GUIDE ON GROUND INVESTIGATION AND GEOTECHNICAL CHARACTERISTIC VALUES TO EUROCODE 7

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Content Page

1. Introduction

1.1 Background

This guide aims to highlight to designers the key aspects of geotechnical investigation to Eurocode 7 for producing a **Ground Investigation report (GIR)** and subsequently for the determination of characteristic ground values as part of the **Geotechnical Design Report (GDR)**.

Eurocode 7 requires designers to be responsible for the planning of the geotechnical investigation and the specifying of the necessary field and laboratory testing to be carried out. Eurocode 7 holds the designers of ground investigation accountable for their decisions and requires the rationale behind all geotechnical parameters used for design to be justified.

BS EN ISO 22475-1 provides guidance to designers on specifying the sampling and testing programme that they would need to determine the geotechnical parameters and produce a GIR. Thereafter, designers have to determine the "characteristic" value of a geotechnical parameter based on the derived data values from the GIR and together will form part of the GDR. The GIR and GDR are key geotechnical reports that the designer is expected to deliver as part of Eurocode 7 requirements (refer section 5 for further details on GIR and GDR). The GIR and GDR will form the basis for the designers to carry out geotechnical design for the project.

This guide will cover the key aspects of the GIR and the GDR as below:

Ground Investigation Report (GIR)

i) Preliminary investigations
    - Geotechnical Categorisation of projects
    - Planning of borehole locations
ii) Design investigations
    - Identification of types of parameters required for geotechnical design
    - Planning of field and laboratory testing, ground water measurement, soil/rock sampling, number of field and laboratory tests to be carried out

Geotechnical Design Report (GDR)

iii) Determination of characteristic ground values for geotechnical design
    - via selection method or statistical evaluation
iv) Detailed geotechnical design
    - Geotechnical calculations and drawings

Notwithstanding this, designers should also refer to relevant references mentioned in section 6 and any other specialist guidance that may be available.

1.2 Compliance of Ground Investigation Practices to Eurocode 7

The National Annex (NA) to SS EN1997-2 has adopted guidance from EN22475-2 and EN 22475-3 for the qualifications criteria and conformity assessment procedures for enterprises and personnel involved in ground investigation. For compliance on the requirements of personnel, the specialist GI firms are suggested to obtain an "Accreditation of Inspection Bodies for Site Investigation" administered by SPRING Singapore.

2. Preliminary Investigations

2.1 Geotechnical Categorisation (GC) of Projects

2.1.1 Designers are required to carry out the preliminary categorisation of the projects based on the guide provided in the Table 2.1 and Figure 2.1. Note a geotechnical categorization may apply to a whole or to part of a project. It is not required to treat the whole of the project according to the highest of these categories. (SS EN 1997-1:2004 Cl 2.1(13))

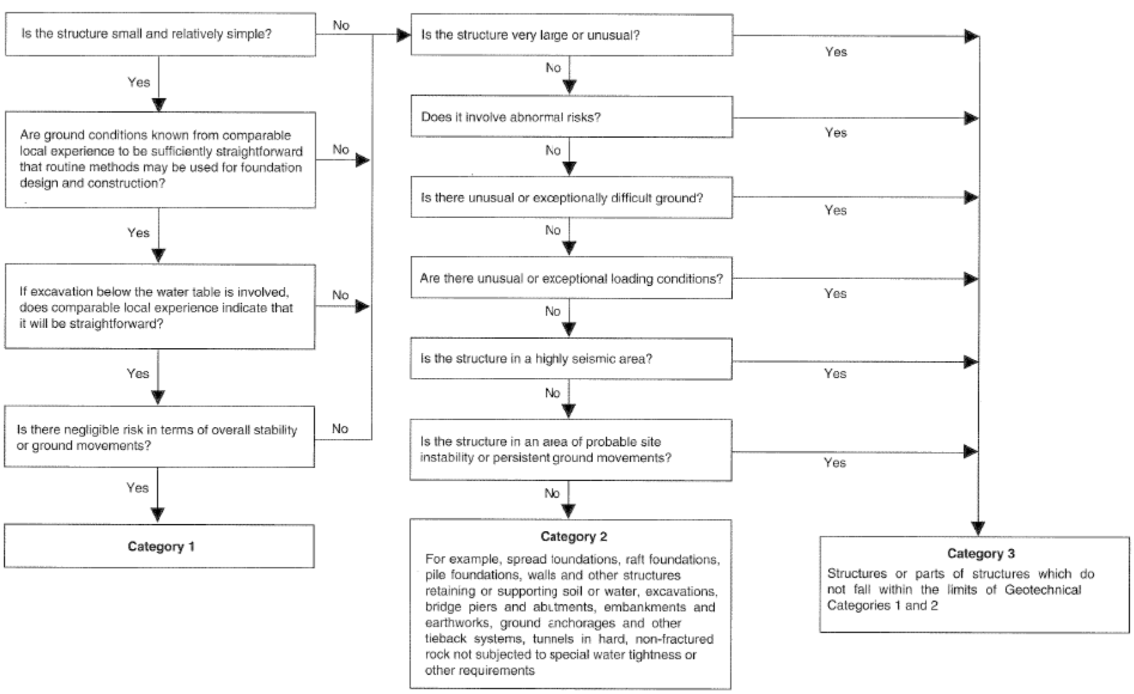


Figure 2.1: Geotechnical Categorisation of projects

Table 2.1: Geotechnical Categorisation of Projects

Geotechnical Category	Description of Category	Example of projects (in Singapore's context)
1	- small and relatively simple structures: - for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations; - with negligible risk.	- Landed housing on shallow foundations in firm residual soil - Single storey sheds - Link-ways - Minor roadside drain
2	- conventional types of structure and foundation - with no exceptional risk or difficult ground or loading conditions	- canal - conventional buildings on - shallow or raft foundations; - pile foundations; - walls and other structures retaining or supporting soil or water < 6m height; - excavations < 6m depth - bridge piers and abutments; - embankments and earthworks; - ground anchors and other tied-back systems; - tunnels in hard, non-fractured rock/ competent soils, and not subjected to special water tightness or other requirements.
3 EC7. Clause 2.1 Expectations of GI, refer table 2.2	fall outside the limits of Geotechnical Categories 1 and 2	- very large structure such as infrastructure projects for rail and road tunnels - utilities tunnels of more than 3 m in diameter - airport terminal buildings - foundation for building of 30 storey or more; - unusual structures such as port structures in poor ground conditions; - structures involving abnormal risks such as dam, dikes - GBW(ERSS) in close proximity to existing buildings except for single unit landed housing development, - unusual or exceptionally difficult ground such as foundation in limestone areas for more than 6 storey or unusually loading conditions -foundation for high-rise of more than 10 storey on reclaimed land, or soft soils with combined thickness of soft soils of more than 8 m -GBW (ERSS) in soft soil ground conditions - special buildings subjected to seismic risks (according BC3);

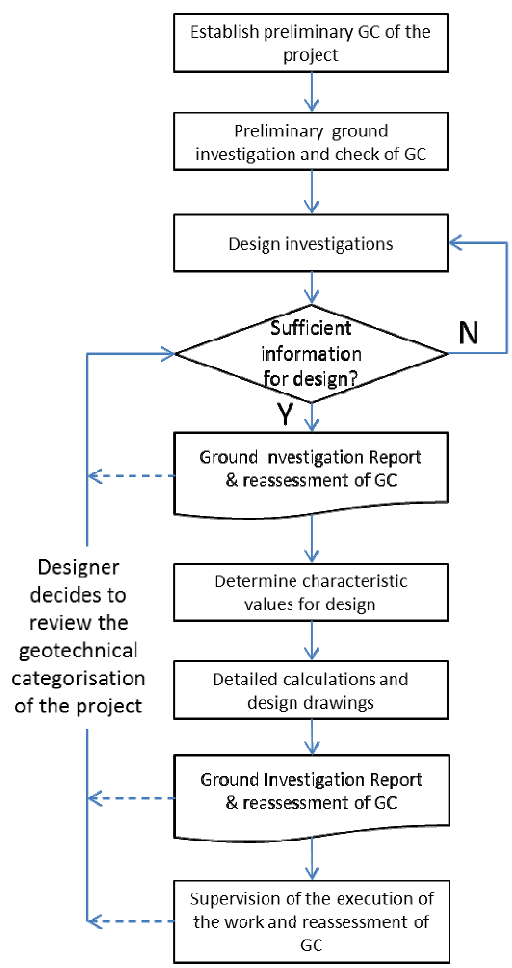
2.1.2 Eurocode 7 requires designers to plan the geotechnical investigations so as to ensure that relevant geotechnical information and data are available at the various stages of the project. *(SS EN1997-2:2007 Cl 2.1.1(1)P)*

2.1.3 Geotechnical investigations is not limited to ground investigations but also include appraisal of the surroundings (near canals, buried utilities, known ground abnormalities), adjacent buildings and history of the site (previous buried rivers etc.). *(SS EN1997-2:2007 Cl 2.1.1(5))*

2.1.4 Depending on the outcome of the geotechnical investigations, a GC 2 project could be reclassified as a GC 3 project. For instance, if underlying cavities were found during the geotechnical investigations, the designer may need to specify more detailed investigations as he deems fit.

2.1.5 In other words, geotechnical categorisation is an on-going process and should be reassessed at different design stages by the designer.

Figure 2.2: Assessment of Geotechnical Categorisation during design process



2.2 Suggested Minimum Number of Boreholes for Local Practices

2.2.1 All projects identified or re-assessed under GC 2 and 3 are required to carry out borehole investigations to sufficient extent and depth. The geotechnical investigations shall provide sufficient data concerning the ground and the ground water conditions for a proper description of the essential ground properties and a reliable assessment of the characteristic values of the ground parameters to be used in design calculations. (Reference SS EN 1997-2 cl.3.2.1) The number of investigation boreholes should meet the requirements as stipulated in Table 2.2. Where appropriate, CPTu may be used to complement the borehole investigation planning.

2.2.2 Boreholes should go more than 5m into hard stratum with SPT blow counts of N>100 or more than 3 times the pile diameters beyond the intended pile toe termination depth, whichever greater. For shallow foundation, the boreholes should be at least 3 times the width of foundations, such as pad footing / strip footing or other types of shallow foundation.

2.2.3 Previous ground investigation carried out could be considered if the borehole meets the requirements, and additional boreholes should be carried out where the designer deems necessary.

2.2.4 Designers should refer to SS EN 1997-2 Annex B for additional guidance and examples.

Table 2.2: Suggested minimum number of boreholes for for local practices

Structures Type	Number of BH required (GC3 projects should adopt the more onerous number of boreholes)
Buildings – Up to 10 stories high (excluding landed housings) More than 10 stories high	 15m to 40m grid, minimum 1 BH per block, and 3 BHs per site 10m to 30m grid, 1 BH per 300sqm, minimum 2 BHs per block, and 3 BHs per site
Large area	≤ 60 m grid per BH, at designer's discretion
Roads, railways, canals, pipelines, inland dikes	1 BH every 20 to 200m
ERSS, retaining wall < 6m high ERSS, retaining wall >= 6m high	1 BH every 15 to 40m 1 BH every 10 to 30m

Tunnelling in built-up area Tunnelling in green field area	1 BH every 10 to 75m 1 BH every 20 to 200m
Dam, costal dikes, weirs	1 BH every 25 to 75m along vertical sections
Road Bridges, tower stacks, heavy machinery foundation	2 to 6 BHs per foundation

2.3 Re-classification of Soil/Rock from Existing GI in British Standards

2.3.1 The classification and description of soil/rock types in Eurocode 7 is different from those in the BS standards. The designer should reclassify the soil/rock types to the Eurocode and this information should be documented as part of the GIR/GDR. Designers could refer to Annex A of this document on how reclassify the soil/rock types. Annex A also provides guidance on key differences between British Standards and Eurocodes.

3. Design Investigations

3.1 Planning of Field and Laboratory Testing

3.1.1 SS EN 1997-2 requires designers to design the investigation programmes to specify the investigation boreholes layout and suitable field and/or laboratory tests relevant to the proposed works at the various stages of the project.

3.1.2 Before designing the investigation programme, the available information and documents gathered during the preliminary investigations should be evaluated in a desk study. *(SS EN 1997-2:2007 CL2.2 (2)P)*

3.1.3 After the desk study, designers are required to visually examine the site and record findings and cross-check against the desk study evaluated information. *(SS EN 1997-2:2007 CL 2.4.2.2(1))*

3.1.4 Test results from existing ground reports that are obtained from field testing are acceptable across all Geotechnical Categories. SS EN1997-2 provides Annexes which give correlations for various geotechnical parameters using common field tests. The list of common field tests to correlate to relevant geotechnical parameters and the suitability of the tests with respect to different soil types are shown in Annex B.

3.1.5 Test results from existing ground reports that are obtained from laboratory testing are only acceptable if the tested samples were obtained from suitable methods of sampling. The table in Annex C suggests different lab tests for obtaining the relevant soil parameters.

3.1.6 The tests must be undertaken and reported in accordance with the corresponding Testing Standard of EN ISO 22476 Annex 9.4 Table A4.2.

3.2 Ground Water Measurement

3.2.1 The existing ground-water levels shall be established during the ground investigation. Any free water levels observed during the investigation shall be recorded.

3.2.2 Ground water measurement shall comply with BS EN ISO 22475 -1 regarding drilling and sampling methods for different soil conditions. *(SS EN1997-2:2007 CL3.6.2(1))*

3.2.3 Measurements must be made at a frequency that ensures that variations are properly detected and equipment must be appropriately selected and installed to allow this to be done.

3.2.4 Field-tested soil permeability values from existing ground reports could be adopted across all Geotechnical Categories.

3.3 Soil Sampling

3.3.1 SS EN 1997-2 imposes requirements on the quality of the samples depending on the sampling methods and ground conditions. The requirements could be found in BS EN ISO 22475-1.

3.3.2 Sampling methods are categorised into Cat A, B and C. BS EN ISO 22475-1 requires appropriate sampling category to be carried out to obtain different quality class of samples. Refer to Table 3.4. The detailed categorisation of the methods of sampling depending on the soil conditions can be found in BS EN ISO 22475-1 Tables 2 and 3.

Table 3.4 Quality class and soil properties that can be determined (SS EN1997-2:2007 Table 3.1)

	Quality Class				
	1	2	3	4	5
Sampling category according to EN ISO 22475 -1	A				
			B		
					C
Unchanged soil properties					
Particle size	■	■	■	■	
Water content	■	■	■		
Density, density index, permeability	■	■			
Compressibility, shear strength	■				
Properties that can be determined					
Sequence of layers	■	■	■	■	■
Boundaries of strata-broad	■	■	■	■	
Boundaries of strata-fine	■	■			
Atterberg limits, particle density, organic content	■	■	■	■	
Water content	■	■	■		
Density, density index, porosity, permeability	■	■			
Compressibility, shear strength	■				

3.4 Minimum Number of Field and Laboratory Tests

3.4.1 The suggested minimum number of tests per soil stratum to be carried out is shown in Appendix D where appropriate.

3.4.2 Test results from existing ground report with appropriate quality class sampling are allowed to be adopted. Additional sampling or field tests would be required if the minimum suggested number of specimens could not be met.

4. Determinate the Value of a Geotechnical Parameter for Design

4.1 Concept of Characteristic Values

4.1.1 Eurocode 7 introduces the concept of characteristic values in which partial factors are applied to obtain suitably safe but economical design values of soil parameters. Eurocode 7 defines the selection of the characteristic value of a geotechnical parameter as “a cautious estimate of the values affecting the occurrence of the limit state”.

4.1.2 The applicable geotechnical parameters required to be determined as characteristic values for design are as follows:

Applicable Geotechnical Parameters	
$\tan\varphi'$	Effective angle of shearing resistance
c'	Effective cohesion value
c_u	Undrained shear strength
N	SPT N values
q_c	CPT q_c values

4.1.3 SS EN1997-1 Clause 2.4.5.2(4)P states, the selection of characteristic values for geotechnical parameters shall take account of the following:

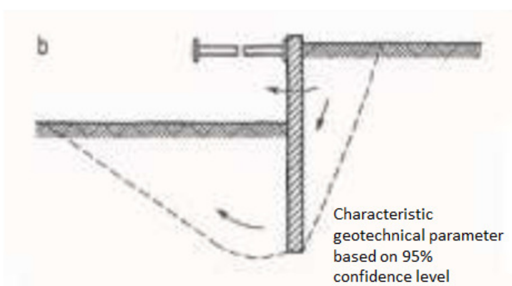
- geological and other background information, such as data from previous projects;
- the variability of the measured property values and other relevant information, e.g. from existing knowledge;
- the extent of the field and laboratory investigation;
- the type and number of samples;
- the extent of the zone of ground governing the behaviour of the geotechnical structure at the limit state being considered;
- the ability of the geotechnical structure to transfer loads from weak to strong zones in the ground.

However, literature has shown that when designers were asked to select characteristic values of various geotechnical parameters, the result revealed a very wide range of interpretation in which the design outcome would be grossly affected. The designer should determine the characteristic value as not more than the mean value of the geotechnical parameter with half a standard deviation reduction (moderately conservative parameters) or 1.65 times standard deviation (inferior parameters).

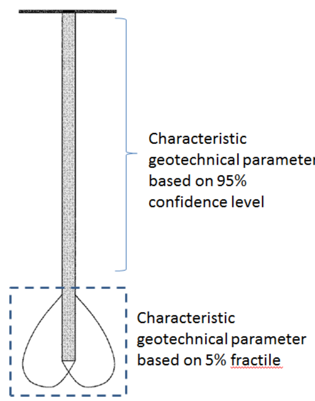
4.1.4 SS EN1997-1 Clause 2.4.5.2(10) suggested statistical methods to determine characteristic ground values. When applying statistical methods, the designer should consider the following:

- adequacy and quality of geotechnical investigations
- distribution of sampling/testing
- highly variable non-conforming nature of geo-materials
- allowing the use of a priori knowledge of comparable ground properties,
- applying engineering judgement

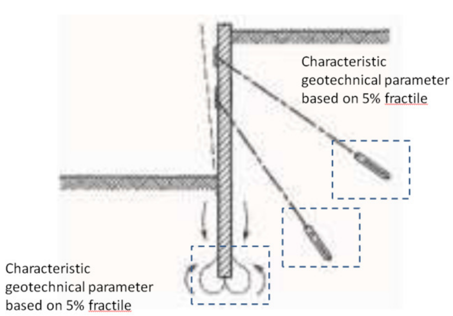
4.1.5 When adopting statistical methods, for most limit state cases where the soil volume involved is large, the characteristic value should be determined such that a cautious estimate of the mean value is a selection of the <u>mean value</u> of the limited set of geotechnical parameter values, with a confidence level of 95% *(moderately conservative parameters)*; where local failure is concerned, a cautious estimate of the <u>low value</u> is a 5% fractile *(inferior parameters).* Figure 4.1 illustrates some examples for better understanding. (SS EN 1997-1 Cl. 2.4.5.2 (11))



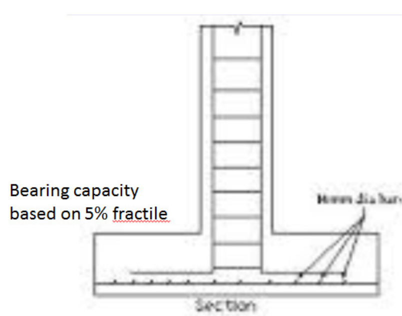
Typical retaining wall design



Pile design*



Anchored wall design



Square footing design

*not applicable if shaft resistance contribute to at least 70% of design pile resistance (i.e. local failure due to pile bearing is unlikely)

<u>Figure 4.1 Some examples of limit state design</u>

4.1.6 Where local weakness is discovered during the ground investigations e.g. faults, localised soft spot due to presence of streams/rivers, the designer shall carry out design based on the low value of 5% fractile for the affected design section.

4.1.7 Designer could consider the statistical methods suggested in Annex E and F.

4.1.8 It is suggested for better estimation of geotechnical characteristic parameters c' and tan φ', designer could specify s'-t tests (stress path) with at least 12 numbers of tested sample with different applied pressure to obtain c' and tan φ' of the same stratum. An example is shown in Annex G.

4.2 Availability of ground investigation data and application of methods to determine characteristic values

4.2.1 Designers should refer to Table 4.3 to determine characteristic values based on the available ground investigation reports.

Table 4.1: Suggested methods to determine characteristic values for different Geotechnical Categories

Geotechnical Category	GI availability	Determining characteristic values
1	Based on available GI, or GI of immediate neighbour plots supplemented with available literature e.g. geological map, published ground parameter	"eyeball method" (Section 4.1.3) could be adopted. Where the values are obtained from the GI of a neighbouring plot, the determined characteristic value should be reduced by a further factor of 1.2.
2	Available GI based on BS and/or new GI to EC stds	"eyeball method" (Section 4.1.3) or Statistical method (Section 4.1.7)
3	Available GI based on BS and/or new SI to EC stds	"eyeball method" (Section 4.1.3) or Statistical method (Section 4.1.7), the latter is suggested if >= 13 sets of data is available (Bond & Harris 2008)

4.2.2 Designers are encouraged to conduct new ground investigations to the latest Eurocode standards to obtain more reliable data for safe and economic design.

4.3 Other design considerations

4.3.1 In some design situations, for example, very soft soil with low undrained shear strength, if the designer could demonstrate that the application of partial factors to the ground characteristic values will lead to design which are unreasonable or even physically impossible, he could apply the partial factors directly to the effects of the actions instead. (reference SS EN 1997-1 cl. 2.4.7.3.2 (2))

5. Submission documents

5.1 Ground Investigation Report (GIR)

5.1.1 Ground investigation report would record the preliminary investigation and the design investigation works prescribed by the design. The geotechnical investigations shall be planned taking into account the construction and performance requirements of the proposed structure. The scope of the geotechnical investigations shall be continuously reviewed as new information are obtained during execution of the work.

5.1.2 Routine field investigations and laboratory testing shall be carried out and reported generally in accordance with international recognised standards and guidance. Deviations from these standards and additional test requirements shall be reported.

5.1.3 Preliminary and design investigations prescribed by the designer shall be reflected in the Ground Investigation Report and provide the following:

- i) Geotechnical categorisation of the project.
- ii) Planning of boreholes and sampling methodology
- i) Evaluation of the field and laboratory reports
- ii) Derivation of the geotechnical values based on the field and laboratory reports
- iii) Information required for an adequate design of the temporary and permanent works
- iv) Information required to plan the method of construction
- v) Information on groundwater
- vi) Any difficulties that may arise during construction

5.1.4 The parameters, for example localised area of poor soil due to pre-existing rivers, which may affect the ability of the structure to satisfy its performance criteria shall be established before the start of the final design.

5.2 Geotechnical Design Report (GDR)

5.2.1 The results of a geotechnical investigation shall be compiled in a Ground Investigation Report (GIR), which shall form a part of the Geotechnical Design Report (GDR). The Geotechnical Design Report (GDR) should form part of the structural design report for submission to BCA and to include the following items:

a) a description of the site and surroundings;
b) a description of the ground conditions;
c) a description of the proposed construction, including actions;
d) design values of soil and rock properties, including justification, as appropriate; (i.e. determination of characteristic values)
e) statements on the suitability of the site with respect to the proposed construction and the
f) level of acceptable risks; (i.e. impact assessment)
g) plan of supervision & monitoring
h) a note of items to be checked during construction or requiring maintenance or monitoring.

5.3 Ground Investigation Data in Standardised Electronic Format

In 21st January 2013, the BCA's Singapore Geological Office (SGO) issued a circular on the implementation of SI Data in standardised electronic format. The '*Guidelines on Electronic Transfer for Site Investigation* Data' which covers Singapore first standardised electronic file format protocol AGS(SG) (Association of Geotechnical and Geo-environmental Specialist) for the geological, geotechnical, geo-environmental, geophysical field and laboratory testing data can be downloaded from the BCA website at the following link: http://www.bca.gov.sg/StructuralPlan/others/Electronic_transfer_SI_data.pdf.

All SI contractors **shall** provide the following items to their client:

1. Ground Investigation report (pdf format) with the labelling of GI report file as **SGO_SI**_xxxx.pdf
2. Ground Investigation data in AGS(SG) format with the labelling of GI data file as **SGO_SI**_xxxx.ags
3. AGS checker log in text format with the labelling of AGS checker log as **SGO_SI**_AGS Checker log.txt
4. GI report Declaration page (pdf format) with the labelling of GI report declaration file as **SGO_SI**_Declaration.pdf

It shall be the duty of the GI contractor to provide the above mentioned items in the prescribed naming convention for electronic submission of GI data.

The submission of GI data in the AGS(SG) electronic format is now a requirement, with effective from 1st July 2013, for all new projects. All Qualified Person doing the first submission for the new project are to submit the files provided by the GI contractor. They are to submit the above mentioned 4 files in “as-it-is” state. Renaming of file or incorporating the GI report into the design report will affect the electronic submission and thus result in Written Direction.

6. Further reading

a. Designers’ Guide to EN 1997-1 Eurocode 7: Geotechnical design – General rules

b. Concise Eurocodes: Geotechnical design

c. Eurocode 7: Geotechnical Design Worked Example, JRC Scientific and Policy Report (available from internet)

Annex A

Guidance on re-classification of soil and rock from British Standards to Eurocode Standards

Annex A.1. Comparing EC 7 and BS 5390:1999

Key Item	Commentary on Practical Application
Relative density (sands & gravels)	No change is required as 14688 permits SPT to be used as basis but without defining scale
Consistency (fine soils)	Terminology is same as BS5930 for clay, the terms are defined solely by hand tests and have no numerical strength connotations (e.g very soft, soft… very stiff). **(See Table A2)**
Undrained shear strength (fine soils)	Introduce terms (e.g low, medium, high…), based on results of field or laboratory tests. The strength term to be presented in log in addition to consistency. **(See Table A3)**
Secondary fractions	Introduce secondary fine constituents to a fine principal soils (silty CLAY and clayey SILT), but these will be used only when secondary constituents is significant. **(See EN ISO 14688-1:2002 clause 4.3.3)** EC7 (**EN ISO 14688-1:2002)** mention using prefixes (slightly, - very) for coarse secondary fractions. No mention of a prefix for fine secondary fractions. As there is no field mechanism for quantification, recommend the prefixes not be applied.
Particle shape	Introduce two additional terms (very angular….well rounded) to extend the range **(See Table A4)**
Particle size	Change boundaries between fractions which were 6.0 and orders of magnitude to become 6.3 Introduce additional sub-fraction of “large boulders” (particles > 630mm) **(See Table A5)**
Principal fraction	Discontinue the hybrid term “CLAY/SILT”
Minor constituents	Introduce defined terms specifically for carbonate content (free, calcareous, highly calcareous) but only use where presence detected.

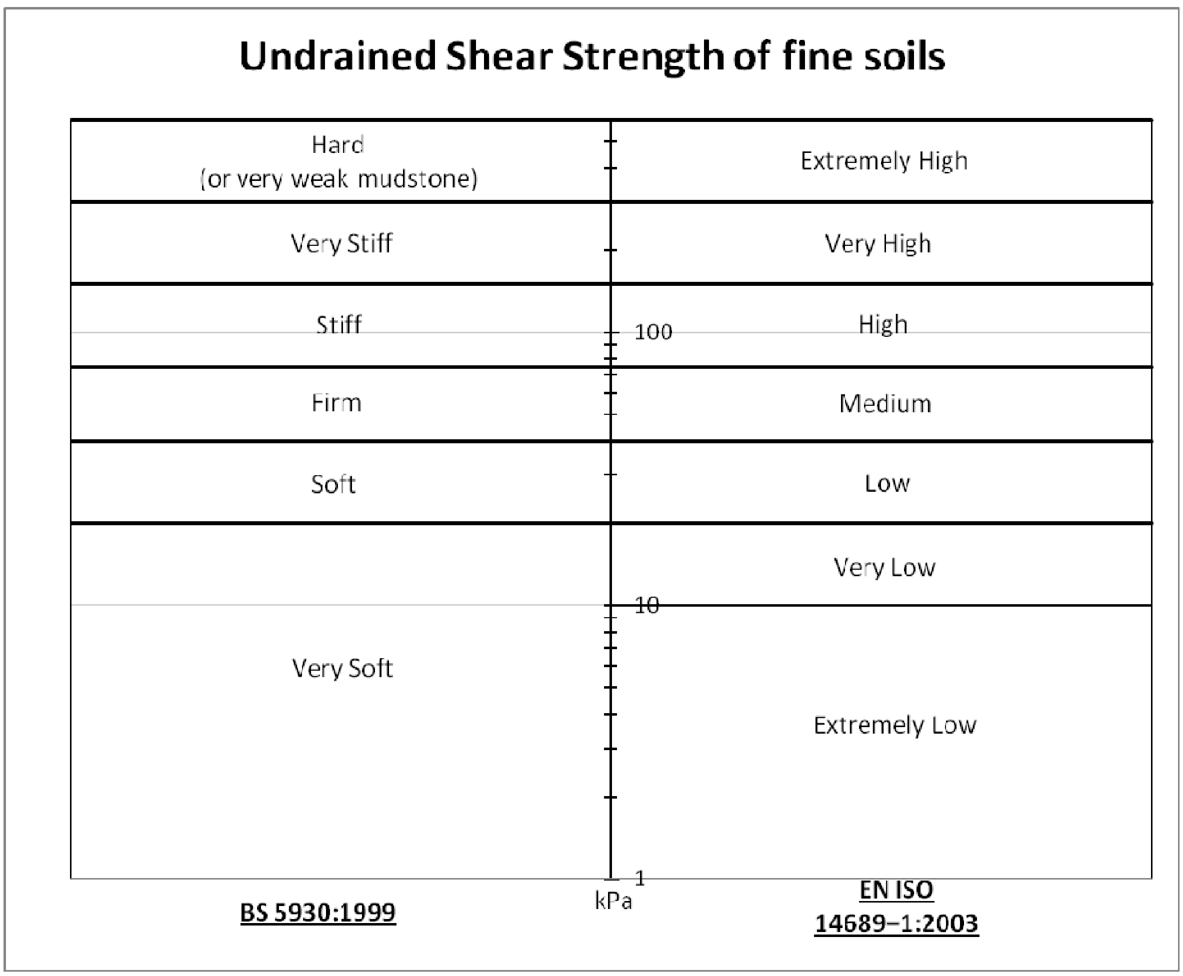
Table A1. SUMMARY OF KEY CHANGES AFFECTING DESCRIPTION OF INORGANIC SOILS

Local Practice extracted From TERZAGHI & PECK (SPT N-value)	**Undrained Shear Strength, Cu (kPa)**	**Terms**	**BS 5930:1999** (Table13, Page114)		**BS 5930:1999 A2:2010** (Table13, Page114)		**EN ISO 14688–1:2002** (Clause 5.14)
0 to 2	<20	Very Soft	Finger easily pushed in up to 25mm		Finger easily pushed in up to 25mm; exudes between the fingers		It exudes between the fingers when squeezed in hand.
2 to 4	20 to 40	Soft	Finger pushed in up to 10mm		Finger pushed in up to 10mm, moulded by light finger pressure		It can be moulded by light finger pressure.
4 to 8	40 to 75	Firm	Thumb makes impression easily		Thumb makes impression easily, cannot be moulded by fingers, rolls to threads		It cannot be moulded by fingers, but rolled in hand to thick threads without breaking or crumbling.
8 to 15	75 to 150	Stiff	Can be indented slightly by thumb		Can be indented slightly by thumb, crumbles in rolling thread; remoulds		It crumbles and breaks when rolled to 3mm thick threads but is still sufficiently moist to be moulded to a lump again.
15 to 30	150 to 300	Very Stiff	Can be indented by thumb nail		Can be indented by thumb nail, cannot be moulded, crumbles		It has dried out and is mostly light coloured. It can no longer be moulded but crumbles under pressure. It can be indented by thumbnail.
>30	>300	Hard (or very weak mudstone)	Can be scratched by thumbnail		Can be scratched by thumbnail		NA

Table A2. Comparison Table for Field Practice For Determination Consistency of Fine Soils

BS 5930:1999			EN ISO 14689–1:2003
Term	**Undrained Shear Strength (kPa)**		**Term**
		<10	Extremely low
Very Soft	<20	10 to 20	very low
Soft	20 to 40	20 to 40	low
Firm	40 to 75	40 to 75	medium
Stiff	75 to 150	75 to 150	high
Very Stiff	150 to 300	150 to 300	very high
Hard (or very weak mudstone)	>300	300 to 600	extremely high

Table A3. Comparison Table for Undrained Shear Strength (kPa) of soil



BS 5930:1999	Particle shape	EN ISO 14688–1:2002
Angular Sub-angular Sub-rounded Rounded	Angularity/roundness	Very angular Angular Sub-angular Sub-rounded Rounded Well rounded
Flat or Tabular Elongate	Form	Cubic Flat Elongate
Rough Smooth	Surface texture	Rough Smooth

Table A4. Comparison Table for Terms for the designation of particle shape

BS 5930:1999			Soil fractions	EN ISO 14688–1:2002		
Particle sizes (mm)	Symbols	Sub-fractions		Sub-fractions	Symbols	Particle sizes (mm)
			Very coarse soil	Large boulder	LBo	> 630
> 200	Bo	Boulder		Boulder	Bo	> 200 to 630
>60 to 200	Co	Cobble		Cobble	Co	>63 to 200
>2 to 60	Gr	Gravel	Coarse soil	Gravel	Gr	>2 to 63
>20 to 60	CGr	Coarse gravel		Coarse gravel	CGr	>20 to 63
>6.0 to 20	MGr	Medium gravel		Medium gravel	MGr	>6.3 to 20
>2.0 to 6.0	FGr	Fine gravel		Fine gravel	FGr	>2.0 to 6.3
>0.06 to 2.0	Sa	Sand		Sand	Sa	>0.063 to 2.0
>0.6 to 2.0	CSa	Coarse sand		Coarse sand	CSa	>0.63 to 2.0
>0.2 to 0.6	MSa	Medium sand		Medium sand	MSa	>0.2 to 0.63
>0.06 to 0.2	FSa	Fine sand		Fine sand	FSa	>0.063 to 0.2
>0.002 to 0.06	Si	Silt	Fine soil	Silt	Si	>0.002 to 0.063
>0.02 to 0.06	Csi	Coarse silt		Coarse silt	Csi	>0.02 to 0.063
>0.006 to 0.02	Msi	Medium silt		Medium silt	Msi	>0.0063 to 0.02
>0.002 to 0.006	Fsi	Fine silt		Fine silt	Fsi	>0.002 to 0.0063
≤0.002	Cl	Clay		Clay	Cl	≤0.002

Table A5. Comparison Table for Particle size fractions

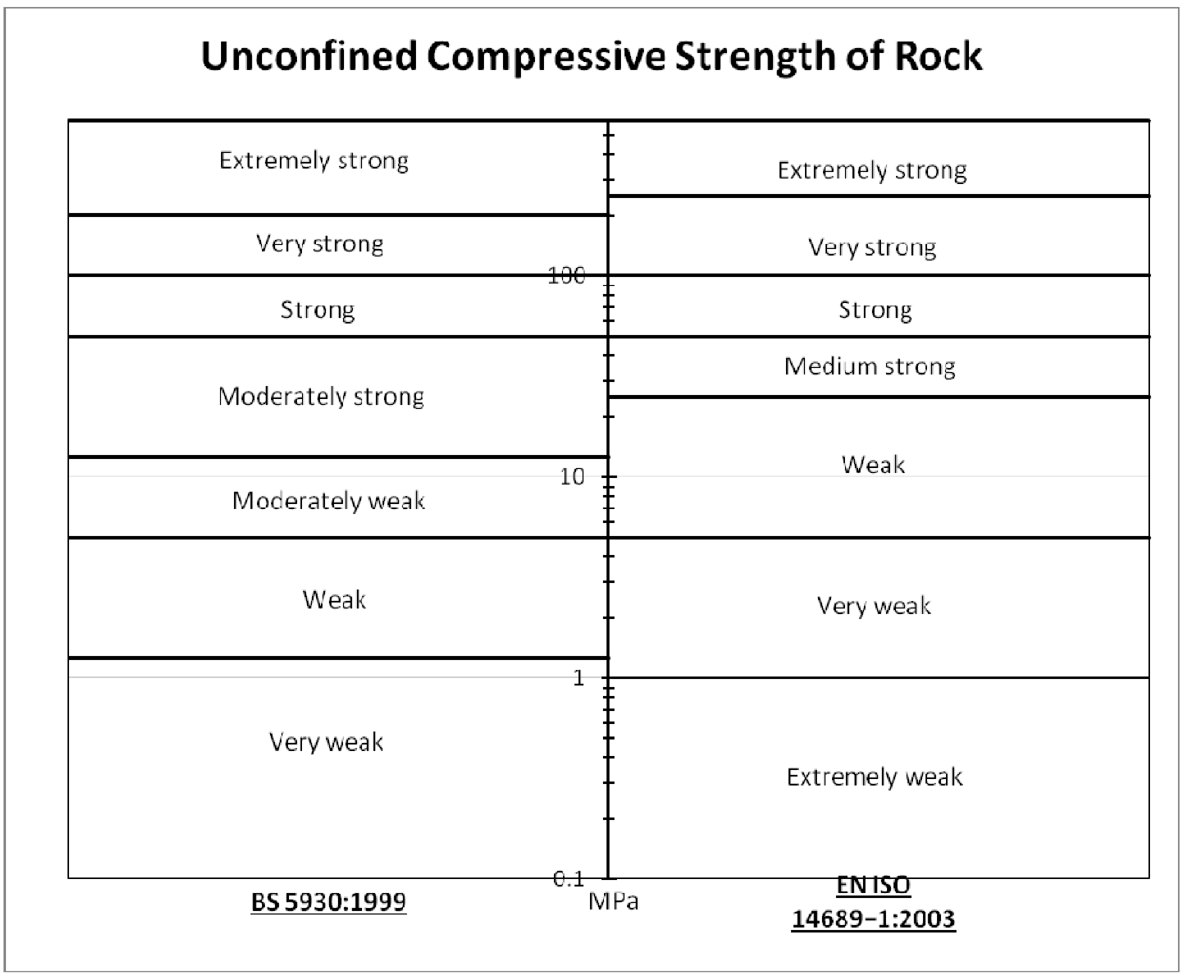
Annex A.2. Comparing EC 7 and BS 5390:1999 for Rock

Key Item	Commentary on Practical Application
Strength	Change in the range of terms have been extended and they have ISRM definitions (both field identification & numerical values) **(See Table B2)**
Grain size	Change in the orders of boundaries magnitude from 6 to become 6.3 (same as for soils)
Minor constituents	Introduce defined terms specifically for carbonate content (same as soils)
Weathering	No change required in Description of weathering effects at material or mass scales (BS5930 Approach 1). Change to CLASSIFICATION is that BS5930 Approach 2 & 3 are discontinued; where appropriate Approach 4 or 5 will continue. **(See Table B3)**
Discontinuities	Spacing: quantifying prefix given to be maintained Roughness: change to definition of scale terms (small, medium, large), to ISRM (mm, cm, m) **(See Table B4)** Aperture: change to terms and definition to ISRM**(See Table B5)** Seepage: change to one of terms ("strong" becomes "large")

Table B1. SUMMARY OF KEY CHANGES AFFECTING DESCRIPTION OF ROCKS

BS 5930:1999		EN ISO 14689–1:2003	
Term	**Unconfined Compressive Strength (kPa)**		**Term**
Very weak	< 1.25	< 1	**Extremely weak**
Weak	1.25 to 5	1 to 5	**Very weak**
Moderately weak	5 to 12.5	5 to 25	**Weak**
Moderately strong	12.5 to 50	25 to 50	**Medium strong**
Strong	50 to 100	50 to 100	**Strong**
Very strong	100 to 200	100 to 250	**Very strong**
Extremely strong	> 200	> 250	**Extremely strong**

Table B2. Comparison Table for Unconfined Compression Strength (MPa) of rock



BS 5930:1999		Standard	EN ISO 14689–1:2003	
Description Classification for Rock Mass and Rock Materials	**Grades Symbols**	**Term**	**Grades Symbols**	**Description Classification of Rock Mass Weathering grade**
Unchanged from original state	I	Fresh	0	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.
Slight discolouration, slight weakening	II	Slightly weathered	1	Discoloration indicates weathering of rock material and discontinuity surfaces.
Considerably weakened, penetrative disco**loration Large pieces cannot be** broken by hand	III	Moderately weathered	2	Less than half of the rock material is decomposed or disintegrated. Fresh or discoloured rock is present either as a continuous framework or as core stones
Large pieces cannot be broken by hand Does not readily slake when dry sample immersed in water	IV	Highly weathered	3	More than half of the rock material is decomposed or disintegrated. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.
Considerably weakened Slakes Original texture apparent	V	Completely weathered	4	All rock material is decomposed &/or disintegrated to soil. The original mass structure is still largely intact.
Soil derived by in situ weathering but retaining none of original texture of fabric	VI	Residual soil	5	All rock material is converted to soil. The mass structure & material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.
Widely and commonly use in local practice for classification of rock materials and rock mass weathering grade.			The descriptive terms are provided and defined in 14689-1(Table2) as Fresh, Discoloured, Disintegrated, Decomposed to describe the results of weathering/ alteration of rock material. These terms may be subdivided using qualifying terms of "partially, wholly and slightly."	

Table B3. Comparison Table for Classification of Weathering Grade

BS 5930:1999 (Table15, Page.135)		EN ISO 14689–1:2003	
Intermediate Scale (m)	**Small Scale (cm)**	**Medium Scale (cm)**	**Small Scale (mm)**
Stepped	Rough	Stepped	Rough
Stepped	Smooth	Stepped	Smooth
Stepped	Striated		
Undulating	Rough	Undulating	Rough
Undulating	Smooth	Undulating	Smooth
Undulating	Striated		
Planar	Rough	Planar	Rough
Planar	Smooth	Planar	Smooth
Planar	Striated		

Table B4. Comparison Table for Surface Roughness of Discontinuities

Aperture size term	Aperture		Aperture size term
BS 5930:1999		**EN ISO 14689–1:2003**	
Very Tight	< 0.1 mm	0.1 mm	**Very tight**
Tight	0.1 to 0.5 mm	0.1 to 0.25 mm	**Tight**
Moderately open	0.5 to 2.5 mm	0.25 to 0.5 mm	**Partly open**
Open	2.5 to 10 mm	0.5 to 2.5 mm	**Open**
Very open	>10 mm	2.5 to 10 mm	**Moderately wide**
Cannot normally be described in cores.		1 to 10 cm	**Wide**
		10 to 100 cm	**Very wide**
		>1 m	**Extremely wide**

Table B5. Comparison Table for Description of Discontinuity Aperture

Annex B

Guidance on field tests to determine soil parameters

List of geotechnical parameters and correlation to relevant field tests common in Singapore

Geotechnical Parameters		Relevant Field Tests	Reference SS EN 1997-2 (unless otherwise mentioned)
φ'	Effective angle of shearing resistance	Cone Penetration Test (CPT)	Annex D
E'	Drained Young's modulus		
E_{oed}	One-dimensional odeometer modulus		
k	Bearing resistance factor for spread foundations	Pressure Meter Test (PMT)	Annex E
k	Compressive resistance factor for piles		
I_D	Density index	Standard Penetration Test (SPT)	Annex F
φ'	Effective angle of shearing resistance		
C_u	Undrained shear strength	Field Vane Test (FVT)	Annex I
E_{oed}	One-dimensional odeometer modulus	Flat Dilatometer Test (DMT)	Annex J
C_u	Undrained shear strength	Plate Loading Test (PLT)	Annex K
E_{oed}	Plate loading test modulus		
k_s	Coefficient of subgrade reaction		

List of suitability of field tests to ground type and useful geotechnical information

Type of Field tests	Type of ground and suitability		
	Rock	**Coarse Soils**	**Fine Soils**
CPT	((Type of Rock [Soft]))	Extension of layers Compressibility (Type of soil) (Groundwater) (Pore water pressure) (Density) (Shear strength) ((Permeability))	Extension of layers Shear strength (Type of soil) (Pore water pressure) (Density) (Compressibility) (Permeability)
PMT	((Type of Rock)) ((Extension of layers))	Shear strength Compressibility ((Types of soil)) ((Extension of layers))	Shear Strength Compressibility ((Type of soil)) ((Extension of layers)) ((Pore water pressure)) ((Permeability))
SPT with sample		(Types of soil) (Extension of layers) (Particle size) (Water content) (Density) (Shear strength) (Compressibility) (Chemical tests)	Type of soils Particle size (Extension of layers) (Water Content) (Atterberg limits) (Density) (Compressibility) (Chemical test)
FVT			Shear Strength [soft to firm soil]
Flat DMT		(Types of soil) (Extension of layers) (Density) (Shear Strength) (Compressibility)	(Extension of layers) (Shear strength) (Compressibility) ((Type of soil density))
PLT	(Shear strength)	Shear strength Compressibility	Shear Strength Compressibility
SUITABILITY => HIGH, (MEDIUM), ((LOW))			

Annex C

Guidance on laboratory tests to determine soil parameters

List of geotechnical parameters and relevant lab tests

Geotechnical Parameters		Type of soil					
		Gravel	Sand	Silt	NC Clay	OC Clay	Peat organic clay
Oedometer modulus	E_{oed}	(OED) (Triaxial)	(OED) (Triaxial)	(OED) (Triaxial)	(OED) (Triaxial)	(OED) (Triaxial)	(OED) (Triaxial)
Compression index	C_c						
One-dimensional compressibility							
Young's Modulus	E	Triaxial	Triaxial	Triaxial	Triaxial	Triaxial	Triaxial
Shear Modulus	G						
Drained (effective) shear strength	c', φ'						
Undrained shear strength	C_u	NA	NA	Triaxial	Triaxial	Triaxial	Triaxial
Bulk Density	ρ	BDD	BDD	BDD	BDD	BDD	BDD
Coefficient of consolidation	c_v	NA	NA	OED Triaxial	OED Triaxial	OED Triaxial	OED Triaxial
Permeability	k	TXCH PSA	TXCH PSA	PTC TXCH (PTF)	TXCH (PTF) (OED)	TXCH (PTF) (OED)	TXCH (PTF) (OED)

( ) => partially suitable only

BDD Bulk Density determination
OED Odeometer Test
PSA Particle size analysis
Triaxial Triaxial Test
PTF Permeability test in the falling head permeameter
PTC Permeability test in the constant head permeameter
TXCH Permeability constant head test in the triaxial cell (or flexible head permeameter)

For more details, please refer to (SS EN1997-2:2007 Table 2.3)

Annex D

Suggested number of samples to be tested to obtain soil/rock parameters

Table 3.3A: Classification tests. Minimum number of samples to be tested in one soil stratum (EN1997-2:2007 Annex M Table M.1)

Classification test	**Minimum number of tests**
Particle size distribution (Sieve + Hydro)	3
Water content	All samples of Quality Class 1 to 3
Strength index test	All samples of Quality Class 1 to 3
Consistency limits (Atterberg limits)	2
Loss on ignition (for organic and clay soil)	2
Bulk density	All samples
Density index	As appropriate
Particle density	1
Carbonate content	As appropriate
Sulfate content	As appropriate
pH	As appropriate
Chloride content	As appropriate
Soil dispersibility	As appropriate

Table 3.3B: Density tests. Minimum number of samples to be tested in one soil stratum

Variability in measured density	**Minimum number of samples**
Range of measured density >= 0.02 Mg/m^3	3
Range of measured density <= 0.02 Mg/m^3	2
Mean value shall be adopted as the final density	

Table 3.3C: Triaxial compression tests. Suggested minimum number of tests[a] for one soil stratum

Geotechnical parameter	**Minimum number of tests[a]**
Effective angle of shearing resistance	3
Undrained shear strength[b]	4
[a] One test means **a** set of three individual specimens at different cell pressures or derived value from correlation to relevant field tests (SS EN 1997-2 Informative Annexes); Minimum 1 number of lab test is to be carried out [b] If ratio max/min > 2, additional 1 test (field or lab) is to be carried out.	

Table 3.3D: Incremental odeometer test. Suggested minimum number of tests[a] for one soil stratum

Variability in oedometer modulus E_{oed}	**Minimum number of tests[a]**
Range of values of $E_{oed} \geq 50\%$	3
~20% < Range of values of E_{oed} <~50%	2
Range of values of E_{oed} < ~20%	2
[a] The number of specimens tested should be increased if the structure is very sensitive to settlements i.e. Kallang Formation Mean value would be adopted as the final E_{oed}	

Table 3.3E: Permeability tests. Suggested minimum number of soil specimens to be tested[a] for one soil stratum

Variability in measured coefficient of permeability (*k*)	**Minimum number of tests**
$k_{max}/k_{min} > 100$	4
$10 < k_{max}/k_{min} \leq 100$	3
$k_{max}/k_{min} \leq 10$	2
The evaluation of the coefficient of permeability can be optimised by a combination of any of these methods: 1. field tests, such as pumping and borehole permeability tests; 2. empirical correlations with grain size distribution; 3. evaluation from an oedometer test; 4. permeability tests on soil specimens in the laboratory. Please refer to SS EN 1997-2 S.3 for suggested methods for different soil types.	

Table 3.3F: Uniaxial compression tests. Suggested minimum number of test specimens to be tested for one rock formation - Brazillian split tests and triaxial tests

Geotechnical parameter	**Minimum number of tests**
Uniaxial compressive strength	4[a]
[a] If standard deviation of measured strength > 50%, additional 2 test specimen is to be tested.	

Annex E

Example of obtaining characteristic values of c' and tan φ' from laboratory tests or other correlation

E.1) Schneider(1999) Method

This method could be applied to determine the characteristic value of a geotechnical parameter.

$X_d = m_X - 0.5s_X$
(upper bound equivalent to 95% mean reliable)

$X_d = m_X - 1.65s_X$
(lower bound equivalent to low value 5% fractile)

where

$$s_X^2 = \frac{1}{n-1}\sum(x_i - m_X)^2$$

X_d = characteristic value
m_X = mean value
s_X = standard variation
n = number of samples

An example of the determination of the characteristic value using the Schneider Method is illustrated as below: (take note of the deviation of φ' shall be based on tan φ' as the characteristic value)

	c′ (kPa)	φ′ (°)	tan φ′ (–)
Borehole/test			
BH 1/1	3	31	0.601
BH 1/2	4	30	0.577
BH 2/1	1	35	0.700
BH 2/2	7	28	0.532
Statistical results			
Mean value	$c_{mean} = 3.75$		$(\tan \varphi')_{mean} = 0.603$
Standard deviation	$\sigma_c = 2.50$		$\sigma_\varphi = 0.071$

$X_d = m_X - 0.5s_X$ (95% reliable)
$X_d = m_X - 1.65s_X$ (5% fractile)

Characteristics values	Upper bound	Lower bound
c'_k	2.5	1.25
tan φ'_k	0.568	0.532
φ'_k	29.6	28.0

The Schneider method assumes a normal distribution of data. Some geotechnical data fits a log-normal distribution especially for very soft soil or soil with very wide variation of parameters, hence using this method can result in characteristic values not complying with a 95% confidence limit.

E.2) Statistical Evaluation Method

For GC3 projects where usually higher frequency of soil tests are carried out, designers should adopt the statistical method where a higher number of samples would give a more favourable characteristic value. Projects with more derived soil data from good quality sampling would benefit from this method.

Assuming homogenous soil, (e.g. residual, fluvial sand/clay) the characteristic mean value of a geotechnical parameter is calculated using: (EC0 D7.2)

$$X_d = m_X (1 - k_n V_X)$$

X_d = characteristic mean value at 95% reliable or 5% fractile, depending on the k_n input

m_X = mean value

k_n = coefficient for 95% reliable of 5% fractile mean value (Table 4.1 or 4.2)

V_X = coefficient of variation (unknown)

Note "V_X unknown" is adopted until more data are available and "V_X known" is established.

For "V_X unknown" case, V_X will be calculated using:

$$V_X = s_X / m_X$$

where $$s_X^2 = \frac{1}{n-1} \sum (x_i - m_X)^2$$

n = number of samples

s_X = standard variation

Hence

$$X_d = m_X (1 - k_{n,95} V_X)$$
$$= m_X - k_{n,95} s_X)$$

This method is more suitable for GC3 projects where usually > 10 data sets are available. However for illustration purpose, we will demonstrate obtaining the 95% reliable characteristic values with a simple example as below: (take note of the deviation of φ' shall be based on tan φ' as the characteristic value)

	c′ (kPa)	φ′ (°)	tan φ′ (–)
Borehole/test			
BH 1/1	3	31	0.601
BH 1/2	4	30	0.577
BH 2/1	1	35	0.700
BH 2/2	7	28	0.532
Statistical results			
Mean value	$c_{mean} = 3.75$		$(\tan\varphi')_{mean} = 0.603$
Standard deviation	$\sigma_c = 2.50$		$\sigma_{\varphi} = 0.071$
Coefficient of variation	$V_c = 0.667$		$V_{\tan\varphi} = 0.118$

Mean values of c' and φ', their standard deviation and coefficient of variation obtained from four triaxial results

$X_{d,95} = m_X (1 - k_{n,95} V_X)$ where $n = 4$, $k_{n,95} = 1.18$ (Table 4.1)

Characteristics values	Mean value (95%)
c'_k	0.8
$\tan \varphi'_k$	0.519
φ'_k	27.5

<u>Values of the coefficient kn for the assessment of a characteristic value as a 95% reliable mean value</u>

n	V_X unknown
3	1.69
4	1.18
5	0.95
6	0.82
8	0.67
10	0.58
20	0.39
30	0.31
∞	0

Values of the coefficient kn for the assessment of a characteristic value as a 5% fractile

n	V_X unknown
3	3.37
4	2.63
5	2.33
6	2.18
8	2.00
10	1.92
20	1.76
30	1.73
∞	1.64

.

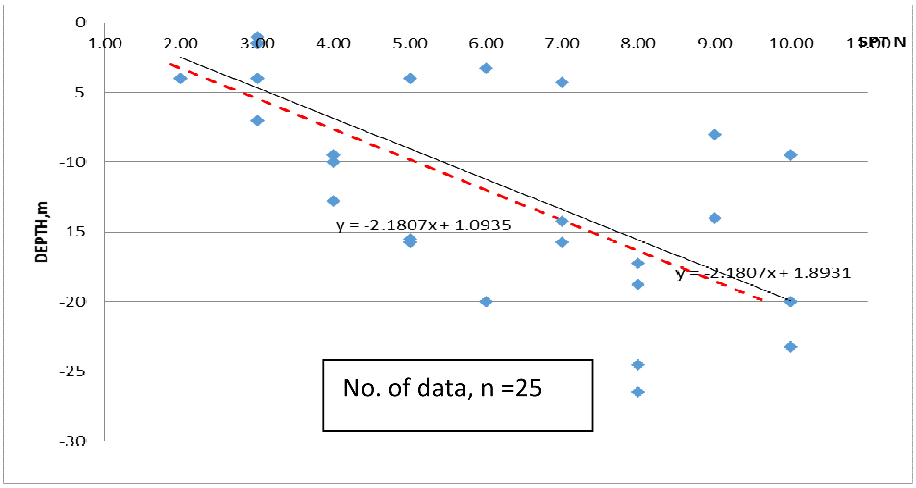
For large amount of data, the mean line could be determined using the plotting Excel spreadsheet trendline function. Some examples of how to determine the ground characteristic values are shown in Annex F.

Annex F

Example of obtaining characteristic SPT N values (large amount of data)

The designer could adopt the following methods to obtain the characteristic SPT N values, where there is large amount of data available.

i) A particular homogenous soil layer shows a linear regression trend.



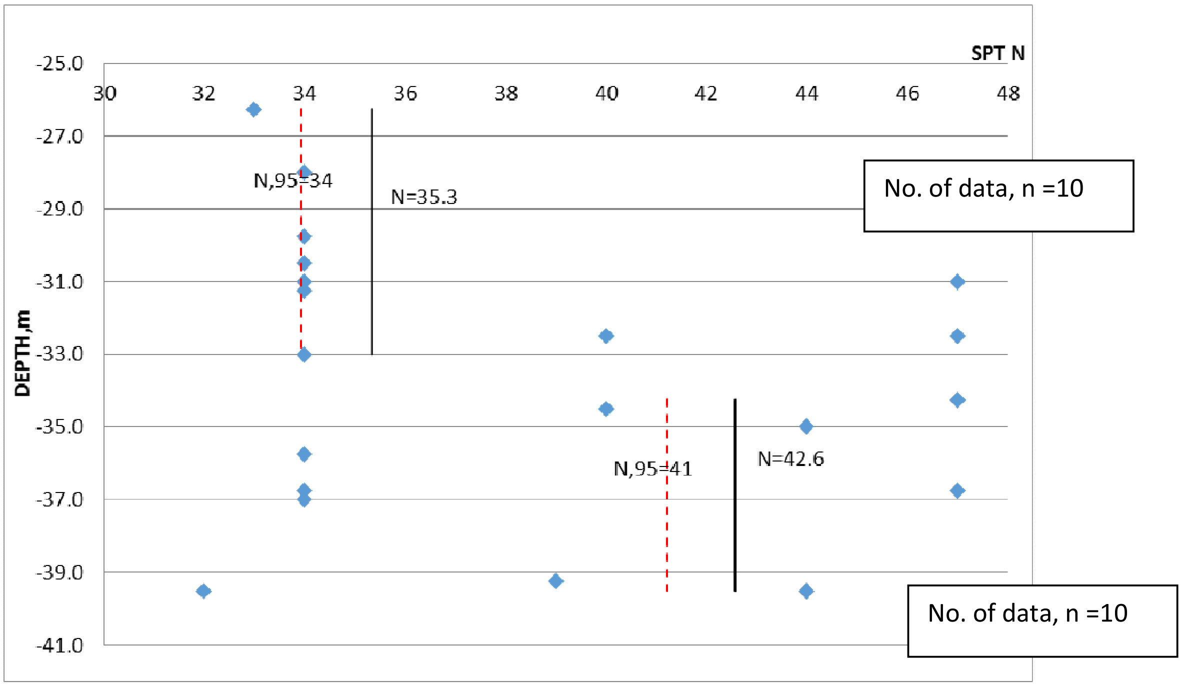
Depth	derived N	Mean N (Xm)	X-Xm		Depth	derived N	Mean N (Xm)	X-Xm
-1.0	3	1.3	1.7		-12.8	4	6.7	-2.7
-1.5	3	1.6	1.4		-14.0	9	7.3	1.7
-1.5	3	1.6	1.4		-14.3	7	7.4	-0.4
-1.5	3	1.6	1.4		-15.5	5	8.0	-3.0
-1.5	3	1.6	1.4		-15.8	5	8.1	-3.1
-1.5	3	1.6	1.4		-15.8	7	8.1	-1.1
-1.5	3	1.6	1.4		-17.3	8	8.8	-0.8
-3.3	6	2.4	3.6		-18.8	8	9.5	-1.5
-4.0	2	2.7	-0.7		-20.0	6	10.0	-4.0
-4.0	3	2.7	0.3		-20.0	10	10.0	0.0
-4.0	5	2.7	2.3		-23.3	10	11.5	-1.5
-4.3	7	2.8	4.2		-24.5	8	12.1	-4.1
-7.0	3	4.1	-1.1		-26.5	8	13.0	-5.0
-8.0	9	4.5	4.5					
-9.5	4	5.2	-1.2					
-9.5	10	5.2	4.8					
-10.0	4	5.5	-1.5					

From derived trendline (using Excel) equation y = mx + C, m = -2.1807, C = 1.8931

⇨ $\Sigma(X\text{-}Xm)^2 = 193$, std deviation, s = 2.6, $k_{n,95} = 0.31$, $C_{95} = 1.0935$

⇨ Plot 95% reliable trendline using formula y = -2.1807 + 1.0935

ii) For a particular soil layer, where there is no apparent linear regression trend, designer could average the SPT N values by depth. (similar to current practice)



Depth	N	n	Mean N (Xm)	X-Xm	$\Sigma(X-Xm)^2$ = 53.6
-26.3	30	10.0	35.3	-5.0	
-28.0	32			-3.0	std deviation, s = 2.4
-29.8	34			-1.0	
-30.5	35			-0.1	$k_{n,95}$ = 0.58
-31.0	36			0.5	
-31.0	36			0.5	$k_{n,95}$ X_m = 1.42
-31.3	36			0.8	
-32.5	38			2.2	N_{95} = 34
-32.5	38			2.2	
-33.0	38			2.8	
-34.3	40	10.0	42.6	4.2	
-34.5	40			4.5	$\Sigma(X-Xm)^2$ = 571.2
-35.0	41			5.1	
-35.8	41			6.0	std deviation, s = 2.4
-36.8	43			7.1	
-36.8	43			7.1	$k_{n,95}$ = 0.58
-37.0	43			7.4	
-39.3	45			10.0	$k_{n,95}$ X_m = 1.36
-39.5	46			10.3	
-39.5	46			10.3	N_{95} = 41

Annex G

Example of obtaining characteristic values of c’ and tan φ’using s’-t tests at failure

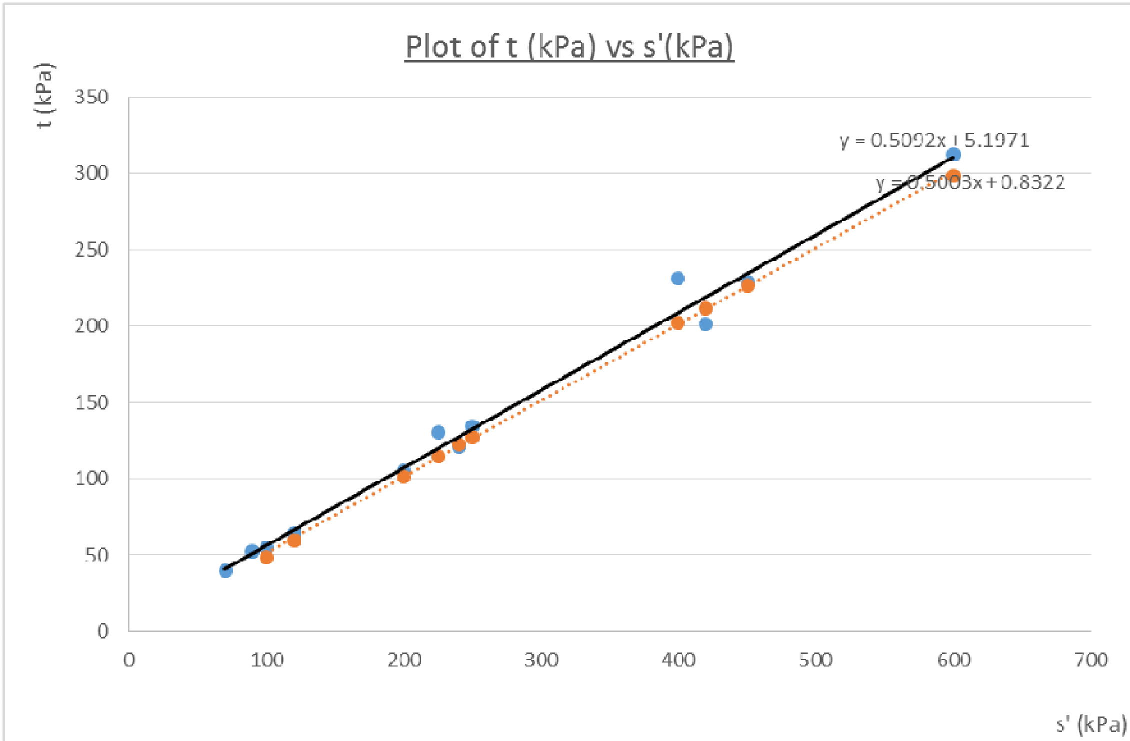
From the triaxial tests of a soil stratum (at least 12 sets), the t-s’ points are derived as below.

The t-s’ points are plotted and using the trendline function from Excel, the trendline and equation could be obtained and back-substituted with s’ values to obtained the t* values.

The example shows how to derive the 95% reliable mean values of c’ and φ’. Refer to the formulas in this annex, denoting z to be s’ and x to be t, the t_k values could be derived and the characteristic trendline of t_k-s’ could be plotted. The characteristic values of c'_k and tan ϕ_k’ may be deduced by linearizing the relation t_k–s’. The appropriate s’ interval should be selected so that the t-intercept (i.e. c'_k) is more than zero. In this example s’ intervals from 100kPa to 600kPa are selected.

Test results		Statistical analysis			
s′ (kPa)	t (kPa)	t*(s′) from linear regression (kPa)	s_1 (kPa)	$t^{0.95}_{(n-2)} s_1$ (kPa)	$t_k = t^* - t^{0.95}_{(n-2)} s_1$ (kPa)
70.0	40.0	40.8	4.5	8.2	32.6
90.0	52.0	51.0	4.2	7.7	43.3
100.0	55.0	56.1	4.1	7.5	48.6
120.0	64.0	66.3	3.9	7.0	59.3
200.0	105.0	107.0	3.1	5.6	101.4
225.0	130.0	119.8	3.0	5.4	114.4
240.0	121.0	127.4	2.9	5.3	122.1
250.0	134.0	132.5	2.9	5.3	127.2
400.0	231.0	208.9	3.8	6.9	202.0
420.0	201.0	219.1	4.0	7.3	211.8
450.0	229.0	234.3	4.4	8.0	226.3
600.0	312.0	310.7	6.7	12.1	298.6

Coefficients of linear regression:
Intercept: $c' = 5.2$ kPa
Slope: $\sin \varphi' = 0.51$, $\varphi' = 30.5°$



c'_k = 0.8kPa and ϕ_k' = 30°

Relevant formulas:

To obtain 95% reliable mean values (denote x = t and z = s' respectively)

$$s_1 = \sqrt{\frac{1}{n-2}\left(\frac{1}{n} + \frac{(z-\bar{z})^2}{\sum_{i=1}^{n}(z_i-\bar{z})^2}\right)\sum_{i=1}^{n}[(x_i-\bar{x})-b(z_i-\bar{z})]^2}$$

$$X_k = [\bar{x} + b(z-\bar{z})] - t_{n-2}^{0.95} s_1$$

$$x^* = \bar{x} + b(z-\bar{z}) \text{: linear regression}$$

where

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + \ldots + x_n)$$

$$\bar{z} = \frac{1}{n}(z_1 + z_2 + \ldots + z_n)$$

$$b = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(z_i-\bar{z})}{\sum_{i=1}^{n}(z_i-\bar{z})^2}$$

To obtain 5% fractile value, substitute s1 with s2.

$$s_2 = \sqrt{\frac{1}{n-2}\left(1+\frac{1}{n}+\frac{(z-\bar{z})^2}{\sum_{i=1}^{n}(z_i-\bar{z})^2}\right)\sum_{i=1}^{n}[(x_i-\bar{x})-b(z_i-\bar{z})]^2}$$

t factor of from student’s distribution could be obtained below, where r = n-2. (n=no of samples)

	t_{n-1} and t_{n-2}
r	p = 95%
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
12	1.782
15	1.753
20	1.725
25	1.708
30	1.686
∞	1.645