SOIL MIX WALLS as retaining structures – Belgian practice

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ABSTRACT

Since several decennia, the deep soil mix (DSM) technique has been used for ground improvement (GI) applications. In recent years, soil mix walls (SMW) have become an economical alternative to traditional excavation support systems.
The present paper concentrates on the application of SMW technology in Belgium. It focuses on the three main types of DSM systems currently used in Belgium: the Cutter Soil Mix (CSM), the Tubular Soil Mix (TSM) and the CVR C-mix® techniques.
In a second step, BBRI information sheets (BBRI, 2012a and b), developed within the framework of the Flemish regional research project IWT 080736, are presented. BBRI info sheets have been established for the purpose of helping contractors to improve the quality control (QC) of their finished product. They consist of guidelines for the execution phases and give some requirements with regard to the material quality, the characteristic dimensions, the bearing capacity and the lateral SMW displacement.
The BBRI info sheets define QA (Quality Assurance)/QC requirements in function of the DSM application – retaining wall, water barrier or foundation – and with regard to the permanent or temporary use of the construction. The acceptance criteria are proposed in terms of the number of unconfined compressive strength (UCS) tests, the limitation of soil inclusion percentage into the mix, the determination of the elastic modulus and the execution tolerances. Finally, the BBRI info sheets are discussed from an international view point regarding QA/QC procedures for deep mixing.

1. INTRODUCTION

1.1. DSM technique as excavation support

The DSM process was introduced in the 70’s in Japan and in the Scandinavian countries. Since several decennia, DSM has been known as a GI technique, as reported in Porbaha et al. (1998 and 2000). Porbaha has notably proposed a terminology for the DSM technology, as given in Table 1.
According to the classification of GI methods adopted by the TC 17 (Chu et al. 2009), DSM can be classified as ground improvement with grouting type admixtures, as illustrated in Table 2.
A lot of reviews describing various Deep Mixing Methods (DMM) are available in Terashi (2003), Topolnicki (2004), Larsson (2005), Essler and Kitazume (2008) and Arulrajah et al. (2009). In parallel, the results of national and European research programs have been published in multiple interesting reports (such as Eurosoilstab, 2002), while also the European standard for the execution of deep mixing “Execution of special geotechnical works – Deep Mixing” (EN 14679) was published in 2005. Most of these research projects focused on the global stabilisation of soft cohesive soils such as peat, clay, gyttja and silt.
More recently, DSM has still increasingly been used for the retaining of soil and water in the case of excavations, as illustrated in Fig. 1. As a matter of fact, SMW represent a more economical alternative to concrete secant pile walls and even in several cases for king post walls (i.e. soldier pile walls).
Rutherford et al. (2005) have proposed a historical background of excavation support using SMW. Table 3 and 4 respectively compare the usual types of excavation support and the GI techniques used for retaining wall construction.

Table 1: Terminology of the deep mixing family, after Porbaha (1998)

CCP: chemical churning pile	DeMIC: deep mixing improvement by cement stabilizer
CDM: cement deep mixing	*In situ* soil mixing
CMC: clay mixing consolidation method	JACSMAN: jet and churning system management
DCCM: deep cement continuous method	Lime-cement columns
DCM: deep chemical mixing	Mixed-in-place piles
DJM: dry jet mixing	RM: rectangular mixing method
DLM: deep lime mixing	Soil-cement columns
DMM: deep mixing method	SMW : soil mix wall
DSM: deep soil mixing	SWING: spreadable WING method

Table 2: Classification of GI methods adopted by TC17 (after Chu et al., 2009)

D. Ground improvement with grouting type admixtures	D1. Particulate grouting	Grout granular soil or cavities or fissures in soil or rock by injecting cement or other particulate grouts to either increase the strength or reduce the permeability of soil or ground.
	D2. Chemical grouting	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate to either increase the strength or reduce the permeability of soil or ground.
	D3. Mixing methods (including premixing or deep mixing)	**Treat the weak soil by mixing it with cement, lime, or other binders in-situ using a mixing machine or before placement**
	D4. Jet grouting	High speed jets at depth erode the soil and inject grout to form columns or panels
	D5. Compaction grouting	Very stiff, mortar-like grout is injected into discrete soil zones and remains in a homogeneous mass so as to densify loose soil or lift settled ground.
	D6. Compensation grouting	Medium to high viscosity particulate suspension is injected into the ground between a subsurface excavation and a structure in order to negate or reduce settlement of the structure due to ongoing excavation.

Figure 1: SMW with ground and water retaining functions

Table 3: Comparison of usual types of excavation support, after Rutherford et al. (2005)

Excavation support system	**Advantages**	**Limitations**
Structural diaphragm (slurry) wall	Constructed before excavation and below ground-water, good water seal, can be used as permanent wall and can be used in most soils. Relatively high stiffness. Can become part of the permanent wall.	Large volume of spoils generated and disposal of slurry required. Costly compared to other methods. Must be used with caution or special techniques must be used when adjacent to shallow spread footing.
Sheetpile wall	Constructed before excavation and below ground-water. Can be used only in soft to medium stiff soils. Quickly constructed and easily removed. Low initial cost.	Cannot be driven through complex fills, boulders or other obstructions. Vibration and noise with installation. Possible problems with joints. Limited depth and stiffness. Can undergo relatively large lateral movements.
Soldier pile and lagging wall	Low initial cost. Easy to handle and construct.	Lagging cannot be practically installed below groundwater. Cannot be used in soils that do not have arching or that exhibit base instability. Lagging only to bottom of excavation and pervious.
Secant wall/Tangent pile wall (similar to DSM walls)	**Constructed before excavation and below ground-water. Low vibration and noise. Can use wide flange beams for reinforcement.**	**Equipment cannot penetrate boulders, requires pre–drilling. Continuity can be a problem if piles drilled one at a time.**
Micro–pile wall	Constructed before excavation and below ground-water. Useful when limited right of way.	Large number required. Continuity a problem, low bending resistance.

Table 4: Comparison of excavation support using GI techniques, after Rutherford et al. (2005)

Excavation support using GI	**Advantages**	**Limitations**
DSM method	**Constructed before excavation and below ground-water. Low vibration and noise levels. Fast construction. Reduced excavated spoils compared to slurry (diaphram) walls. Improved continuity with multi-drill tool.**	**Difficult with boulders and utilities, spoil generated.**
Permeation grouting	Constructed before excavation and below ground-water.	Pre–grouting to control flow of grout through cobbles, does not penetrate soil with more than 15% fines.
Soil nailing	Rapid construction, boulders could be drilled through. Can be used in stiff soils.	Cannot install below groundwater, easements required, cannot be used in soft soils or soils that exhibit base instability. Excavation must have a stable face prior to installation.
Jet grouting	Constructed before excavation and below ground-water.	Difficult with boulders, large volume of spoils generated. Obstructions can obstruct lateral spread of mixing
Soil freezing	Constructed before excavation and below ground-water.	Difficult to install with flowing groundwater and around boulders. Very costly for large area and/or prolonged time. Temporary. Ground heave during freezing and settlement during thaw.

In a more general perspective, Bruce et al. (1998) provided a chronology of the major events related to the DMM and proposed a classification of the DSM systems largely used to date.
In the DSM process, the ground is in situ mechanically mixed while a binder, based on cement, is injected. The DSM cylindrical columns or rectangular panels can be placed next to each other, in a secant way. By overlapping the different DSM elements, a continuous SMW is realised, as illustrated in Fig. 2. Steel H or I-beams are inserted into the fresh DSM material to resist the shear forces and bending moments. The maximum installation depth of the SMW lies – so far – in the order of 20 m. The main structural difference between SMW and the more traditional secant pile walls is the constitutive material which consists of a mixture of soil and cement instead of traditional concrete.

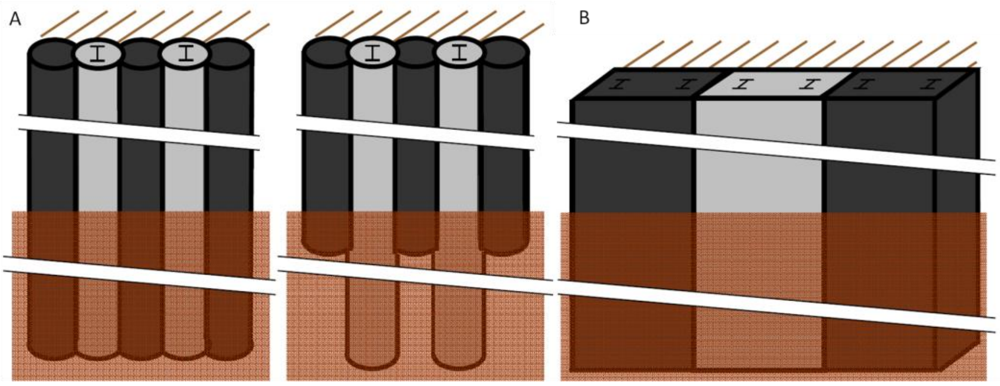

Figure 2: Schematic plan view of the secant execution of (A) cylindrical DSM columns and (B) rectangular DSM panels

1.2. Deep Soil Mix (DSM) material

Several parameters have an influence on the produced DSM material. Terashi (1997) highlighted the factors affecting the strength of the DSM material, as illustrated in Table 5. The DSM material quality depends on the cement type and content, on the in situ soil and on the execution process.
The hardening agent is usually a mixture of cement, water, and in several cases bentonite. The water/binder mixture (w/b weight ratio) is also a governing parameter which plays a major role in the mechanical/durability characteristics of the material.
Moreover, the nature of the ground has a huge impact on the strength and uniformity of the material. For example, stiff cohesive soil does not allow an effective mix of the components and can lead to the presence of unmixed material in the DSM element.
Finally, the final product will be the result of a given DSM system available on the local market. There are a lot of differences between the various systems – especially with regard to the drilling/mixing tools – and the execution process influences the quality of the DSM material in terms of strength, uniformity and continuity. The following paragraphs present the three main DSM systems available on the Belgian market.

Table 5: Factors affecting the strength of the DSM material, after Terashi (1997)

I. Characteristics of hardening agent	1. Type of hardening agent 2. Quality 3. Mixing water and additives
II. Characteristics and conditions of soil	1. Physical chemical and mineralogical properties of soil 2. Organic content 3. pH of pore water 4. Water content
III. Mixing conditions	1. Degree of mixing (Mixing energy) 2. Timing of mixing/re–mixing 3. Quantity of hardening agent
IV. Curing conditions	1. Temperature 2. Curing time 3. Humidity 4. Wetting and drying/freezing and thawing, etc.

2. DEEP SOIL MIX SYSTEMS IN BELGIUM

The CVR C-mix®, the TSM and the CSM are the three most widely used DSM systems in Belgium. All three are wet soil mixing systems.

2.1. CVR C-mix®

The CVR C-mix® is performed with an adapted bored pile rig and a specific designed shaft and mixing tool. This tool rotates around a vertical axis at about 100 rpm and cuts the soil mechanically. Simultaneously, the water\binder mixture (w\b weight ratio between 0.6 and 0.8), is injected at low pressure (< 5 bar). The injected quantity of binder amounts mostly to 350 and 450 kg binder/m³, depending on the soil conditions and specifications. The binder partly (between 0% and 30%) returns to the surface. This is called 'spoil return'.
The resulting DSM elements are cylindrical columns with diameter corresponding to the mixing tool diameter, varying between 0.43 and 1.03 m. For retaining structures, the production rate is about 160 m² of SMW per day (single 8 hrs shift).
In order to increase the production rate, a CVR Twinmix® and a CVR Triple C-MIX® have been designed. A twinmix has two mixing tools, mixing two overlapping cylindrical columns (wall element length of 0.8 to 1.2 m) at the same time. The daily production increases till 210 m²/day. A CVR Triple C-mix® has three mixing tools in line, with a wall element length of 1.5 to 1.8 m. The production rate increases to 300 m²/day. Figure 3 illustrates the CVR C-mix® machine and its Triple version.

Figure 3: CVR C-mix® machine and its Triple version

2.2. Tubular Soil Mix (TSM)

As represented in Fig. 4, the TSM technique uses a mechanical and a hydraulic way of mixing. Apart from the rotating (around the vertical axis) mixing tool, the soil is cut by the high pressure injection (till 500 bars) of the water\binder mixture with w\b chosen between 0.6 and 1.2. The injected quantity of binder mixture amounts mostly to 200 and 450 kg binder/m³. Part of the binder (between 0% and 30%) returns to the surface as spoil return.
The resulting DSM elements are cylindrical columns with a diameter between 0.38 and 0.73 m. The production rate is about 80 m² of SMW per day.

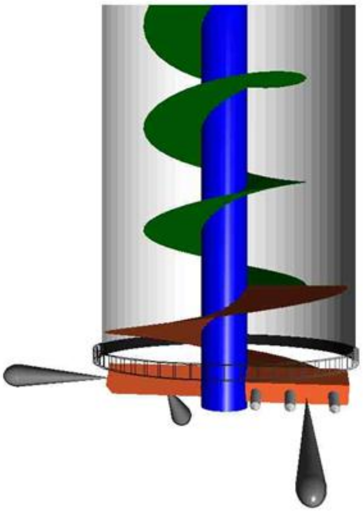

Figure 4: Scheme of the TSM mixing tool (Smet-F&C)

Again, a twin and a triple version exist, leading to wall element lengths respectively varying between 0.8 and 1.4 m or 1.2 and 2.1 m. The production rate is increased till about 180 (twin) and 250 m² (triple) of SMW per day. Figure 5 illustrates a retaining structure executed with the help of the triple version of TSM.

Figure 5: SMW performed with the help of the triple version of TSM (SMET-F&C)

2.3. Cutter Soil Mix (CSM)

A CSM device is commercially available. Two cutting wheels rotate independently around a horizontal axis and cut the soil. At the same time, the water\binder mixture is injected at low pressure (< 5 bar) with w\b ratio chosen between 0.6 and 1.2. The injected quantity of binder amounts mostly to 200 and 400 kg binder/m³. Again, spoil return ranges between 0% and 30%.

The resulting DSM elements are rectangular panels. In Belgium, these panels have usually a length of 2.4 m and a thickness of 0.55 m, though cutter devices with other dimensions are internationally available. The production rate is about 100 m² to 250 m² of SMW per day. Figure 6 illustrates the CSM cutting wheels and the resulting DSM panel. Figure 7 gives an example of a CSM wall.

Figure 6: The cutting wheels of the CSM machine and the resulting CSM panel (Soetaert - Soiltech)

Figure 7: SMW performed with the CSM technique (Lameire Funderingstechnieken n. v.)

3. BBRI INFORMATION SHEETS: FIRST STEPS FOR BELGIAN GUIDELINES

Unfortunately, up to now, guidance rules and recommendations concerning the realization of SMW with soil and/or water retaining functions are lacking. In view of QA/QC development and in the context of European standardization, basic rules are required with regard to design, execution and control of the different DSM processes.

For the purpose of investigating this question, the Belgian Building Research Institute (BBRI) initiated the "Soil Mix" project (IWT 080736) in 2009 in collaboration with the KU Leuven and the Belgian Association of Foundation Contractors (ABEF). Financial support has been obtained from IWT, the Flemish government agency for Innovation by Science and Technology (http://www.iwt.be/). Numerous tests on in situ DSM material have been performed. A good insight has been acquired with regard to strength and stiffness characteristics that can be obtained with the CVR C-mix®, the TSM and the CSM systems in several Belgian soils (Denies et al., 2012a). In addition, info sheets have been developed within the framework of the project (BBRI, 2012a and b). They consist in guidelines for execution phases and give some requirements with regard to the quality of the DSM material, the characteristic dimensions, the bearing capacity and the lateral SMW displacement. The BBRI info sheets are structured as follows:

a. Types of DSM systems
b. Execution: general remarks
c. Materials
d. Dimensions of the SMW elements
e. Bearing capacity
f. Horizontal deflection
g. Domain of use
h. Special attention points
i. Variants (if existing)
j. Quality Control (QC) aspects

The following paragraphs concentrate on the execution sequence, the domain of use, the QC aspects and the execution tolerances detailed in these info sheets.

3.1. Execution of the DSM elements

Figure 8 illustrates the usual execution sequence for DSM columns and panels. In both cases, a guidance device can be used in such a way to control the positioning of the DSM elements during the down grade of the mixing tool into the soil.

As illustrated in Fig. 8a, only the secondary columns are reinforced with the help of steel beams. For the use of reinforcement cage, additional investigation is required. The excavation is performed until the depth of the first horizontal support or until its final depth. Potential horizontal support (anchors, struts, tension piles) can be applied. Anchors and tension piles must be installed at the intersection between primary and secondary columns. After their installation, the excavation is carried on until the next level of horizontal support or until its final depth, usually limited to 20 m. The minimum overlap between the primary and secondary columns is 6 cm. If the SMW is used as a silo structure or in case of water retaining application, the minimum overlap becomes D/8 where D is the column diameter.

As illustrated in Fig. 8b, the primary and secondary panels are reinforced using steel beams. The overlap between the primary and secondary panels must be larger than 10 cm.

3.2. Domain of application

SMW can be used for temporary soil and/or water retaining application. The effects of potential deviations in the positioning of the DSM columns/panels during installation on the SMW sealing should be assessed prior to the execution. The resulting leaks must immediately be treated. Bearing capacity is related to the soil mechanical characteristics, the cement content, the execution parameters and the reinforcement. In view of permanent use, additional testing must be planned.

Little vibration occurs during execution. Underground obstacles are critical for the design and should be considered prior to the execution. If previous dewatering is not required, eventual washing of DSM material should be examined in presence of groundwater flows.

The applicability of DMM also depends on the in situ ground, as illustrated in Table 6. Special attention should be awarded to coarse gravel layers and peaty soils.

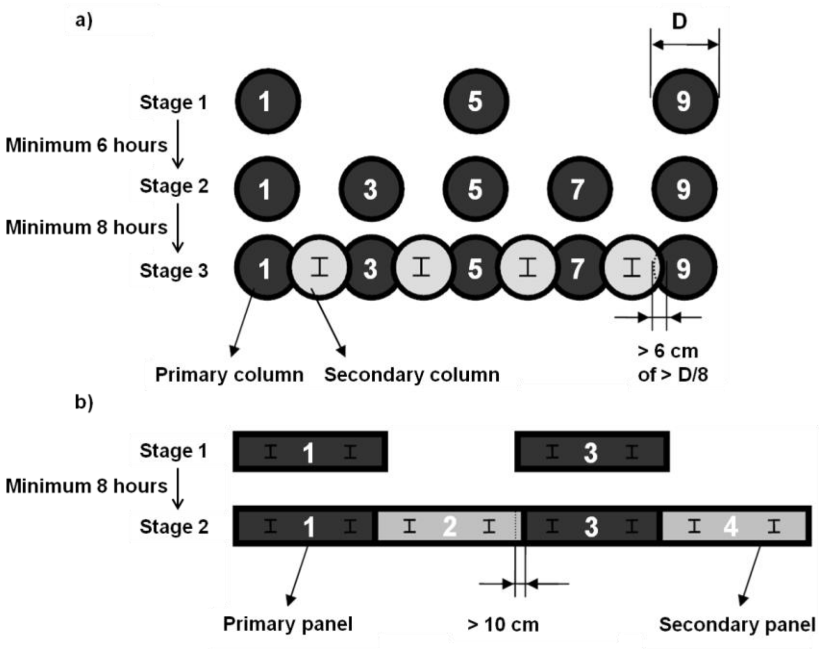

Figure 8: Scheme of the execution sequence for DSM columns (a) and panels (b) according to the BBRI info sheets

Table 6: Applicability of DMM in function of the in situ ground

Sand	Loam	Soft clay	Firm clay
VVV‡	VV†	VV†	V*

VVV‡: always applicable;
VV†: almost always applicable;
V*: applicable in certain circumstances.

3.3. Quality Control (QC) aspects

QC of DSM material depends on the function of the SMW.

3.3.1. Temporary SMW with earth retaining function

If the role of the DSM material only coexists in transmitting the earth pressure to the steel reinforcement, the SMW stiffness is related to the stiffness of the steel reinforcement. The following tests and acceptance criteria are required:

- 1 sample for 150 m³ of DSM material (with a minimum of 6 samples) must be cored;
- the UCS must be determined;
- the amount of unmixed soil inclusions in the DSM material must remain less than 20%;
- and the method of sampling shall be defined in the project specifications.

These requirements become optional if the contractor has gathered experience in terms of test results for minimum two construction sites with the same DSM system and in similar circumstances (including soil conditions).
Additionally, the determination of the modulus of elasticity of DSM material is required if this parameter is integrated into the calculation of the SMW stiffness.

3.3.2. Temporary or permanent SMW with water retaining and/or bearing functions

The requirements are adapted as follows:

- 1 sample for 75 m³ of DSM material (with a minimum of 12 samples);
- determination of the UCS and the modulus of elasticity;
- amount of soil inclusions again less than 20%;
- and the method of sampling shall be defined in the project specifications.

The test programme can be limited to 1 sample for 200 m³ (with minimum 6 samples) if the contractor has gathered test results for minimum two construction sites with the same DSM system and in similar circumstances. In case of soil inclusions larger than 1/3 of the SMW thickness, the designer must specify if immediate remediation of the SMW should be applied.

3.3.3. Execution tolerances

Execution tolerances are illustrated in Fig. 9. The tolerance on the inclination is limited to 1.3 %. In the presence of cavities or large hard stones or in weak layers, large enlargements are unavoidable. Hence, local enlargements of 100 mm are tolerated. The project specifications shall take into account the effect of these tolerances on the implantation of the underground constructions and the possible related additional costs.
Other QC procedure and tolerances can be required in function of the owner's specifications. For example, for SMW used as a silo structure and for water retaining function, the inclination is often limited to 0.5 %.

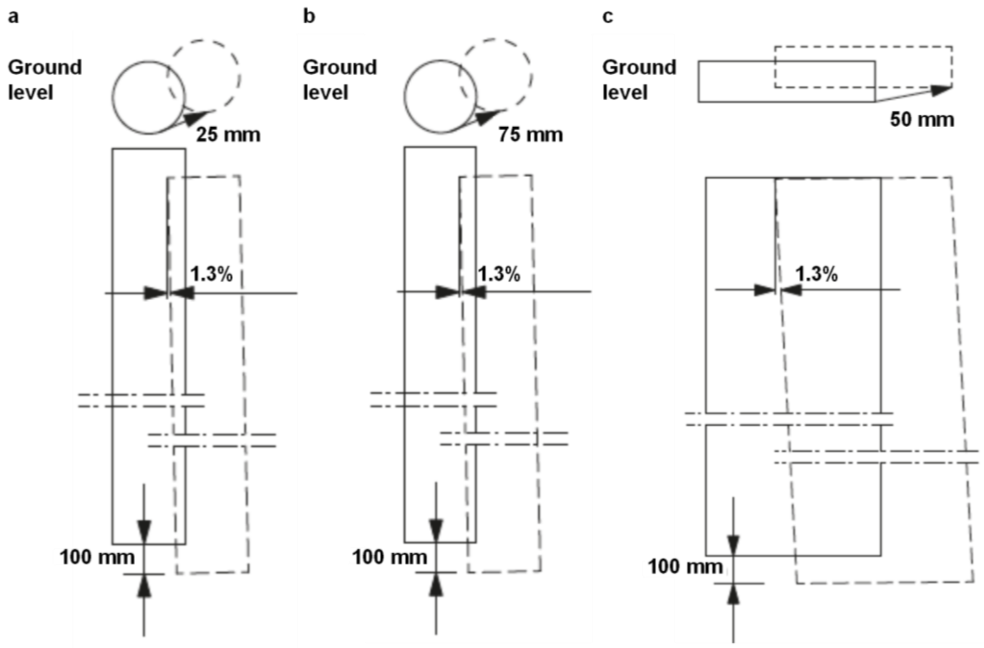

Figure 9: Scheme of the execution tolerances for SMW with regard to the positioning of the (a) DSM columns performed with the help of a guidance device (b) DSM columns performed without guidance device (c) DSM panels

4. BELGIAN VS. INTERNATIONAL QA/QC PROCEDURES

4.1. Workflow of DSM project according to Terashi and Kitazume (2011)

BBRI info sheets adhere to the international workflow of deep-mixing project, developed by Terashi and Kitazume (2011). This workflow is represented in Fig. 10, where q_{uf} means UCS of core samples and q_{ul} UCS of laboratory mix samples. These authors discussed the similarities and differences in the QA/QC procedures followed in different countries (Finland, Japan, Sweden, UK, USA and more generally in Europe), and proposed future research needs with this regard.
As a conclusion of their study, conducted in collaboration with experts of 45 organisations from seven countries, the current QA/QC activities are commonly related to laboratory mix tests, field tests, monitoring and control of the execution parameters and verification of the final products by measuring the mechanical characteristics of the DSM material by tests on core samples (usually UCS tests) or by sounding.

4.2. QA/QC activities of DSM project according to Maswoswe (2001)

In 2001, Maswoswe described the development and the implementation of QA/QC procedures for installation of 410 000 m³ of DSM material with the help of triple-auger DSM rigs, in the framework of the Central Artery/Tunnel (CA/T) project, in Boston. At the beginning of the 90's, it was the largest land-based DSM installation in the USA, and perhaps in the world. Maswoswe (2001) related the **QC activities** to:
- the choice of the **suitable DSM equipment**,
- the determination of the **process parameters** ensuring acceptable performances: the grout mix composition, the auger rotation (or withdrawal) rate and the grout (and drilling water) flow rate,
- and the selection of **procedures** allowing auger penetration and verticality.

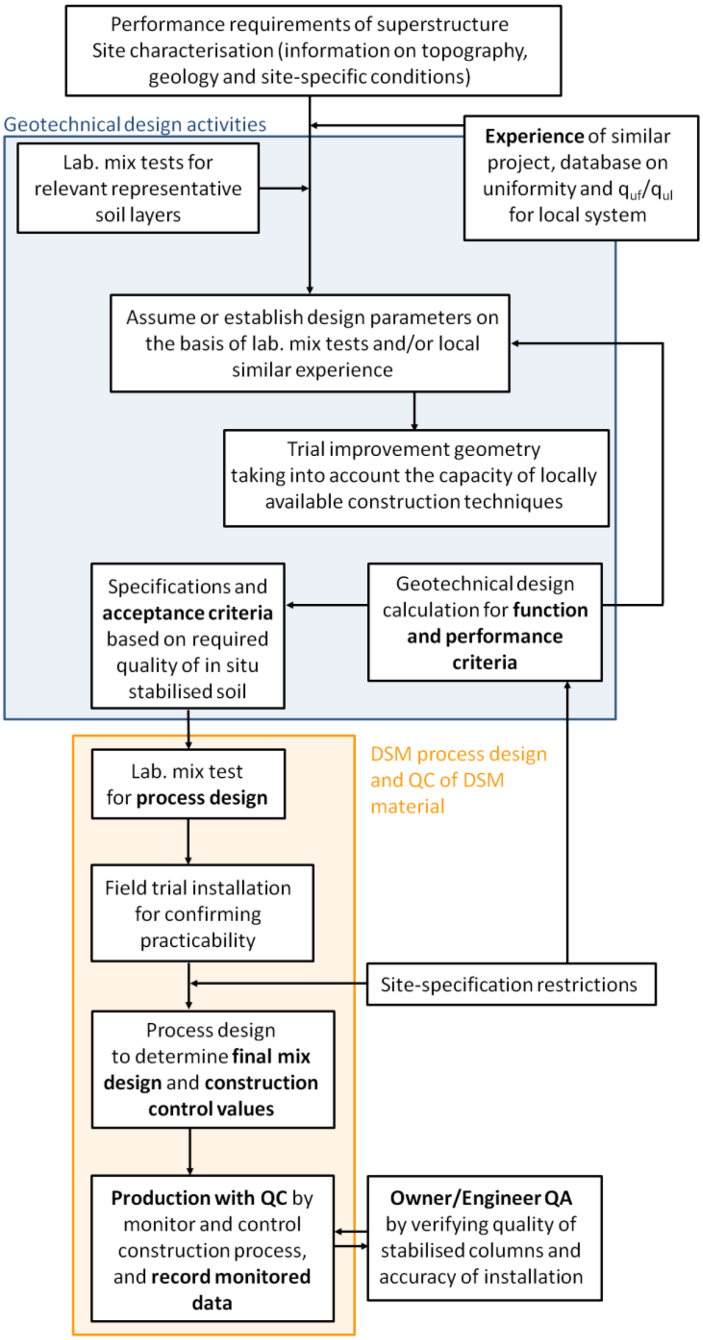

Figure 10: Workflow of deep-mixing project, after Terashi and Kitazume (2011)

If the choice of the DSM equipments, the installation parameters and the procedure were left up to the contractors, specifications would require the DSM material to meet the following **acceptance criteria for QA** related to:

- the minimum and maximum values of **UCS** on wet samples, after a determined number of days,
- the control of the **homogeneity and uniformity**,
- the minimum **unit weight** of core samples,
- the **vertical tolerance** with a limitation of the horizontal deviation with depth in any direction,
- the control of the auger penetration and the **final depth**.

It is to be noted that cores can be considered more representative than fluid samples.

If BBRI info sheets support all the QA/QC activities, reported by Maswoswe (2001), they specify the QA/QC aspects in function of the DSM application (retaining wall, water barrier or foundation) and take the temporary or permanent character of the construction into account. Indeed, as underlined by Terashi and Kitazume (2011), the acceptance criteria and verification procedures should depend on the DSM function.

As explained in Holm (2001), uniformity and homogeneity of DSM material can be controlled computing the coefficient of variation of UCS test results on core samples or comparing field and laboratory UCS test results (calculation of q_{uf}/q_{ul}). Nevertheless, in the framework of the BBRI 'Soil Mix' project, a methodology taking into account the amount of unmixed soil inclusions into the mix was developed and illustrated with case studies of DSM material executed in several Belgian soils (Denies, 2012b). BBRI info sheets refer to this methodology with an acceptance criterion in terms of a limit on the percentage of soil inclusions.

4.3. QC by monitoring

According to Maswoswe (2001), the critical factor in the execution of SMW is to maintain an auger withdrawal rate consistent with the grout flow rate. One way to control the success of the procedure and its efficiency is to estimate the cement factor or cement content (the cement mass per cubic meter of DSM material) at different locations. The cement factor can be estimated considering the grout flow rate, the auger withdrawal rate and the assumed percentage of grout loss during the process.
Beyond the mechanical characterization, the continuity and the overlapping of the SMW components (columns/panels) must be verified with regard to the execution tolerances. Locations and verticality of the DSM elements should be controlled during execution.
The best way to ensure QC during execution is by monitoring. Current technology allows not only to record execution data but also to visualize the parameters during the production process, as illustrated in Fig. 11 and 12.

Figure 11: QC monitoring of grout flow rates, injection volume and pressure and penetration rate during execution of CSM wall (photo with courtesy of Malcolm Drilling Company)

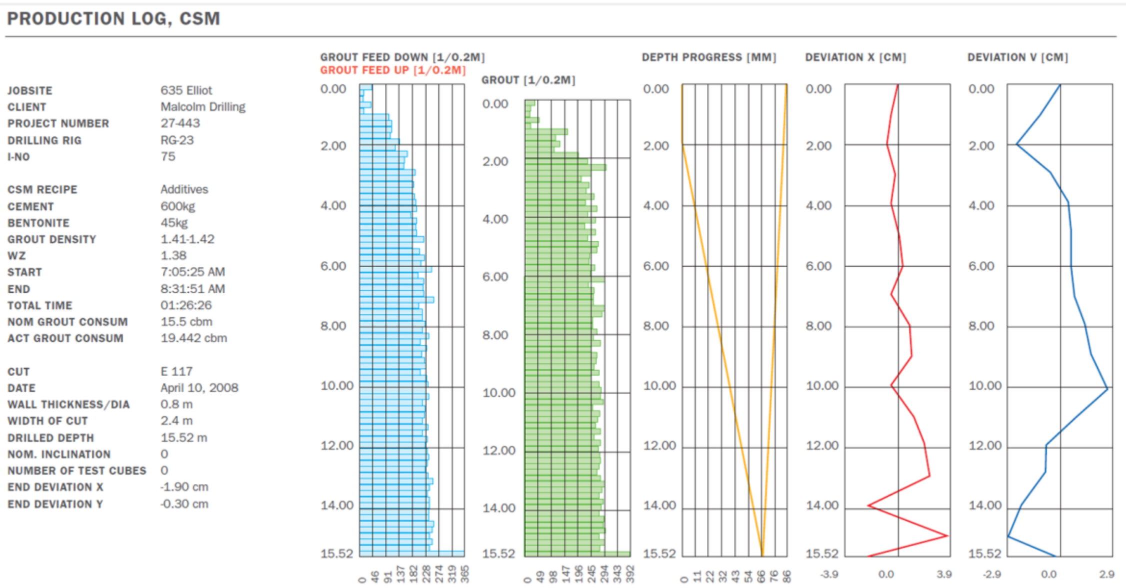

Figure 12: Typical production log (photo with courtesy of Malcolm Drilling Company)

For wet mixing, EN 14679 (2005) puts the emphasis on the continuous monitoring (or at least at a depth interval of 0.5m) of the following construction parameters and information during execution:
- slurry pressure; air pressure (if any),
- penetration and retrieval rate,
- rotation speed (revs/min. during penetration and retrieval),
- quantity of slurry per meter of depth during penetration and retrieval.

4.4. Laboratory mix vs. field tests

Concerning the laboratory test results, Terashi and Kitazume (2011) highlight the influence of the test procedure, especially the method of preparation and the curing of the specimens. Methods differ from one country to another and even in the same region. These differences must be taken into account when comparisons are made. The sample preparation (mixing time/energy, time between mixing and moulding, moulding procedure) and the curing conditions (temperature, humidity, potential application of surcharge) differ from one procedure to another.
Moreover, the quality of DSM material, in terms of strength, stiffness, continuity and uniformity depends on the execution process. Indeed, the way the soil is mixed during the process varies from one system to another. The result will be different if the soil stratification is preserved after the mix or if the soil is transported from depth to the surface during the process. Hence, field tests are essential in comparison with laboratory mix tests which can not entirely simulate the field conditions.

4.5. Belgian deep mixing experience and database

According to the BBRI info sheets, in the case of temporary SMW with an earth retaining function, preliminary laboratory mix tests (for QC stage) can be considered as facultative if the deep-mixing contractor can demonstrate that its deep-mixing experience is large enough (for a DSM system in a given soil type). Indeed, the test campaign on in situ DSM material, performed within the framework of the BBRI ‘Soil Mix’ project, coupled with the experience accumulated by each contractor in several types of Belgian soils, provides a useful database in order to assume or establish the design parameters, as well as the performance and the acceptance criteria. In Belgium, the decision on the mix composition is therefore left to the deep-mixing contractors who determine this latter in function of the soil/cement characteristics and the equipment/installation devices in such a way to reach the design requirements.
In practice, the DSM material quality is often controlled with the help of UCS tests regardless of the DSM application. Within the framework of the BBRI ‘Soil Mix’ project, various tests were performed to determine characteristics of DSM material such as porosity, permeability, UCS, creep and tensile strength, as well as the modulus of elasticity, the ultrasonic pulse velocity and the adherence between DSM material and steel reinforcement (Denies et al., 2012a).

5. CONCLUSIONS

The present paper concentrates on the application of SMW technology and focuses on the three main types of DSM systems currently used in Belgium: the Cutter Soil Mix (CSM), the Tubular Soil Mix (TSM) and the CVR C-mix®.

BBRI information sheets, developed within the framework of the Flemish regional research project IWT 080736, are then presented. They adhere to the international QA/QC activities, as reported in Maswoswe (2001) and Terashi and Kitazume (2011), and are specially adapted to the SMW applications in Belgium. BBRI information sheets complete the information available in EN 14679 (2005) with regard to the QA/QC requirements. They provide for the owner/contractor/engineer practical criteria in terms of the execution sequence and tolerances and give some requirements with regard to the quality of the DSM material.

Generally, QA/QC procedures should be defined as soon as possible at the beginning of the project according to the BBRI info sheets or with a logic similar to the QC workflow (presented in Fig. 10) and deep soil mix should be discussed using the international terminology proposed in Table 1.

As for all engineering projects, a precise and preliminary definition of the responsibilities and acceptance criteria is a significant point to make sure the DSM process goes smoothly. In several cases, test procedures can even be proposed or imposed for the QA/QC of the final DSM product. In function of these requirements, the deep-mixing contractors will choose the most adapted mixing tool alternative and the best execution process.

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