Ground investigation and Eurocode 7: A Scottish perspective

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Introduction

As everyone in the geotechnical community should already know, the foreword to EN 1997-2:2007 states: "This European standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2007, and conflicting national standards shall be withdrawn at the latest by March 2010." On the matter of soil and rock sampling and groundwater measurements, section 3.2(2)P of EN 1997-2:2007 states: "The requirements of EN ISO 22475-1 shall be followed."

Just over a year has passed since the above documents have become the accepted standards of the industry. To date, the experience of South Lanarkshire Council is that complying with the documents, in particular EN ISO 22475-1:2006, has been difficult, a view echoed by professional colleagues in both consultancy and contracting.

This paper briefly outlines the difficulties experienced by South Lanarkshire Council in complying with Eurocode 7, by referring to relevant sections of EN 1997-1:2004, EN 1997-2:2007 and EN ISO 22475-1:2006, and proposes a way forward that seeks to comply with the philosophy of Eurocode 7.

Eurocode 7: General

According to Bond and Harris (2008) a distinctive feature of the Structural Eurocodes is the "separation of paragraphs into Principles and Application Rules. Design which employs the Principles and Application Rules is deemed to meet the requirements provided the assumptions given in EN 1990 to EN 1999 are satisfied. Principles identified by the letter 'P' after their paragraph numbers – are general statements and definitions that must be followed, requirements that must be met and analytical models that must be used. The English verb that appears in Principles is 'shall'. Application Rules – identified by the absence of a letter after their paragraph numbers – are generally recognised rules that comply with the Principles and satisfy their requirements. English verbs that appear in Application Rules include 'may', 'should', 'can' etc."

EN 1997-2:2007 Ground Investigation and Testing

Section 3.4(2)P states: "Three sampling method categories shall be considered (EN ISO 22475-1), depending on the desired sample quality as follows (for sample quality see table 3.1)." Table 3.1 specifies the quality classes of soil samples for laboratory testing and sampling categories to be used; at this stage it is noted that compressibility and shear strength can only be tested on soil samples of quality class 1 obtained by category A sampling methods.

For the avoidance of doubt, as commented by Powell (BGA, 2007), this implies that "only certain sampling methods can be used to obtain samples of a certain quality class". A critical issue arises that due to the type of soils within the geographical area of South Lanarkshire Council (and indeed across many parts of Scotland), in particular stony glacial tills, the adoption of certain sampling methods is not possible, which in turn has limited the potential to obtain samples of quality class 1.

Section 3.4.3, Planning of Soil Sampling, sub-section (1)P states: "The quality class and number of samples to be recovered shall be based on the aims of the soil investigations, the geology of the site, and the complexity of the geotechnical structure and of the construction to be designed." Before planning the ground investigation a desk study should always be carried out (3.4.2(2) of EN 1997-2:2007, 6.2(3) P of EN 1997-2:2007, SISG 2, 1993; AGS, 2006).

As mentioned in section 2.1.1(6) "the available information and documents should be evaluated in a desk study". The desk study should collate all the available information pertaining to the site and is an initial or preliminary appraisal which forms the basis for the ground investigation. However, there can be no guarantee that the information obtained from the desk study, especially regarding soil types, will actually reflect what is in the ground.

While it is the practice within South Lanarkshire Council to carry out a desk study before undertaking a ground investigation, it is not uncommon to find that the soils within the site are not as anticipated from the available geological information or from the environmental geology maps available for the required study area. This is generally the case when investigating soils emanating from glacial origins, in particular the group of soils generically referred to as "glacial till".

In reality this term does not refer to a single soil type, but rather to a broad and complex spectrum of deposits that can range from completely stoneless clays to "clean" sands and gravels. Moreover, the engineering properties of glacial till are also subject to significant variation, depending on a complex inter-relation of factors including source lithology, glacio-tectonics and weathering. These factors mean that it is difficult in practice to predict what form glacial till deposits will take from the generic information that is typically available at the desk study stage.

Section 3.4.3(3)P states: "The sampling categories shall be selected considering the desired laboratory quality classes, as detailed in table 3.1, the expected soil types and groundwater conditions." Thereafter, section 3.4.3 sub-section (4)P states "the requirements of EN ISO 22475-1 shall be followed, for the selection of the drilling or excavation methods and sampling equipment adequate to the soil sampling category prescribed". Compliance with this requirement has proven difficult. As mentioned, all too often the predicted soil type as gleaned from the desk study proves to be too generic. Thus choosing suitable sampling equipment to obtain the desired samples of the necessary quality class has become increasingly difficult.

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EN ISO 22475-1:2006 Geotechnical investigation and testing

EN ISO 22475-1:2006 provides detail on sampling equipment and testing. Section 6 – Soil Sampling Methods – is an important section of the standard. Table 1 of sub-section 6.2 details the categories of soil sampling methods pointing out that certain classes of soil sample can only be obtained by certain sampling categories. In this regard table 1 presumes that the various sampling methods for each category can indeed provide the stated class of soil sample.

As will be shown, it is the view of the authors of this paper that this is not always the case, in some instances it may be necessary to change equipment or bring on other sampling equipment which will have a knock-on effect to both cost and time for the ground investigation: aspects which some clients will not be prepared to fund. Furthermore, according to Powell (2007): "There is, in places, a lack of detailed guidance, particularly on the planning and extent of site and ground investigations compared with eg BS5930:1999."

For example, consider sub-section 6.3.2.2.1, which refers to sampling by rotary drilling, wherein reference is made to "flushing medium is used", but no guidance is provided to assist with the selection of flushing medium that should be used, bearing in mind that sub-section 6.3.2.2.5 states, "sampling by rotary core drilling is generally suitable for clay, clayey and cemented composite soils and boulders; it is unsuitable for all non-cohesive soils".

It would be useful for the document to contain some guidance, even if it was to dissuade the use of certain flushing media, given the potential effects that, for example, water may have on clay deposits. In contrast, Section 20.7.3 of BS 5930:1999+A2:2010 points out: "Careful selection of the flushing medium, which is compatible with the ancillary surface and in-hole equipment employed, and which is suitable for the anticipated geological conditions to be drilled, is very important."

"It is difficult to know where the standard leaves us in the event that thin-walled samplers prove totally ineffective in soils including coarse particles."

The section continues by giving a description of the effects that the various flushing media can have on quality of soil samples. Whilst this information is helpful it has to be borne in mind that here again we are looking at the "anticipated geological conditions" which might not necessarily reflect those that are present in reality on site, particularly when dealing with stony glacial till deposits. Also, not all geotechnical designers will have the necessary experience of using rotary cored boreholes in fine soils, in which event the client is arguably faced with the cost for the designer gaining this experience.

In table 2, sampling by drilling in soils, on page 16 and 17, the achievable sampling categories and achievable quality class of soil samples are provided. From inspection of this table it is clear that there is only one method that will achieve a quality class 1 sample in all cases, that is rotary core drilling using a triple-tube corebarrel (conventional or wireline corebarrel).

Single or double-tube corebarrels are considered to lie within the achievable sampling category B or at best A, "in particularly favourable ground conditions, which shall be explained in such cases". Rotary core drilling using a double/triple-tube corebarrel with extended inner tube is regarded as an achievable sampling category A, but will only produce a quality class 2 sample unless favourable ground conditions can be explained. Table 2 quite clearly infers that obtaining a quality class 1 sample by drilling in fine soil deposits will be difficult.

Consider the foregoing in the context of Section 22.2 of BS 5930:1999+A2:2010 which states: "Whichever sampling methods are used, it is sometimes only possible to obtain samples with some degree of disturbance, ie class 2 at best." This latter statement would appear to be at odds with EN ISO 22475-1:2006, which seems to infer that class 1 samples can be obtained, if this were not the case then surely EN ISO 22475-1:2006 would have provided guidance for this dilemma?

According to sub-section 6.4.1.2: "Depending on the soil conditions, different samplers can be used (see table 3)." On examination of table 3, soil sampling using samplers, it is noted that there are three samplers that will provide category A, quality class 1 samples, two of which are thin-walled with the third being a large cylinder sampler.

As is mentioned later the authors have been unable to obtain a suitable cutting shoe that complies with the geometry stated in Section 6.4.2.3.2 of sufficient durability to penetrate stony glacial till without deformation.

Figure 1: deformation of thin-walled cutting shoe in stony glacial till

While the use of a cylinder large sampler is stated it should be borne in mind that it is difficult to use and limited to particular types of soils (Clayton, 1995).

Furthermore, on examination of table 3 it is observed that there appears to be a number of contradictions. Consider line one, columns five and six. According to column five the use of thin-walled soil samplers is unsuitable for "firm cohesive soils, soils including coarse particles" yet in column six the same sampler is recommended for use in "cohesive or organic soils of soft or stiff consistency", so are we to believe that the sampler is unsuitable for firm cohesive soils?

As a further example consider line two of the table, which refers to a thick-walled soil sampler. In column five it is stated that this sampler is unsuitable for "pasty and firm cohesive or organic soils, soils including coarse particles", yet in column six the sampler is recommended for use in "cohesive or organic soils of soft to stiff consistency, and including coarse particles". Similar confusion arises from line one of table 3, which states that a thin-walled soil sampler is considered to be a category A method and can produce an achievable quality class 1 sample, while line two notes that in favourable conditions a thick-walled soil sample can be considered as a category A method producing a quality class 2 sample.

Again, consider the foregoing statements with that provided in Section 22.4.4 of BS 5930:1999+A2:2010 which states: "In fine soils of stiff or lower consistency, the standard open tube sampler may sometimes give class 2 samples but, more often, class 3 samples. In brittle or closely fissured materials, such as certain weak rocks and very stiff clays, and also in stony materials, the sampler gives class 3 samples; this is because sampling disturbs these materials, reducing the sample quality to class 3, or class 4 if water has been added to the borehole." Clarification of all these contradictions would be welcome.

Sub-section 6.4.2.6.3 states, "thick-walled open-tube samplers are mostly suitable for stiff and dense soils and for soils containing coarse particles (see line two of table 3)". Looking at sub-section 6.4.2.6.4 it is stated that: "The thick-walled open-tube sampler is usually regarded as a category B sampling method." Again, clarification of this would be welcomed as the sample obtained could be a category A class 2, according to table 3, or even less according to BS 5930:1999+A2:2010.

On page 28, table 4, which »

» refers to examples on sampling methods with respect to the sampling category in different soils, it is noted that open tube thick-walled samplers can be used to obtain category A samples, but only in favourable conditions and subject to the detailed geometry. However, the table does indicate that suitability depends on stiffness, strength, sensitivity and plasticity. While this apparent piece of flexibility is welcomed, the experience of the Scotland-based authors is that it is difficult to gauge these likely parameters based on the information compiled from a desk study when, as has been mentioned, the geologic information is typically generic and potentially subject to significant variation between and indeed also within sites.

On the matter of the geometry of an open tube thin-walled sampler South Lanarkshire Council, through the auspices of a contractor, knows that the main manufacturer for cutting shoes, Archway, has been unable to manufacture a thin-walled sampler cutting shoe that will not deform during use in certain soil types such as stony glacial till (see Figure 1). According to Archway, the standard does not take into account the practicalities of sampling and manufacturing a suitably robust product. It is difficult to know where the standard leaves us in the event that thin-walled samplers prove totally ineffective in soils including coarse particles.

The difficulties discussed so far highlight, certainly from the authors' point of view of working within the geographical area of central Scotland, that compliance with EN ISO 22475-1:2006 and, as such, compliance with EN 1997-1:2004 may not be fully achievable. This is not to say that compliance will never be attained.

Given that every site is unique, it might well be that at some point in time on some site compliance will be achieved. However, ground investigation work undertaken to date indicates that this compliance for most of the sites within areas underlain by stony glacial till would seem unlikely.

Therefore, if the geotechnical designer, rightly or wrongly, is not fully aware of the contents of this standard then there is the likelihood that practitioners will simply follow the tables and potentially assume that the table says that the use of a particular type of sampling equipment will provide a particular quality sample class. This could mean that samples of less than class 1 could be used for strength and compressibility testing when in fact they should not be.

Table 1: Laboratory results for site 2

Borehole	Depth (mbgl)*	Triaxial (kN/m²)	Type of Test	Sampler	Soil Type**
CPBH05P1	1.2	70	single stage	U100 plastic	firm sandy silty CLAY
CPBH05P2	1.2	58	multistage	UT100	firm/soft sandy silty CLAY
WRBH05P	1.4	59	single stage	wireline	firm sandy gravelly CLAY
WRBH05P	2.7	146	single stage	wireline	firm sandy gravelly CLAY
CPBH05P1	2.75	164	single stage	U100 plastic	firm/stiff sandy gravelly CLAY
CPBH05P1	3.9	59	multistage	U100 plastic	firm/stiff sandy gravelly CLAY
CPBH05P2	4.3	171	single stage	U100 15°/111.50 OD	firm/stiff sandy gravelly CLAY
WRBH05P	4.8	168	single stage	wireline	stiff/firm sandy gravelly CLAY
CPBH07P1	4	311	single stage	U100 plastic	firm/stiff sandy gravelly CLAY
WRBH07P	1.75	-	-	wireline	slightly gravelly, silty SAND
WRBH07P	3.05	-	-	wireline	slightly gravelly, silty SAND
WRBH13P	1.5	80	single stage	wireline	soft/firm silty sandy gravelly CLAY
CPBH13P2	1.6	150	single stage	UT100	stiff/firm sandy CLAY
CPBH13P1	1.7	148	single stage	U100 steel	firm/stiff sandy gravelly CLAY
CPBH13P2	2.6	68	single stage	UT100	firm/soft laminated silty CLAY
CPBH13P1	3.0	81	single stage	U100 steel	firm/soft laminated silty CLAY
WRBH13P	3.2	29	multistage	wireline	soft gravelly silty CLAY
CPBH13P1	3.7	101	single stage	U100 steel	firm/soft laminated silty CLAY
CPBH13P2	4.1	51	single stage	U100 15°/115 OD	stiff sandy gravelly CLAY
CPBH15P1	4.5	261	single stage	U100 steel	stiff sandy gravelly CLAY
WRBH15P	5.1	206	single stage	wireline	stiff sandy gravelly CLAY

(CPBH = cable percussion borehole; WRBH = wireline rotary borehole). *Metres below ground level, **EN ISO 14688-1:2002.

Adapting to EN ISO 22475-1:2006

Given the potential difficulties with EN ISO 22475-1:2006 how does the geotechnical designer keep on the right side of current best practice? The geotechnical engineers of South Lanarkshire Council gave thought to this question and concluded that the best way forward was to carry out their own field tests to confirm or otherwise that the requirements provided in tables 2, 3 and 4 of the standard were achievable within the typical sandy, gravelly glacial till with variable cobble and boulder content encountered within the geographical area of South Lanarkshire Council.

To date field tests on two sites have been carried out. These field tests reveal some interesting findings which are outlined below.

Site 1

This site had been previously investigated by the standard shell and auger rig using a U100 thick-walled open tube sampler with plastic liner, which is commonly used throughout the UK. The soils are typically medium to high strength sandy gravelly CLAY (a reworked glacial till). According to table 2 in the standard the use of rotary coring with a triple-tube corebarrel will or should attain sampling category A and produce quality class 1 soil samples.

A second phase of investigation was undertaken with sampling being carried out using a Geobore S wireline rotary drilling rig with various flushing media of air, air-mist, water, foam and polymer. In all respects the sample cores recovered were "disturbed" to some extent. Where gravel was found within the sample, evidence was noted that this had been pushed and/or rotated within the sample, leading to gouging of the sample in some instances. This allowed infiltration of the sample by the various flushing media and caused a "washing out" of sandier soil with liquid flushing media and increased fracturing of the sample with air and air-mist.

The issue with sample quality and recovery appeared to be determined by gravel content and consistency of the matrix. While recovery was good for some of the core samples, the results indicated it would be unrealistic to say that the quality of the samples could have been regarded as class 1 as the full sample length had been subjected to the torque responsible for the gouging observed.

No testing of the samples was undertaken as the purpose of the

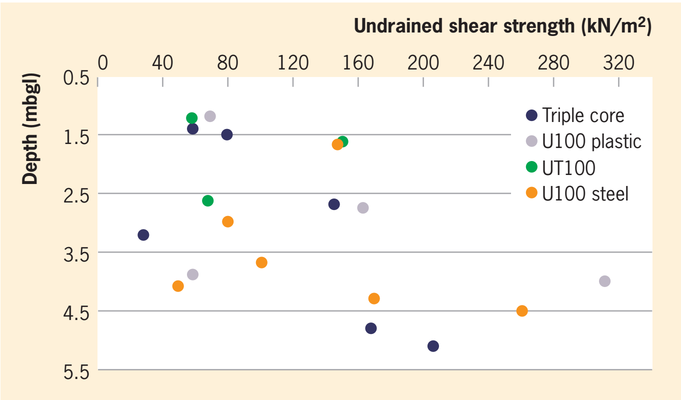

Figure 2: triaxial test data (sampler type)

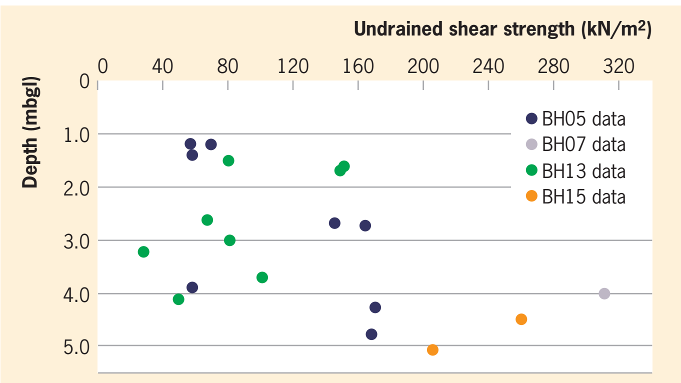

Figure 3: Triaxial test data (borehole number)

investigation was to simply test recovery methods through use of various flushing media.

Site 2

The purpose of this exercise was to compare and contrast the quality of samples retrieved and resultant test results obtained from three sampling methods.

Planning of the ground investigation for this site took into account the findings regarding the use of rotary cored borehole drilling gained from site 1. It was therefore decided to carry out the ground investigation in two parts. Whereas shell and auger drilling with driven sampling would have been normal practice, it was decided to carry out a series of test boreholes at specific "pilot" locations across the site. At each specific location up to three boreholes were drilled; either by the standard shell and auger rig using (a) thick-walled U100 samplers with either plastic or steel liners and (b) using the new UT100 thin-walled sampler with the final borehole drilled using a Geobore S rotary drilling rig using triple-tube corebarrel.

Cutting shoes of differing edge taper angles and wall thickness were employed with UT100 liners for comparison purposes and to determine the usefulness of a more robust shoe. Shoes with a 10-degree and 15-degree cutting edge and 111.5mm and 115mm outside diameter were commissioned.

The geometry complies with the requirements of EN ISO 22475-1:2006 only if it can be proven there is no effect on sample disturbance. These shoes were damaged during the trials and the effect on sample quality cannot be determined. However, the fact that the cutting edge has deformed means that the shoe no longer complies with the specified geometry stated in EN ISO 22475-1:2006 and as such will not produce the required quality class of sample. The results of sample recovery and subsequent laboratory triaxial test results from the different methods could then be compared.

The relevant test boreholes were drilled at locations no greater than 2m apart to minimise the potential risk of lateral variation in soil properties. Four pilot locations were chosen numbered 05, 07, 13 and 15. Table 1 (above left) details the depth at which the samples were taken, the soil type at the sample horizon (consistency described per EN ISO 14688-1:2002), the type of sampler and liner used and the results of the triaxial tests carried out on the various samples.

It will be noted from Table 1 that both single stage and multistage

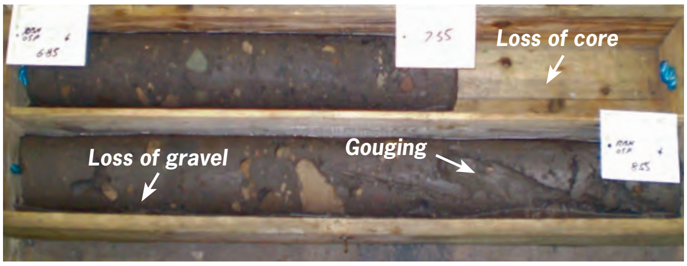

Figure 4: core of stiff with locally firm glacial till obtained by triple tube rotary core Geobore S drilling

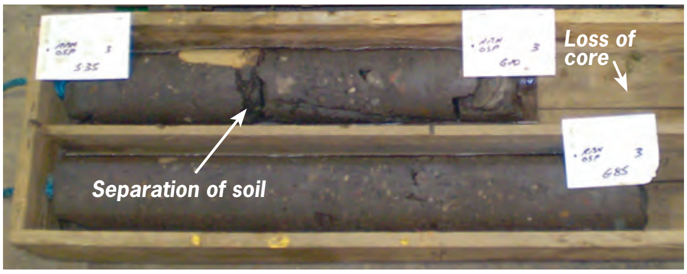

Figure 5: core of stiff with locally firm glacial till obtained by triple tube rotary core Geobore S drilling

Figure 6: very stiff glacial till

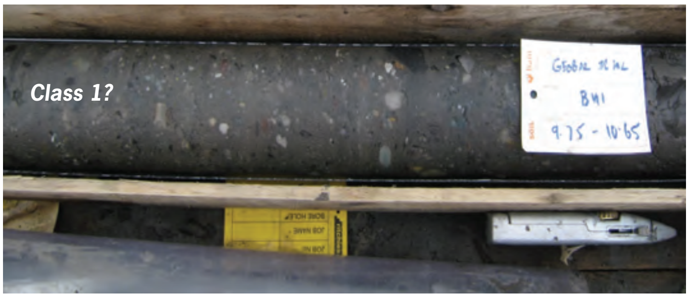

Figure 7: very stiff glacial till obtained by triple-tube rotary core Geobore S drilling

triaxial testing was carried out. While it is now standard practice to seek triaxial tests on three separate samples at different confining pressures, our laboratory contractors have indicated that within the geographical area of South Lanarkshire Council it is difficult to obtain acceptable specimens from either a U100 tube or rotary cored liner. This comment is not new, indeed, Anderson (1974) refers to such difficulty and recommended multi-stage testing of single specimens 100mm high by 100mm diameter.

The first thing to note is that Table 1 highlights the variability of the soils within the site, even over short lateral and vertical distances – such can clearly be seen in the case of borehole 13. The soil descriptions highlight the general presence of coarse particles.

From the triaxial test results plotted in Figures 2 and 3 it would seem, at least in a number of cases, that there is sufficient parity between the results to infer that there is little difference of sample quality/disturbance by way of sampling equipment for this particular site. What the information in Table 1 does highlight and confirm is the difference between the actual soil type within a site and the generic »

» description as may be obtained from a desk study.

For this particular site the drift geology maps simply indicated glacial till comprising "clayey, silty or sandy deposits with stones and boulders" – a common soil type throughout much of Scotland. Our experience within the South Lanarkshire Council area is that preliminary drilling is necessary to determine in more detail the soil type within the site and from this preliminary drilling, determine what type of sampling equipment should be used with reference to table 2 of EN ISO 22475-1:2006 to obtain the required quality class of sample: notwithstanding, there is no guarantee that the selected sampling equipment will produce a class 1 sample in such soil types, a factor that is likely to be exacerbated by the potential for variation in soil type across short distances both laterally and vertically.

Figure 4 illustrates an example of "good" rotary core recovery. However, note the gouging that has occurred, presumably due to gravel movement over the core together with the loss of gravel in part of the core and the slight loss of core recovery. In Figure 5, the loss of core recovery is more evident as is the movement of the core around the gravel. In both instances the soil consistency was described as "stiff".

In contrast, Figures 6 and 7 demonstrate what triple tube rotary core Geobore S drilling may achieve in very stiff stony cohesive glacial till at another site (regrettably this site does not lie within the geographical area of South Lanarkshire Council and no further information can be made available). In this particular example several runs were undertaken using polymer flush, but progress was slow.

Full core recovery was achieved on all the runs and the quality of the core recovered was high, much of it arguably class 1. While this does prove that rotary cored boreholes can provide quality class 1 samples this is not to say that such sampling equipment will always do so. The percentage and size of coarse particles within the soil and the type of flushing medium used could render this type of sampling equipment unsuitable.

Alternatively, it may well be that rotary drilling is only suitable for very stiff glacial till with minimum coarse particle content. The experience of the geotechnical designer will be important in answering these questions, but as has been mentioned this presupposes that the designer is sufficiently experienced in the use of these drilling techniques (rotary drilling of soils has certainly not been commonly-used in Scotland to date). If not, will the client be prepared to pay the cost for the designer's education?

> "There is thus evidence that comparable experience and local experience can be used in applying EN 1997-1:2004 and EN 1997-2:2007 provided, however, that the experience can be substantiated."

The results as shown in Table 1 and Figure 1 highlight that it may not always be possible to get good core recovery or a class 1 sample, or more important, a sufficient number of class 1 samples to determine a reasonable characteristic value from which to derive a design value. Bearing in mind that EN 1997-2:2007 states that only class 1 samples can be used to determine shear strength and compressibility, what is the geotechnical designer to do if class 1 samples cannot be obtained?

The use of local knowledge, experience and interpretation

On closer inspection of EN 1997-1:2004 and EN 1997-2:2007 it will be noted that reference is made to "comparable experience" and "local experience". In sub-section 1.5.2.2 of EN 1997-1:2004 a definition of "comparable experience" is provided and it states: "Information gained locally is considered to be particularly relevant." In general the import of these phrases is that local knowledge and experience can be used, for example to check design results (section 2.1(7)), for carrying out works considered as Geotechnical Category 1 (section 2.1(14) to (16)), checking the values of geotechnical parameters (section 2.4.3(5)) and for the selection of geotechnical parameters (section 2.4.5.2(1)P).

Similar examples can be found in EN 1997-2:2007, for example section 2.4.2.3(2) which states: "The laboratory test programme depends in part on whether comparable experience exists. The extent and quality of comparable experience for the specific soil or rock should be established." The amount of testing necessary (section 2.4.2.4(4)) can also be influenced by comparable experience. There is thus evidence that comparable experience and local experience can be used in applying EN 1997-1:2004 and EN 1997-2:2007 provided, however, that the experience can be substantiated.

Both documents also refer to the use of empirical methods and correlations. However, care is required in their use. For example, consider section 2.4.3(1)P (a mandatory requirement of EN 1997-1:2004) which states: "Properties of soil and rock masses, as quantified for design calculations by geotechnical parameters, shall be obtained from test results, either directly or through correlation, theory or empiricism, and from other relevant data." This statement certainly seems to indicate that interpretation, for example obtaining an estimate of undrained shear strength from standard penetration tests (SPT's) or cone penetration tests, (CPT's) can be carried out.

However, consider the statement when combined with section 4.2.3(4)P (also a mandatory requirement of EN 1997-2:2007), which states: "If correlations are used to derive geotechnical parameters/coefficients, their suitability shall be considered for each particular project"; and sub-section (5)P which also states: "When using Annexes D to K, it shall be ensured that the ground conditions of the site under investigation (soil type, uniformity coefficient, consistency index etc) are compatible with the boundary conditions given for the correlation. Local experience shall be used for confirmation, if available."

While Section 2.4.3(1)P indicates that interpretation can be applied, when it is read in conjunction with Section 4.2.3(4)P, bearing in mind both sections are principles, it is clear that the geotechnical designer can only use interpretation if the designer knows and can substantiate that the correlation, theory or empirical rule is appropriate.

Thus this leads to the question: how does the geotechnical designer know if the correlation, theory or empirical rule is appropriate? For example, in this regard, when dealing with SPT's section 25.2.3 of BS 5930:1999+A2:2010 it states: "Interpretation of the test results into derived geotechnical parameters is important but great care has to be taken when selecting correlations for this purpose. BS EN 1997-2 gives some examples of interpretation in Annex F; any correlations used should be reported in the Ground Investigation report. Unfortunately, a lack of enforced and consistent standardization for the drilling technique and SPT tests equipment outside the UK has meant that SPT results and soil parameters derived from data from other countries might not correlate with results from SPT's derived in accordance with previous UK standards."

As an example of this, research by Reid (2009) has shown that the standard correlation for converting SPT results into mass undrained shear strength published by Stroud & Butler (1974) is not applicable to certain fine soils within the geographical area of South Lanarkshire Council. Therefore, do sections 2.4.3(1)P and 4.2.3(4)P mean that in the event that the geotechnical designer wishes to use a correlation, theory, or empirical rule they will need to "prove" the research behind it before they can use it?

While the use of comparable and local experience is without doubt helpful in determining or analysing parameters and planning testing regimes etc, these tools do not transfer to EN ISO 22475-1:2006. Therefore they can only be helpful once the designer has the information from the ground investigation. The fundamental question therefore arises: what if the specified sampling equipment is not suitable for a particular geographical area and/or what if the designer cannot obtain quality class 1 samples to conclude the ground investigation? On these matters EN ISO 22475-1:2006 is unclear.

It could be argued that the designer could minimise the quandary above by considering insitu testing as a means to obtain the parameters of undrained shear strength and/or stiffness. Insitu testing could include cone penetration tests, dynamic probing, plate load tests and/or pressuremeter tests. While undoubtedly these forms of tests can prove useful, it must be remembered that in the context of testing within stony glacial till, their use may not be appropriate. For example, cone penetration and dynamic probing tests are unsuitable for stony glacial tills and in any event are only suitable for preliminary investigations, forming part of an overall ground investigation.

Furthermore, as mentioned in the previous section, the correlations used to determine undrained shear strength need to be substantiated as suitable for the particular site and in the case of dynamic probing, appropriate correlations are only just being developed (BS 5930:1999+ A2:2010). Pressuremeter testing has been used within Scotland to a limited extent, generally in soft clays, but again this type of test is not regarded as suitable for soils with excessive amounts of gravel size particles.

The use of plate load tests in boreholes is, to the authors' knowledge, unheard of in Scotland primarily due to the required diameter of the borehole and the resultant cost. It also has to be remembered that the use of all these tests is highly dependent upon the operator and the results obtained depend upon how close the soils within the site in question compare to those from which the empirical equations were derived. Consequently, within certain parts of Scotland, insitu testing may not be an alternative option.

Conclusions

Are we to believe that EN ISO 22475-1:2006 is as inflexible as it may seem? Do we honestly believe that if we cannot obtain a quality class 1 sample we cannot undertake strength and compressibility testing? If such were so, then surely we are in a worse position than we were prior to the mandatory application of Eurocode 7? For in effect we could not progress a ground investigation to its logical conclusion across certain locales.

The matter is further compounded by apparent contradictions in sample classes and the way in which these can be obtained: for according to section 5.8.2(1) of EN 1997-2:2007: "For the determination of the shear strength of clay, silt and organic soil, undisturbed samples (Quality Class 1) should be used..." However, section 5.8.2(7) states: "If samples of Quality Class 2 are tested, the effects of the sample disturbance should be considered in the interpretation of the results"; indicating that quality class 2 samples can be used to determine shear strength, which confirms the statement given in section 22.2 of BS 5930:1999+A2:2010 that: "The tests carried out on such samples should be treated with caution."

Given that table 3 indicates that a thick-walled sampler can be classed as a category A method producing quality class 2 samples, it would seem that this form of sampling equipment could be used to obtain samples for shear strength testing. However, this would not be the case for compressibility testing as section 5.9.2.2(1) states quite categorically that "undisturbed samples (Quality Class 1) shall be used".

Furthermore, the requirement by EN 1997-2:2007 for class 1 quality samples conflicts with BS 5930:1999+A2:2010 which latter guidance is supposed to be "non-contradictory complementary information" as mentioned in section NA.4 of the National Annex to BS EN 1997-1:2004 and with section NA.4 of the National Annex to BS EN 1997-2:2007, which refers to BS 5930:1999+A1:2007 which has been withdrawn and replaced by BS 5930:1999+A2:2010. In any event it is understood that where conflict arises, Eurocode documents supersede national guidance.

From the information to hand we remain in a quandary. EN 1997-1:2004 and EN 1997-2:2007 allow the use of comparable and local experience on the information subsequently obtained from the ground investigation through testing of soil samples and reviewing the data obtained from there. Unfortunately, EN ISO 22475-1:2006 does not allow the similar use of comparable and local knowledge to obtain suitable soil samples for testing; apparently use of the tables 2, 3 and 4 does not seem to take account of particular geographical and geological needs and the document provides no alternative guidance.

The authors of this paper are of the view that in such an event the designer needs to return to the controlling documents of EN ISO 22475-1:2006, namely EN 1997-1:2004 and EN 1997-2:2007. In these latter documents the use of comparable experience as amplified in section 1.5.2.2 of EN 1997-1:2004 is made clear. Accordingly, if it can be clearly demonstrated by comparable and or local knowledge that the relevant sampling equipment will not provide a quality sample of class 1, then alternative measures must be allowed. To this end the authors are of the view that:

- Initial or pilot drilling works should always be carried out to obtain a clearer picture of the underlying soil in comparison to the generic information obtained by the desk study;
- On receipt of the information from the pilot drilling works the formal ground investigation should be planned, where possible complying with the requirements of EN ISO 22475-1:2006;
- In the event that local knowledge and experience dictates that the use of particular sampling equipment will not provide appropriate quality class of samples, alternative equipment should be used to obtain lesser quality class of samples;
- Testing of lesser quality class of samples should be allowed subject to the inclusion within the geotechnical design report of the circumstances resulting in the use of lesser-quality class samples together with a statement confirming that the results have been utilised with an appropriate level of caution in arriving at design values.

Such a procedure would demonstrate the intent of the geotechnical designer to comply with the requirements of EN ISO 22475-1:2006 and substantiate reasoning where this could not be achieved. In effect, it is hoped that this procedure would be seen as "reasonable" practice on behalf of the geotechnical designer, although only time and perhaps legal decisions will tell if this is the case. Should the above practice be considered inappropriate then the fundamental question that remains to be answered is: in the event that recommended drilling and sampling equipment does not provide a quality class 1 sample, what does the geotechnical designer do to conclude the ground investigation?

It could be argued that recourse should be made to insitu testing, but as previously mentioned the use of these techniques would require confirmation that they are suitable for the particular soils in question and that sufficient experience exists in their use and interpretation. Also, any correlations, for example converting CPT data to undrained shear strength, would require validation of the relevant multiplying factor and again this should be checked by proper strength tests which require quality class 1 samples which may not be available.

It is hoped that this paper will give geotechnical designers some food for thought. Certainly, the experience of the authors is that compliance with EN 1997-2:2007 and EN ISO 22475-1:2006 is not straightforward. This could have implications for the geotechnical designer if difficulties in applying Eurocode 7 are perceived and not resolved. If, as most parties believe, the British Standards will no longer be updated then there is the likelihood that the courts will regard Eurocodes as the benchmark for geotechnical design. Further investigative testing and comparative work by those who practice within the geographical area of Central Scotland would certainly add to the comments made in this paper and may help form a more comprehensive consensus.

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