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Deep soil mixing – Finnish guideline for stabilisation tests

Mélange profond de sol - Lignes directrices finlandaises pour les tests de stabilisation

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ABSTRACT: There has not been a uniform national guideline on laboratory methods for deep soil stabilisation tests currently in Finland. That is why there has been a need to prepare a guideline for both mass and column stabilisation pretesting in laboratory. Based on this new guideline, stabilisation test results in different laboratories should be more comparable. This paper describes the reasons for the differences in deep soil stabilisation test results based on the different practices used in the laboratories. It also reviews and organizes the source material to identify the crucial factors that have an effect for susceptibility of the stabilisation test results. In the preliminary survey, Finnish laboratories were interviewed about their stabilisation test practices and clear differences in procedures were found. These were particularly the homogenisation of aggregate, the method of compaction, and the storage of samples. The differences were also observed in the reference tests conducted in the laboratories using identical test material. The Finnish Transport Agency's guideline for the design of deep stabilisation (11/2010) was updated during 2017 – 2018 and published in 8/2018. The update was supplemented by a fully new guideline on the laboratory methods for deep stabilisation tests. This paper presents aspects and procedures that were included in the laboratory guideline. The laboratory guideline was completed and based on the preliminary survey. The content of the laboratory guideline has been agreed by the deep soil stabilisation workgroup.

RÉSUMÉ: En Finlande, il n'existe pas actuellement un directive nationale uniforme sur les méthodes de laboratoire pour les essais de stabilisation des sols. Pour cette raison, il a été nécessaire de définir des lignes directrices pour les essais de stabilisation en masse et stabilisation en profondeur en laboratoire. En conséquence, les résultats des tests de stabilisation dans différents laboratoires devraient être plus comparables. Cette article décrit les différences entre les résultats des différentes pratiques utilisées dans les laboratoires avec des tests de stabilisation des sols en profondeur. Il examine et commande également les documents de base pour identifier les facteurs cruciaux qui ont un effet sur la susceptibilité de la stabilisation. Lors de l'enquête préliminaire, les laboratoires finlandais ont été interrogés sur leurs pratiques en matière de tests de stabilisation et des différences nettes en matière de procédures ont été constatées. Il s'agit en particulier de l'homogénéisation des granulats, de la méthode de compactage et du stockage des échantillons. Les différences ont également été observées lors

d'essais de référence menés dans des laboratoires utilisant du matériel d'essai identique. Les directives de l'Agence finlandaise des transports 11/2010 pour la conception de la stabilisation profonde ont été mises à jour en 2017-2018 et publiées le 8/2018. La mise à jour a été complétée par une toute nouvelle directive sur les méthodes de laboratoire pour les tests de stabilisation en profondeur. Ce document présente les aspects et les procédures inclus dans les directives de laboratoire. La ligne directrice de laboratoire a été complétée et basée sur l'enquête préliminaire. Le contenu de la directive de laboratoire a été approuvé par le groupe de travail sur la stabilisation des sols en profondeur.

Keywords: deep stabilisation; geotechnical laboratory; unconfined compression test; binder

1 BACKGROUND

Until 2018, there was no uniform guideline on laboratory methods for deep soil stabilisation tests in Finland and all laboratories had their own procedure for stabilisation tests. There were differences in procedures, particularly in the homogenisation of aggregate, the method of compaction, and the storage of samples as well as in compression testing and reporting. As a result, stabilisation test results between laboratories were not fully comparable. The need for uniform practices and guidelines was urgent, and before that a proper survey of the prevailing situation was necessary. International information was available mainly from Sweden and Japan.

Due to this, the *Preparatory survey on deep soil stabilisation laboratory test guidelines* was written as part of the updating process of the guidelines on deep soil stabilisation design of the Finnish Transport Agency (Niemelin et al. 2018). Based on this preparatory survey and the facts that were observed during the process, it was noted that a fully new guideline on the laboratory methods for deep soil stabilisation tests should be produced.

Finnish Transport Agency guidelines of design of deep stabilisation 11/2010 were updated and they are valid from 08/2018 (Forsman et al. 2018). The update was supplemented by a fully new guideline on the laboratory methods for deep soil stabilisation tests. The aim of this paper is to introduce this new guideline.

2 PREPARATORY SURVEY ON DEEP SOIL STABILISATION LABORATORY TEST GUIDELINES

In the *Preparatory survey on deep soil stabilisation laboratory test guidelines*, the differences in deep soil stabilisation test results based on the differing practices of laboratories were described. Also, national and international source material was reviewed in order to identify the crucial factors that affect stabilisation test results.

In the preliminary survey of the stabilisation test practices of Finnish laboratories, clear differences were found in procedures, particularly in the homogenisation of aggregate, the method of compaction, and the storage of samples. These factors have crucial significance on the results of stabilisation test results. The differences were also observed in reference tests conducted in the laboratories using identical test material.

In Figure 1, the effect of temperature during the curing time is compared in the laboratory and in situ at the site. Temperature measurements show that the temperature of the stabilised soil is clearly higher in the early stage of the hardening reaction and it becomes slowly and gradually even. It is also seen that the storage temperature

has a great significance in the development of the strength in a laboratory. Therefore, storage temperature is a key factor to be controlled during the curing time.

Three key persons from the leading research laboratories in Finland were interviewed for the survey. Likewise, national and international publications regarding stabilisation were reviewed as source material. Stabilisation method, designing principles, effects of different factors on stabilisation test results, practices at the site and in the laboratory have been described most widely in the following publications:

- *Development of design and construction methods to stabilise soft organic soils* (EuroSoilStab 2002)
- *Djupstabilisering med bindemedelsstabiliserade pelare och masstabilisering* (Larsson 2006)
- *The Deep Mixing Method* (Kitazume & Terashi 2013)
- *Mass stabilisation handbook* (Forsman et al. 2015)

Based on the reviewed source material, the key factors affecting the stabilisation test results are the homogenisation and compaction of the sample, the storage method, and the used temperature. It is of vital importance that these factors are taken into account similarly in all laboratories to make the results comparable. Therefore, this preparatory survey presented recommendations for aspects and procedures to be included in the laboratory guideline. Also, the research methods should represent the real circumstances in the site better than the present ones.

To achieve high-quality laboratory results and geotechnical design, it is essential that all the operators use the same, mutually agreed principles in the testing, and any differences from the guidance shall be justified and documented.

The laboratory guideline was compiled on the basis of the preliminary survey. The content of it was agreed by the deep soil stabilisation experts workgroup consisting of representatives from Finnish Transport Agency, Aalto University and other experts from design companies and contractors.

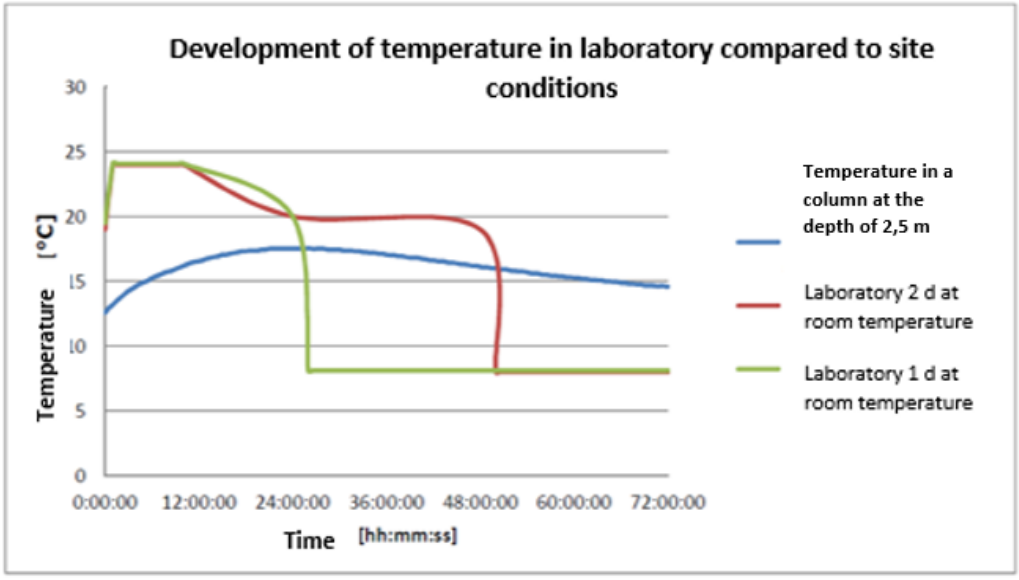

Figure 1. Development of the temperature measured from two laboratory samples and in situ in a column at depth of 2,5 m (R&D records, Ramboll Finland Oy, measurements in situ by VR Track Oy).

3 GUIDELINE ON LABORATORY METHODS FOR DEEP SOIL STABILISATION TESTS

The following procedures and instructions are included and described in the guideline and presented here shortly.

3.1 Sampling and the amount of sample material

Soil samples may be disturbed but not oxidised. It can be estimated that the required sample amount for the laboratory tests is one litre for three clay test pieces and one litre for one peat test piece. Additional amount of sample is needed for classification tests and for backup in case of extra tests are considered or there are mistakes during the laboratory tests.

Samples must be stored in the temperature of 8±2 °C for at least 3 months after the completion of the tests. If the classification properties of sulphite soil samples will be determined, they must be packed airtight in a cooler bag with extra coolers for the transport to laboratory.

3.2 Storing of soil samples and binders

Soil samples must be stored in the temperature of 8±2 °C. Binders are kept in tight containers preventing air moisture contact. The maximum age of the binders used in stabilisation tests is six months. The same batch of binder should be used through the same project if it is reasonable, regarding the storing time of binders which is under one year. Maximum storing time of binders based on by-products or wastes can be one year. Sulphide soil samples are not allowed to have oxygen contact, because oxidised organic or sulphide soil samples alternate during storing.

3.3 Mixing of soil samples

Soil samples are moved from the temperature of 8±2 °C to room temperature 24 hours before starting the preparation of stabilised samples. The whole sample from the same sampling point is mixed together before homogenising, though it may have been divided into separate containers during sampling. The mixing must be done properly. Regarding sulphide soils, the instructions in chapter 3.1 should be followed, to prevent samples from oxidizing.

3.4 Index tests of soil samples

Water content (w), loss of ignition (LoI) and pH must always be determined from the soil samples. It is also recommended to determine grain size distribution and Atterberg limits. These and other index property tests are done, if needed. If the sample is suspected to be sulphide soil, sulphide (S) content is determined and additional analyses done if necessary.

3.5 Mixer and mixing time

The mixture for the stabilisation test, containing soil sample and binder/binders, is mixed with a powerful kitchen mixer. Mixer tool is hook-like as presented in Figure 2 a, not whipper-like or flat (Figure 2 b, c). Mixing time is two minutes, maximum five minutes. It must be noticed that a mass mixed with kitchen mixer is usually more homogenous than the homogeneity achievable in the site.

a) b) c)

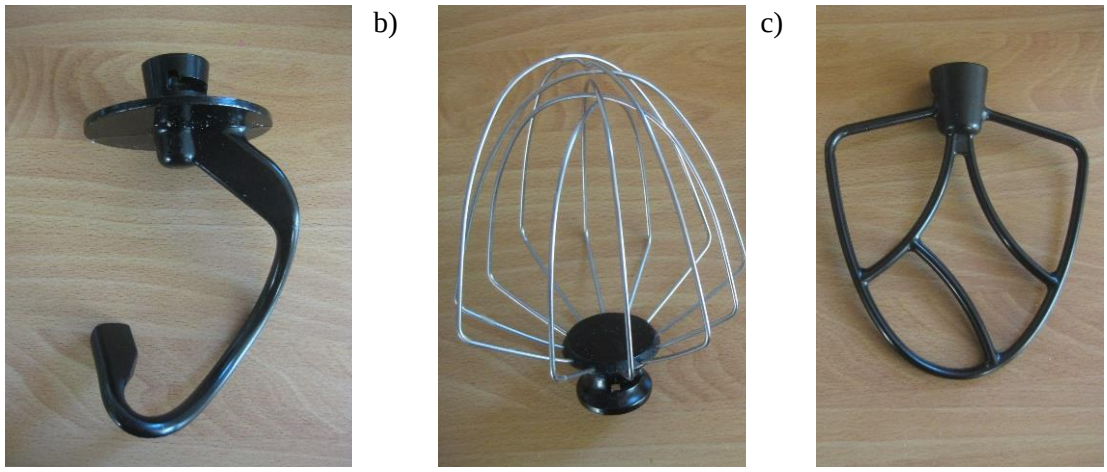

Figure 2. Hook-like mixer's tool a). Flipper-like b) and flat c) are not applicable.

3.6 Amount of test specimens and the size of the mould

The recommendable amount of parallel test specimens is three and the minimum amount is two parallel test specimens made of the same binder mixture for one curing time. Diameter for the mould for clay and silt test specimens is 40-50 mm and for peat 60-80 mm. Test specimens are cylinder-shaped and their height should be 2 x diameter (height/diameter -rate 2:1). The moulds can be solid or they can be split.

3.7 Compaction method and preloading

Compaction method depends on the properties of the material. The graph about choosing the applicable compaction method is presented in Figure 3. Stabilised peat samples are preloaded during the curing time. Typical load is 18 kPa, which remains constant while the sample is being compressed. If the targeted thickness of the compaction embankment in the construction project in question differs essentially from 18 kPa, a designed case-specific preload should also be used during the curing time of laboratory testing.

3.8 Storing of test specimens

Test specimens are stored in their moulds if possible. The ends of the moulds or the moulds overall are closed tightly. The test specimens are stored at room temperature for the first two days in insulation boxes, each binder types in separate boxes. After two days they will be moved to the temperature of +6 to +10°C for the rest of the curing time. The storing method is the same regardless of the properties of the binders or binder mixtures. Test specimens are removed from the moulds carefully before the compression test and protected from drying.

3.9 Rate and duration of compression test

Test specimens are compressed at the rate of 1 mm/min until the test specimen is clearly fractured. Unless the fracture is observed, the compression is continued until 10% deformation is reached. If any noticeable fracture does not occur, the maximum value of the compressive strength is taken when the deformation (change of height) is 10 %. It must be documented in the test report in case a different rate has been used.

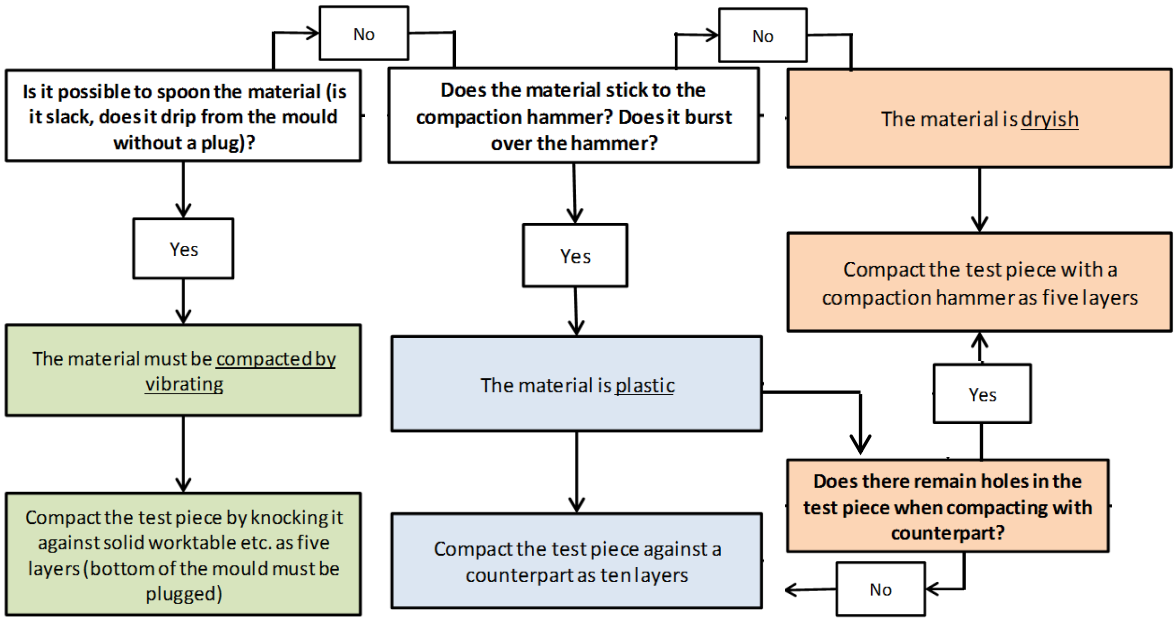

Figure 3. Choosing the applicable compaction method

3.10 Compression equipment and calibration

Compression equipment should be selected so that the measuring range of the load transducer used is calibrated to the force range required to be used, and the measuring range of the displacement transducer is adequate. The measuring must be continuous, and it is not sufficient to measure only maximum values. The load transducer and the displacement transducer of the compression equipment must be calibrated once a year. The calibration process is described specifically in the guideline.

3.11 Content of the test report

The following information is always included in test report:

- *index properties of the original soil sample, at least w* [%]*, bulk density* [kg/m^3], pH, LoI [%]
- *overall dimensions and mass of the test specimen*
- *stress [kPa] - strain* [%] *curves*
- *1-axial compression strength q_u and shearing strength c_u derived from q_u ($c_u = q_u / 2$), [kPa]*
- *average value of parallel compression test results [kPa]*
- description of the procedure, if any noticeable fracture does not occur under 10% deformation, and consequently the maximum value of the compressive strength is taken when the deformation (change of height) is 10 %
- *documentation of any exceptions from the procedures of this guideline*
- *any possible additional information that is needed for the appropriate interpretation of the test results*

The following information is included in the test report if needed:

- additional index properties of soil samples e.g. grain size distribution

- water content of the stabilised test specimen
- density calculated from the overall dimensions and mass of the test piece
- compressive strain at fracture, ε [%]
- load *[N]* - displacement *[mm]* data shall be saved for one year (not to be delivered with the results)
- *calculations of the modulus, elasticity modulus is determined by the formula:* $E_{50} = (q_u / 2) / (\varepsilon_{50\%} / 100\%)$, *where* E_{50} *= deformation modulus of the stabilised soil at the stress level of 0 to 0.5 x* σ_1 *fracture [kPa],* q_u *= unconfined compression strength [kPa] (=* σ_1 *fracture),* ε*50% = deformation [%] equivalent to unconfined compression strength / 2 (Figure 4)*

All the exceptions from the instructions must be documented in the test report.

4 COMPARISON OF THE FINNISH TESTING LABORATORIES

Currently (08-12/2018) a reference testing programme is going on in the five leading Finnish geotechnical laboratories aiming to test this new laboratory method guide. The identical series of test samples will be produced in all the laboratories and same soil samples, binders and binder mixtures will be used in all the laboratories. The samples are stored, tested and reported identically and the new laboratory guide will be followed in detail in all stages of the process. Test reports of all the participating laboratories will be compared and analysed. Consequently, conclusions are made and if any improvements or corrections are required, the guide will be supplemented.

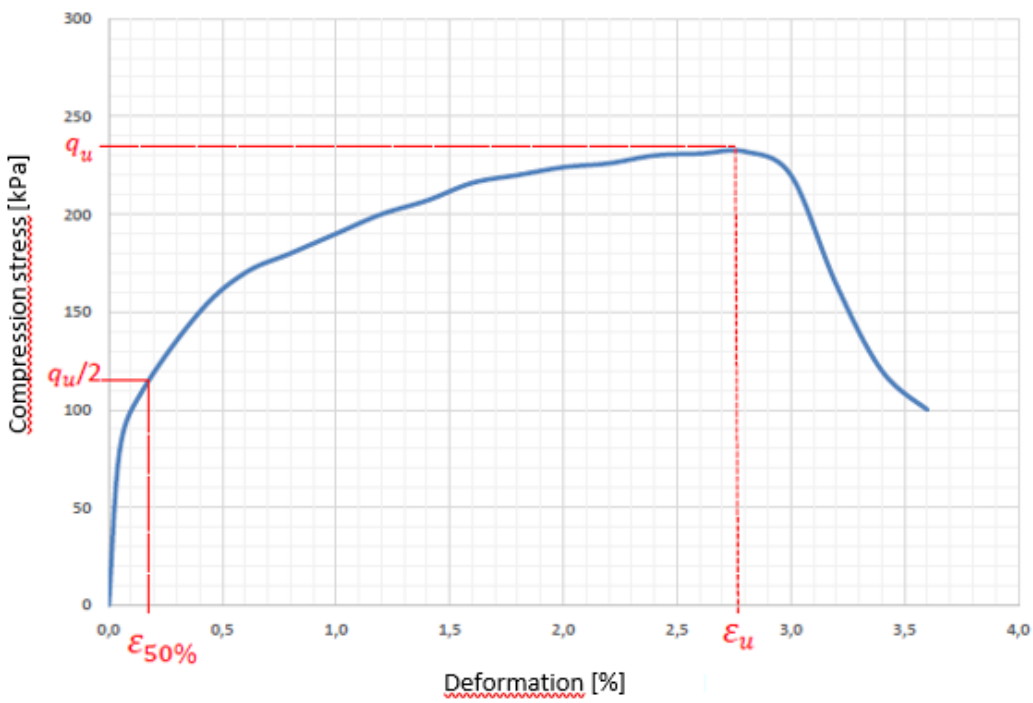

Figure 4. Example of determining of E50 modulus from stress – deformation graph.

5 CONCLUSION

There have not been uniform guidelines on laboratory methods for deep soil stabilisation tests in Finland previously. Guidelines on deep soil stabilisation design (Finnish Transport Agency guideline number 17/2018) have become valid on the 1st of August 2018. The guidelines will be followed in all projects ordered by the Finnish Transport Agency, which is a leading agency maintaining codes of practice concerning all the infrastructure sector in Finland, managed by the Ministry of Traffic and Communications.

The guidelines were supplemented by a fully new guideline on laboratory methods for deep soil stabilisation tests. The guideline will be applied by all laboratories in infrastructure sector in Finland. To achieve high-quality laboratory test results, it is essential that all the operators use the same, uniform principles in the testing and reporting. Any exceptions from the guidance shall be justified and documented in the test report, hence the designer has a possibility to estimate the effect of it to the results. Uniform laboratory guidelines will facilitate the comparison of test results between laboratories and thus increase the reliability of the deep stabilisation method.

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