subsequently, Baldwin & Gosling (2010) discussed the development and field trials of a thin wall open drive sampler (UT100).

The field trials were carried out in a variety of soil types, including glacial tills, but were limited to sites in England. The results allowed Baldwin & Gosling to conclude that "the UT100 sampler is capable of taking a sample that meets the standard as being suitable for strength and compressibility testing in the laboratory".

Baldwin & Gosling also state: "Down to about 9m the undrained shear strengths determined from the UT100 and U100 without a liner are similar to each other, whereas those determined on the U100 with a liner are much lower."

Albeit the information may be geographically limited, it begs the question why the U100 without a liner cannot be used at least in some areas. The article also points out that "undrained shear strengths of between about 50kPa and 220kPa have been measured in the laboratory on the samples recovered from the UT100".

The higher values indicate soils of very high strength, analogous to the former description of "very stiff" soils in terms of BS5930 (2007d) and as such it is unclear as to whether or not the use of the UT100 sampler in these soils would comply with Table 3 of BS EN ISO 22475-1:2006.

In January 2010 South Lanarkshire Council commenced limited field testing of the Archway UT100 cutting shoe, following the guidelines provided in Eurocode 7.

To date testing has been very limited and only carried out on two sites. In both instances the sites comprised medium-to-high-strength boulder clays.

The results on the cutting shoe are shown below. During the trials crumpling and deformation of the cutting shoe was noted. The results tend to indicate that, due to the nature of Scottish glacial tills, which can include pre-consolidated fine soils with gravel, cobble layers and or boulders, the use of this type of shoe is unlikely to produce undisturbed samples that would comply with Eurocode 7.

Notwithstanding that the testing was limited, the indications are that the UT100 sampler is unlikely to be suitable for the geographical area of South Lanarkshire. Indeed the contractor involved in the testing has been advised by Archway that the UT100 will not be suitable for the Scottish area.

On this basis it would seem that the only alternative will be to utilise rotary cored wireline drilling with the attendant increase in cost and possibly time, unless clarification of Tables 2, 3 and 4 of BS EN ISO 22475-1:2006 can be produced by the Technical Committee.

The experience in South Lanarkshire is that, irrespective of the type of sampler used, there can be no guarantee that the quality of data when plotted on an Excel chart will provide any better correlations than those that are typically obtained.

The problem is not so much about quality of samples but about the interpretation of the results. After all, a test is only a test carried out on a sample from a specific locality, it is not definitive. It is the geotechnical engineer who must arrive at a design value as design values obtained from a laboratory test.

The use of rotary cored boreholes to obtain suitable undisturbed soil samples has major implications for the Scottish market, not least in cost and time. Inevitably there is the option to scale back the extent of the investigation to control costs, but this is likely to lead to a reduction in the amount of detail across the site.

Limiting the detail simply means decreasing the sample size of the data and, consequently, increasing the margin of error. In other words obtaining good quality samples and obtaining results thereof is of little use if you have an insufficient sample size upon which to statistically determine the characteristic value and subsequently the design value.

It could be argued that it is up to the geotechnical engineer to specify what is required within the ground investigation – the contractor merely carries out the requirements of the engineer.

Therefore there is the potential that, if the engineer does not comply with Eurocode 7 and damage to a structure is subsequently sustained, then the engineer could be held liable for non-compliance.

Scottish soils are notoriously variable and, as such, there is a need for flexibility in obtaining samples, in terms of number and cost. Accordingly there is a need for a comparable sampler to the U100 which meets the standard set by Eurocode 7.

The work to date carried out by Baldwin & Gosling is to be commended but it needs to be extended to other geographical areas, after all Eurocode 7 is a European guidance note.

Further testing might reveal that the UT100 is satisfactory for some particular types of Scottish clays and would provide some degree of an alternative to rotary cored wireline drilling, subject to amendment of Table 3.

However, it is unlikely that sites will fall into a neat category to suit only rotary cored drilling or piston sampling etc; more likely sites will require a combination of methods, for example to allow pre-boring of medium-to-high-strength clays to allow insertion of a soil sampler to sample underlying clays of medium strength or less.

Availability of rotary or soil rigs may prove to be a problem, in turn extending the period normally expected for the site investigation.

While the objective behind Eurocode 7 is to be welcomed it would seem that there is a lack of awareness of the implications of the code by professionals and contractors alike. One thing is for sure, Eurocode 7 is not going to go away.

It would seem sensible for the industry as a whole to gather now, before it gets too late, and work as one to better understand the implications of the new code.

A deformed (left) and new (right) Archway UT100 cutting shoe provided by BAM Ritchies

References

Baldwin, M and Gosling, D (2009)
Technical note – BS EN ISO 22475-1: Implications for geotechnical sampling in the UK. *GE*, vol. 42, No. 8, pp28-31.

Baldwin, M and Gosling, D (2010)
Technical note – Development of a thin wall open drive tube sampler (UT100). GE, vol. 43, No. 3, pp37-39.

British Standard (2007a)
Eurocode 7 – Geotechnical design – Part 2: Ground investigation and testing. British Standard Institution, BS EN 1997 -2:2007, ISBN 0 580 50569 0.

British Standard (2007b)
Geotechnical investigation and testing – Identification and classification of soil – Part 2: Principles for a classification. British Standard Institution, BS EN ISO 14688-2:2004, ISBN 0 580 47508 5.

British Standard (2007c)
Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution. British Standard Institution, BS EN ISO 22475-1:2006, ISBN 0 580 5056 9.

British Standard (2007d)
Code of practice for site investigations. United Kingdom, British Standard Institution, BS 5930:1999, ISBN 0 580 61622 8.

British Standard (2010)
Eurocode 7 – Geotechnical design – Part 1: General rules. United Kingdom, British Standard Institution, BS EN 1997 – 1:2004 – Incorporating corrigendum February 2009, ISBN 978 0 580 67106 7.

Charles, J.A. (2005)
Geotechnics for building professionals. Watford: British Research Establishment.

Reid, A D (2009)
The use of the standard penetration test to estimate the undrained shear strength and the coefficient of volume compressibility of clay soils; MSc dissertation, University of Glasgow.

Sivrikaya, O and Togrol, E (2006)
Determination of undrained shear strength of fine-grained soils by means of SPT and its application in Turkey. Engineering Geology, 86, pp 52-69.

Stroud, M A (1974)
The standard penetration test in insensitive clays and soft rocks. In Proceedings of the European Symposium on Pentration Testing ESOPT, Stockholm 1974. Stockholm, National Swedish Building Research, pp367-375.

Stroud, M A and Butler, F G (1975)
The standard penetration test and the engineering properties of glacial materials. In: Proceedings of the Symposium of glacial materials, University of Birmingham, April 1975.

Terzaghi, K and Peck, P (1948)
Soil mechanics in engineering practice, 1st ed. London: Chapman & Hall, pp 299-300 & 430-431.

Tomlinson, M J (2001)
Foundation design and construction. 7th ed. England: Pearson Prentice Hall, p11.

Winn, K, Rahardjo, H and Peng, S C (2001)
Characterization of residual soils in Singapore. Journal of the Southeast Asian Geotechnical Society, Vol. 32, No. 1. pp1-13.