

## Remarks on wet deep soil mixing quality control

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**Abstract.** As wet soil mixing has a lot of advantages in comparison to other soil improvement methods it is used more often all over the world. It can be used as sealing element instead of diaphragm walls or also as load bearing element as an alternative to stone columns or even to piles. For these challenging uses the quality control is important to guarantee that the values in the field match with the original design criteria. Since a soil mixing element consists mainly of the in-situ subsoil also the quality of the final product has a natural spread. To ensure the quality of the product and thereby the stability of the founded building quality control is a big issue that has to be followed, keeping in mind that the base material is natural and a certain spread of the samples is normal. This article gives a general overview of different methods of taking samples, analyses UCS values of different jobsites and different methods. The article outlines a possible way for quality control on soil mixing projects.

*Keywords:* DSM, Quality check ; Samples; Soil-mixing; UCS;

### 1 INTRODUCTION

Soil mixing is a construction method which mixes the existing subsoil with a binder to increase the strength and stiffness of the ground. It can also be used for decreasing the permeability and creating tightening elements. In both cases quality control is an important, not so clear and easy topic.

#### 1.1 Method statement

The production sequence is quite simple. A drilling rig drills a hole while slurry - consisting of water and binder - is pumped through the auger into the ground. The special designed auger mixes the soil with the slurry and creates a homogeneous column with defined characteristics. If needed, the drilling and mixing process is repeated several times. The quantity of injected slurry and number of mixing sequences is defined depending on the base material (ground) and on the needed quality (strength, stiffness, permeability).

#### 1.2 Use of soil mixing

The most important characterization of wet soil mixing is that the main quantity of the product is the existing subsoil which is improved. As a result, there is no excavated material and also less material transport as for concrete or gravel. As long as water is available this method is independent of material supply since only cement which can be stored in silos needs to be delivered on site.

Soil mixing is an easy and cost-efficient method for improving the characteristics of the subsoil to create tight and load bearing elements. Therefore, it is used for diaphragm walls for retaining systems but also as deep foundation for buildings and soil strengthening. Soil mixing can also be used as a supporting system for construction pits.

The advantage of using the existing soil mainly may also be the biggest disadvantage. Depending on the original ground, the used quantity of cement and many other factors, uniaxial strengths between

1 N/mm<sup>2</sup> and 7 N/mm<sup>2</sup> is usually reached. Compared to concrete the characteristics of this material have a certain spread which makes quality control important and not easy as well.

## 2 QUALITY CONTROL

As already mentioned quality control of soil mixing is important as the final product consists not of homogeneous materials such as concrete used for piles or columns.

Before starting a project, preliminary tests are performed. For his purpose material is dug on site and mixed in a laboratory with binder and water. Depending on usage in future the created samples are tested for the uniaxial compressive strength or permeability. Based on these results the production on site starts with a defined cement content and grout density which can be adapted after first samples from the field have been tested.

This second step is a most difficult one because reliable results of samples taken from the ground are needed.

### 2.1 Sampling methods

Basically, there are three common ways for getting samples that can be used for quality control of wet soil mixing elements which have different advantages and disadvantages:

- Wet sampling method: material is taken out of the mixed element as long as it is still wet and soft. It is poured into forms to create cylinder or cubic moulds which are stored under laboratory conditions until they are tested (usually UCS). While with this method it is easy to create a big number of samples one problem is that the samples can be very different in behaviour to the original element. Although they consist of the same material compaction and also curing process can be very different.
- Core samples: samples are drilled out of a hard column on a defined depth. The extracted cores show in-situ condition of soil mixing element in a quite representative way. After the samples have been prepared they can also be tested as wet samples as well. The biggest problem of this method is that it is very difficult to get proper core samples drilled out of elements with an UCS of less than 5 N/mm<sup>2</sup>. Moreover, it is expansive and time consuming (drilling must be in bonded, quite stiff material) which means it is not a suitable method for getting a huge number of samples.
- Liner samples: a pipe is placed in a wet column until the material inside gets hard. Thereafter the pipe is pulled out. After several days the pipe is opened and cylinder samples can be cut off for testing. This method combines the two others mentioned before.

As all of these methods have positive and negative points, all of them can be used in the right time, as long as it is kept in mind when the results of the samples are evaluated.

### 2.2 Regulations and standards

Basic European standard is the EN 14679. This document defines most relevant points for deep mixing projects. Beginning with the method itself, the design, all phases of execution and also the control of deep mixing is mentioned. Although this standard seems to be quite complete and treats all aspects of this construction method, it has the weakness that it does not instruct a certain way of quality control which can be used as standard method and can guarantee a quality standard for all parties.

The Austrian guideline (ÖBV) for soil-mixing brings good ideas and also methods for sampling on soil mixing columns. It also contains a way for statistical analyses of how to deal with the spread of samples. It is also mentioning a certain way to consider samples not passing the original design criteria. Nevertheless a mandatory regulation for taking sample is missing.

### 3 DISCUSSING AND COMPARING UCS-TESTS

During execution of a soil-mixing project a lot of samples have been taken and tested. When receiving the first UCS-test results after a short construction period, it is obvious that there is a certain spread of the values. There are several explanations for that phenomena:

- errors in sample preparation
- cracks of the sample before testing because of not suitable storing
- insufficient testing equipment
- natural heterogeneity of material

As most samples are taken as wet-sample in the above mentioned method the easiest explanation is that the production of samples was wrong. For example, bad compacted or the extracted material has a varying content of cement.

In Figure 1 the results of the UCS-test of one jobsite are shown. The blue crosses are 53 wet samples, taken out of the soil-mixing column. The green crosses symbolize the UCS-values of 11 core samples which were drilled out of columns. All results were tested after a period of at least 56 days. Although there is a huge spread between the UCS-test results it is interesting that the average value for both testing methods has the same range between 3 N/mm<sup>2</sup> and 4 N/mm<sup>2</sup>. A logical explanation for the fact that the spread of the wet samples is bigger are different procedures in production of samples.

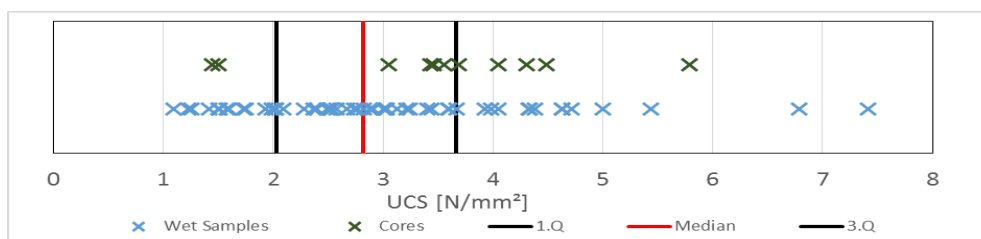


Figure 1. Comparison of wet samples and core samples of one jobsite.

Outgoing from this experience results of five other job sites have been compared. In four out of six jobsites the spread between the lowest and the highest UCS-value from wet samples is greater than from the core ones.

The results shown in Table 1 were the reason for making several tests on two different soil mixing columns. The results of the UCS-test of the core samples are shown in figure 2. As can be seen, there is a spread of minimum and maximum UCS of 2 or even 3. While in one column there seems to be a cluster at 4,8 N/mm<sup>2</sup> the other column has no cluster.

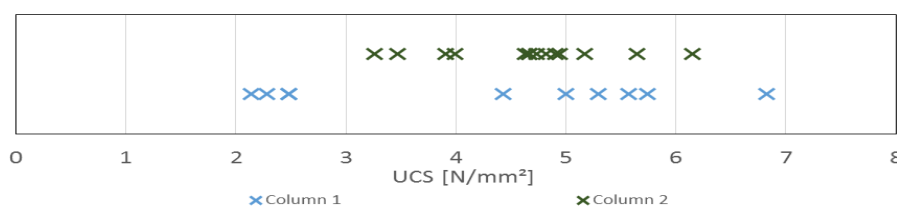


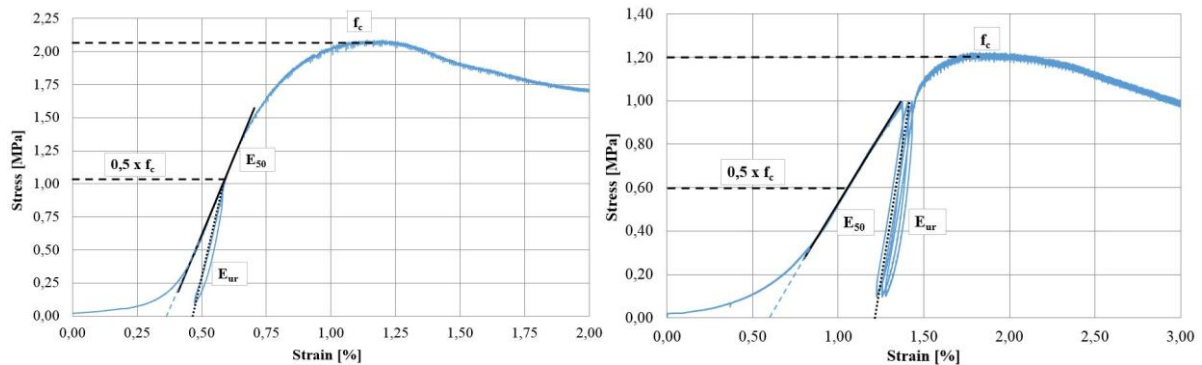
Figure 2. UCS-test of the core samples.

**Table 1.** Comparison of UCS-test results of six sites

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	Wet s.	Core	Wet s.	Core	Wet s.	Core	Wet s.	Core	Wet s.	Core	Wet s.	Core
<b>Number of samples</b>	53	11	27	22	81	10	24	43	18	18	17	23
<b>Min UCS value</b>	1,09	1,45	2,60	1,30	1,60	2,50	2,60	1,00	1,96	1,90	2,40	0,84
<b>Max UCS value</b>	7,42	5,79	8,00	3,00	5,60	3,30	8,47	9,60	7,10	7,50	6,33	2,68
<b>Max-Min</b>	6,33	4,34	5,40	1,70	4,00	0,80	5,87	8,60	5,14	5,60	3,93	1,84
<b>p=0,25</b>	2,03	3,24	3,40	1,73	2,00	2,73	3,98	4,25	3,83	2,93	2,70	1,24
<b>P=0,50</b>	2,82	3,56	4,00	2,00	2,30	2,85	4,90	5,90	4,50	3,80	3,10	1,49
<b>P=0,75</b>	3,67	4,18	5,30	2,20	3,20	3,08	6,43	6,80	4,88	6,62	4,73	2,18
<b>Mean value</b>	3,04	3,53	4,51	2,03	2,64	2,89	5,29	5,40	4,37	4,37	3,84	1,68
<b>Standard deviation</b>	1,33	1,19	1,54	0,45	0,91	0,25	1,78	2,47	1,35	1,93	1,31	0,56

#### 4 YOUNG MODULUS ESTIMATION

Columns material stiffness can be checked on the same samples as the strength. The deformations can be checked during uniaxial compression or triaxial tests. Knowing the stress and strain of the sample Young modulus can be estimated. Below (figure 3) two example of stress-strain curves obtained from uniaxial compression test are shown. Two possible moduli are shown on the graphs  $E_{50}$  (the inclination of curve in 50% of the strength) and  $E_{ur}$  (inclination of curve during unloading and reloading). According the recent state of knowledge the values of  $E_{50}$  modulus are correlated to  $f_{cm}$  and  $f_{ck}$  strength [1]. There is a lack of such a correlation for  $E_{ur}$  modulus which is in most cases higher than  $E_{50}$  [2], [3]. However due to results of the simulations shown in [3] the use of  $E_{ur}$  modulus can give results which are closer to field results (stiffness obtained from load tests). The beginning of the test curve is neglected due to bedding error correction [4].



**Figure 3.** Stress – strain curves from laboratory uniaxial test of wet samples.

#### 5 LOAD TESTS

Another method of the quality control can be load tests. This type of test is not too often applied. However even if this type of testing is performed the results interpretation is not easy. The results of the test do not give a simply way to define stiffness of the column or column-soil stiffness. The load distribution in real structure will be different than during the tests so to gain conclusions numerical back analysis is suggested. That kind of analysis can be made only by geotechnical designer.

Below figure 4 the results of 20 trial load tests are shown. Deep soil mixing columns with the diameter of 1,2 m and length between 3,6 – 9,6 m were tested. The tests have been done between 38 and 63

days after columns performance. Ground conditions in all cases were similar while the tests were performed within one building site. Different colors indicate uniaxial strength of wet samples tested the same day as the load test. Analyzing the results, it can be seen that there is no direct link between the strength and the settlement. The same results are shown on figure 5, but the columns are differentiated due to length. The results are similar to the previous one, there is no link between the settlement and the length.

It can be noticed that the relationship between force and settlement is linear to the value of about 1200 kN (stress equal to 1,05 MPa). In this range of stresses, the stiffness varies from 200 MN/m to 600 MN/m. This level of stiffness should be considered as satisfactory, however the settlement which occurs at higher stresses seems to be significant for some type of structures (for example bridge foundations). However, the settlement values at characteristic load level (1200 kN in this case) are most important, what is over this level can be used to show the safety factor on settlements.

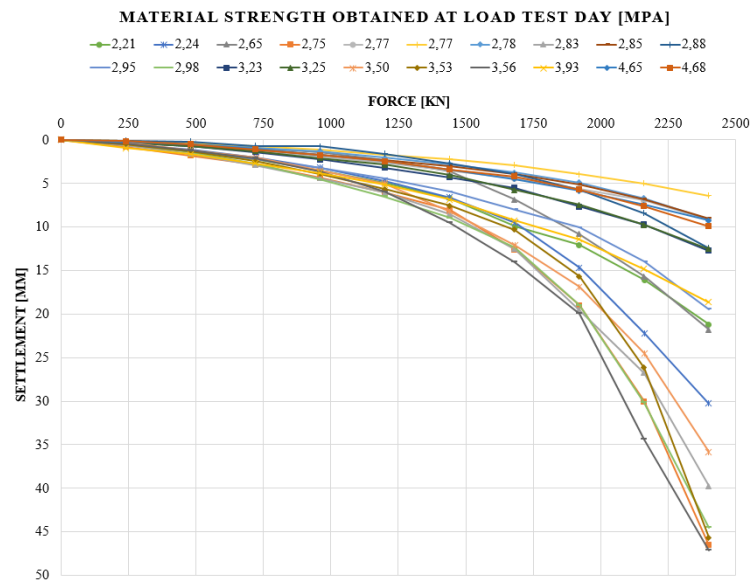


Figure 4. Load tests results from 20 DSM columns of different material stiffness.

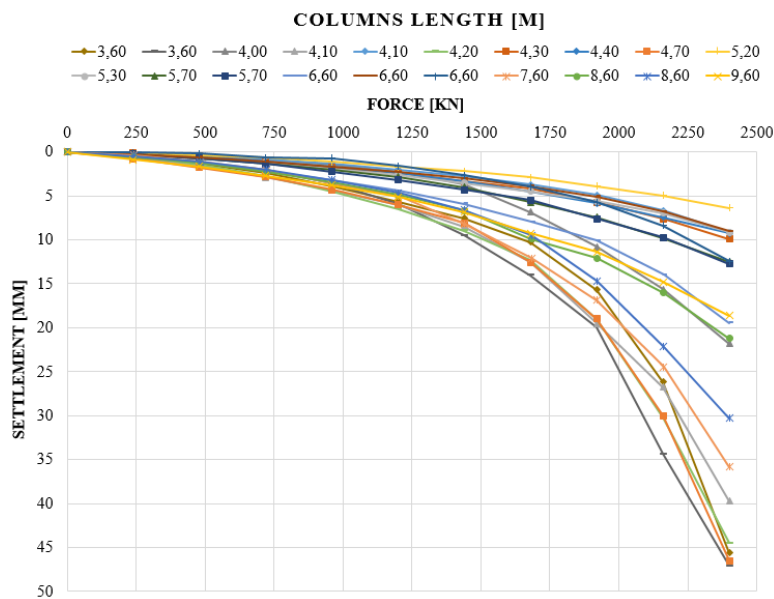


Figure 5. Load tests results from 20 DSM columns of different length.

## 6 CONCLUSIONS

In section 3 the results of UCS-tests on wet samples and also on core samples have been shown. Based on these results it is obvious that the sample quality of wet samples is not the (only) reason for the big spread between the minimum and maximum value. Even core samples which were drilled out of one column have a spread of factor 3. The reason for that is on one hand the fact that soil mixing elements are mixed in-situ and the base material is the natural existing soil which leads to inhomogeneity. The other problem is that a small sample (15 cm cube) shall represent a big column (at least 60 cm diameter). A weak point like some cubic centimetres of clay have an enormous effect on the small sample while the strength of the column might not be shortened.

Another point that should be kept in mind when thinking about quality control is the aim of the column. In most project soil-mixing is carried for reducing the settlement. In that case it is wrong to focus on the uniaxial strength instead of keeping an eye on the stiffness which is mentioned in section 4.

For small diameter, single columns load tests can give a realistic prediction of the future settlements of the structure based on soil-mixing elements. They can also be the answer to the problem that wet samples and even core samples have an enormous spread. When increasing the scale of the tested samples up to a column or even a group of columns the spread can be reduced to a minimum. This idea fits to the fact that there is no link between the UCS and the settlement of the load tests which were analysed in section 5.

In most cases soil-mixing is designed as ground improvement and so it cannot be compared to piles.

As soil-mixing is getting more often used and the diameters of the columns are getting bigger it is worth to think about the quality control of this method. As this method uses mainly the existing subsoil which has a natural spread, quality control is important to meet the design criteria but the performed control has to take account on the spread which was shown in this article. Furthermore, the criteria which needs to be tested has to be defined in an intelligent way thinking about the whole system and not simple looking on soil-mixing columns as on piles. Therefore, there is a need for a standard which defines the control of soil-mixing more precisely to allow clarity between client and contractor.

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