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CSM-cutter soil mixing—worldwide experiences of a young soil mixing method in soft soils

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ABSTRACT: The CSM method of deep mixing has been in operation now for nearly seven years. In many applications so far in already fifteen countries all over the world, the method has given excellent results both technical and economical. Its use has been extended to replace many Jet grouting and other conventional deep soil mixing projects as well as plastic diaphragm walls, sheet piles and other cut-off walls on prestigious projects. The paper will show a range of applications executed all over the world in soft soils.

1 INTRODUCTION

BAUER Maschinen GmbH developed the CSM technique in 2003 by drawing on the experience gained in the production and deployment of diaphragm wall cutters in the construction of cut-off and diaphragm retaining walls.

2 CONSTRUCTION PRINCIPLE

The CSM System differs essentially from traditional techniques in that the in situ mixing of the existing soil with self-hardening slurry is performed by mixing tools rotating about horizontal axis rather than the traditional vertical axis. The in-situ soil mixed with self-hardening slurry produces a wall construction material that takes on the role of a cut-off and/or structural retaining wall.

The cement and bentonite content and the water/cement ratios of the mixing slurry are determined by the strength and/or permeability requirements of the project and the properties of the soil being mixed. In general, for a stronger wall, cement content is increased and water/cement ratio is lowered. Typically, sandy soils will require a larger amount of bentonite in the slurry than clays. At some clay sites where enhanced resistance to permeability is not required, acceptable fluidization of the soil can be achieved without the use of bentonite.

A typical construction sequence is as follows:

a. Construction of a good sized open guide trench for retaining excess slurry.
b. Fluidization of the soil mass during penetration to the final depth as an appropriate slurry is simultaneously introduced. Depending on the prevailing conditions, either bentonite slurry is added to the mixing and fluidization process or cement slurry is introduced into the soil during penetration. The volume of slurry injected is determined by the rate of cutter penetration.
c. During withdrawal, the precise volume of slurry required for producing the final wall construction material is injected.
d. A continuous wall is formed by the construction of individual panels in an alternating sequence of overlapping primary and secondary panels. Secondary panels can be constructed immediately after completion of primary panels, i.e. "wet-into-wet". The cutter technology does, however, also enable cutting into panels that have already hardened, i.e. "hard-into-hard".
e. To utilize the wall as a structural retaining wall, steel columns (IPB sections) are inserted into the freshly mixed wall panels.

In mixing applications less than 15 m deep in relatively soft ground, a one phase mixing procedure may be used. In the one phase procedure, the final slurry product consists of cement and water or a cement, bentonite and water mixture, which is injected on both the down stroke and the upstroke of the machine. Advantages of this procedure include the additional mixing of the cement and the soil and the simplicity of only having one slurry mix.

When mixing deeper panels or penetrating difficult (slow) to mix soils or rock, a two phase system is used. Instead of using self-hardening slurry from the beginning onward as in a one-phase system, just bentonite slurry is used on the down stroke. Once the final depth is achieved, the cement slurry is introduced and mixed on the upstroke. This method prevents the mixing tool from being

trapped in the panel if the panel construction time exceeds the initial set time for the cement slurry.

The size of individual panels is determined by the type and size of equipment being deployed. Panels can be constructed in lengths ranging from 2.4 m to 2.8 m and wall thicknesses of 0.55 m to 1.2 m.

3 EQUIPMENT

The most important elements of the CSM unit are the cutter gear drives. They are driven by hydraulic motors which are located in a water-tight housing. The slurry is introduced into the soil directly between the mixing wheels. During construction, the counter-rotating mixing wheels and vertically mounted plates are effectively acting like a forced action mixer. Because of this mixing principle, CSM is suitable for mixing cohesive soils. For loosening and mixing the soil different types of mixing wheels were developed.

The mixing unit (Fig. 1) is either mounted on a guided Kelly bar or on a wire rope-suspended cutter frame equipped with special steering devices. The standard set-up is the "Kelly-guided" setup, capable of reaching depths up to 43 m (Fig. 2).

"Rope-suspended" systems are particularly suited for construction of deep soil mix walls. The greatest depth to date at which a wire rope-suspended unit has successfully installed a soil mix wall to date is 60 m, using a compact unit called QuattroCutter (Fig. 3).

Both systems must be accompanied by an intensive quality assurance programme. All process-specific production and plant-specific operating data are visualised throughout the construction phase and stored for subsequent documentation and evaluation. Information presented includes penetration rates, alignment, and slurry injection rates and volumes (Fig. 4).

Figure 1. Mixing wheels and housing for hydraulic gear drives.

Figure 2. Kelly-guided CSM unit, USA.

Figure 3. Wire rope-suspended CSM unit, QuattroCutter, Japan.

Figure 4. Rig operator's on-board computer screen.

4 COMPARISON WITH OTHER TECHNIQUES

The CSM process has significant advantages over conventional techniques like e.g. secant pile walls or sheet piling walls. These are:

- The existing soil is utilised as construction material.
- Very little spoil material is generated; this renders the technique particularly suited for work on contaminated sites.
- CSM is an ideal alternative to the traditional "Berlin wall" system, which is better known as soldier beam wall with timber lagging, for the use in high groundwater conditions, or to sheet pile walls in soil formations unsuitable for pile driving or in close proximity to vibration-sensitive buildings.
- CSM is a vibration free method.
- No delivery of ready mixed concrete is necessary.

In comparison to traditional deep soil mixing methods CSM has the following advantages:

- A high degree of verticality of wall panels is achieved by the counter-rotating cutter wheels.
- The cutter principle ensures construction of clean and trouble-free joints even between wall panels of different construction age e.g. after weekend breaks or prolonged stoppages on site.
- Harder soil formations can be easily penetrated, broken down and mixed by using the cutter wheels as cutting and mixing tool.
- Homogenise the cohesive soils and self harden slurry through horizontal mixing.
- In relation to small base units, high daily output and high panel depth may be achieved.

5 APPLICATIONS IN SOFT SOILS

5.1 *Retaining walls*

The CSM system is very commonly used to construct water-tight soldier beam retaining wall system for excavation pits especially near sensitive inner-city building where vibration free system are essential. It provides an alternative solution to conventional methods such as secant pile walls and/or sheet piles

An example for an excavation pit shows a jobsite executed in Osaka, Japan (Fig. 6) for the construction of the new Hanjin Expressway. Soil conditions are shown in Figure 5.

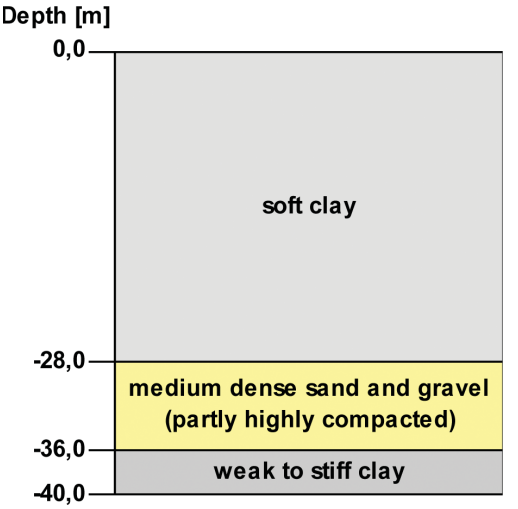

Figure 5. Soil conditions Hanjin Expressway, Osaka, Japan.

Figure 6. Wire rope-suspended CSM unit, QuattroCutter Osaka, Japan.

The CSM panel was socked for 1.5 to 2 meters into the clay layer under the sand layer. The wall was 0.55 meter wide and extended to approximately 38 m deep; the excavation depth was 13 m deep. Steel beam sections were inserted into the fresh mixed panels and extended to a depth of 18 m. The wall functioned as a cut-off-wall beyond the tip of the steel section. Due to the relatively long production time associated with the high depth of the panel, the two phase system was selected. The BAUER QuattroCutter was used to execute the task. The QuattroCutter is made of a frame combining two BCM 5 mixing heads; one at the bottom and one at the top of the frame. The arrangement of two mixing heads ensures an intensive and homogeneous mixing as well as a high directional accuracy for high depth.

Another example for a retaining wall in soft soils was done in Meise, Belgium (Fig. 8). An excavation pit for building a storage basin for rain and used water was executed. Soil conditions are represented in Figure 7.

The retaining wall had a width of 0.55 meters and about 13 m deep. One of the main reasons the CSM method was chosen is the nearness of the surrounding houses. Therefore a vibration free method had to be used. The 1-Phase system and a BAUER MBG 24 were used for the execution of the jobsite. Figure 8 shows the Kelly guided CSM unit and the tight space at the jobsite.

Figure 8. MBG 24 with Kelly guided SCM mixing head, executing a retaining wall, Meise, Belgium.

5.2 *Foundations*

On several building projects CSM panels were used as foundation elements. Apart from the main advantages of the CSM process, such as the use of the existing subsoil as construction material and the minimized spoil removal, a further advantage results from the fact that the same equipment can be deployed to construct first the retaining wall for the excavation and then the foundation elements. The system can be used for single elements as well as for strip foundations or it's possible to construct the foundation elements concurrently with the retaining wall and connect with each other in such a way that the retaining wall is subsequently also capable of carrying vertical loads.

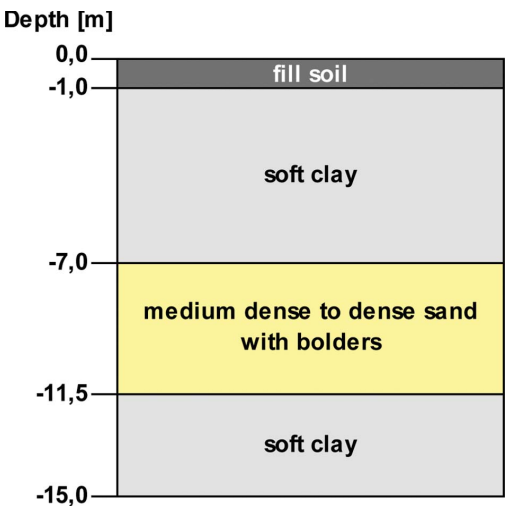

Figure 7. Soil conditions, Meise, Belgium.

For a project in Vittorio Veneto, Italy, where a new sport hall building was being constructed, the CSM panels, 7 meter deep, were reinforced with tension bars HEA120 which were used as uplift anchors to tie-down a raft foundation in adverse groundwater conditions (Fig. 9). The soil was mainly soft silt. Additionally a 9.5 m, back-anchored and reinforced CSM retaining wall was executed for a 4.5 meter excavation pit.

5.3 *Soil improvement*

Soil improvement can be another application for the use of CSM system.

One of the largest CSM projects ever constructed was for ground improvement purpose. It was part of

Figure 9. CSM Wall and CSM panels with tension bars used as uplift anchors, Vittorio Veneto, Italy.

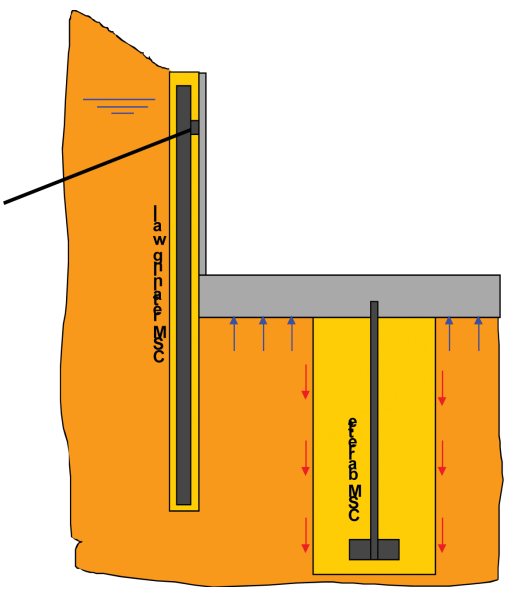

Figure 10. CSM panels (barrettes) reinforced with tension bars and back anchored CSM wall, Vittorio Veneto, Italy.

the new main station in the city centre of Bologna, Italy. The foundation of the new station will be supported on diaphragm walls extended to a depth of 23 meter. The subsurface soil consisted mainly of medium to soft clay (Fig. 11) and needed to be stabilized with a CSM wall before the diaphragm walls execution, to prevent settings of the buildings and the old main station located nearby.

Two BAUER BG 28 and one RTG RG 25 S with BCM cutters used on the jobsite. Each of these three BAUER units is supposed to produce about

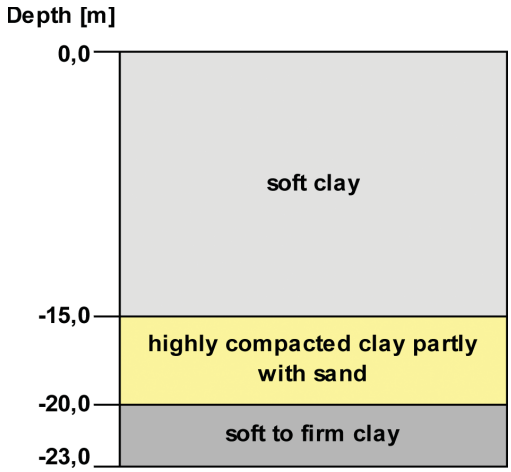

Figure 11. Soil conditions, Bologna, Italy.

Figure 12. Soil improvement, Bologna, Italy.

25.000 m² (total 75.000 m²) of CSM-wall with a tolerance in deviation of less then 0.5% per meter. The CSM-wall itself was also 23 meter deep and 0.8 meter wide. The required 28 days of the CSM-wall compressive strength was 1.6 MPa. Therefore a two phase system is used. Tests prior to the execution indicated that the requested deviation and strength of the CSM-wall could be achieved.

Figure 13. BAUER SideCutter, Japan.

The BAUER units were showing a remarkable performance in this difficult soil conditions. The average production rate was about 15–20 m² per hour.

Further more soil stabilization has been used for liquefaction mitigation or slope stabilization in single cases in Canada, Italy and Portugal.

6 SUMMARY AND OUTLOOK

The described examples have demonstrated that this young construction technique, which combines the advantages of the cutter and the soil mixing technique, has been successfully established in the market all over the world even in very traditional soil mixing markets like Japan. The technique offers a great diversity of possible applications, such as cut-off walls, structural retaining walls, foundation elements and numerous others.

The capacity to reach big depths offers an enormous potential for the construction of deep walls especially for cut-off walls for dams or the en-capsulation of contaminated sites.

The demand of reaching big depth in combination with limited space ends up with the latest development of a rope-suspended unit, a so called SideCutter. The SideCutter has the ability to turn just the cutting head without turning the upper carrier (Fig. 13).

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