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Cutter Soil Mixing (C.S.M.) An innovation in soil mixing for creating cut-off and retaining walls

La nouvelle méthode CSM pour la construction des parois souterraines

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ABSTRACT
Deep mixing methods for the construction of cut-off walls or excavation support systems are carried out typically by the use of single or multiple augers to produce a series of circular columns that may be arranged in different patterns. The New CSM method produces well blended rectangular panels of treated soil. They offer a number of advantages over circular column solutions, the most significant of which are: cost, a reduction in the number of joints in a wall, the freedom to use different types of reinforcement. The machines give the possibility of introducing control instrumentation deep in the ground and thereby to monitor and control quality.

RÉSUMÉ
Les méthodes de consolidations de sol par mélange mécanique sont généralement exécutées par forage circulaire avec une ou plusieurs tarières, afin de former des parois étanches, des colonnes, des barrettes. La nouvelle méthode C S M permet le forage de panneaux rectangulaires de sol mélangé mécaniquement. Cette technique comparé ou système rotatif offre de nombreux avantages, qui sont : les coûts, la réduction des joints de panneaux, et l'emploi de différents types de cages de renfort. Les machines offrent la possibilité d'installer des systèmes d'enregistrement et de contrôle permettant de suivre sur écran et à l'avancement la qualité du forage exécuté.

1 CUTTER SOIL MIXING C.S.M.

In the year 2003 BAUER Maschinen developed the CSM method by exploiting its experience in the manufacture and use of the trench cutter systems to excavate diaphragm walls panels.

The CSM method differs from the traditional DMM method in so far as it makes use of two sets of cutting wheels that rotate about a horizontal axis to produces rectangular panels of treated soil rather than one or more vertical rotating shafts that produce circular columns of treated soil. Two cutter gear boxes are connected to a special mounting that is in turn connected to a robust Kelly bar. The Kelly bar is connected to the mast of a drill rig by two guide sledges that steer and provide crowd and extraction force and, if necessary, rotation to the cutting head.

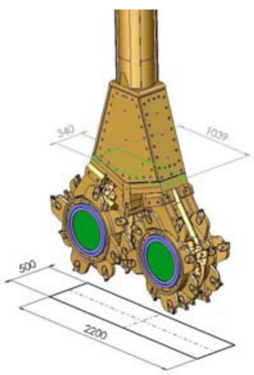

Fig 1: Cutter units

Length of panel	= 2200 mm to 2800 mm
Width of panel	= 500 mm to 1000 mm
Torque	= 30 kNm, to 80 kNm
Max cutting wheel speed	= 40 rpm
Max cutter unit power	= 150 kW, to 300 kW
Weight of cutter unit	= 5500 kg, to 7000 kg

As the cutting wheels rotate and penetrate into the ground they break up and loosen the soil. During this phase a fluidifying agent or the binder itself is injected into the area between the two cutting wheels. In the extraction phase the cutting wheels rotate in a mixing mode and blend the binder and soil to form a rectangular panel of treated material.

The parameters of the machines we have designed and built to-date are:

Length of panel	2200 mm, 2400 mm, 2800 mm
Width of panel	500 mm to 1000 mm
Maximum depth capability with a single tube Kelly	30 m
Maximum depth capability with a telescopic Kelly	40 m

On future machines the lengths of the panels could be extended to 3200 mm and their width capability up to 1500 mm.

The rectangular panel, when compared to a series of contiguous or secant columns, offers a number of distinct advantages: structurally, if we compare the properties of a rectangular shaped panel to those of secant or contiguous columns whose diameter is equivalent to the width of the panel, we find that the former is a much more efficient shape; the areas of treated soil in compression and tension are larger and the lever arm of the rectangular section is larger; this implies a higher moment of resistance. When considering a secant column wall, column diameters need to be much bigger than the thickness of the rectangular panel to produce a section of equivalent width. This means that when using the CSM method we need to treat significantly smaller volumes of soil to obtain the same effect. Clearly this implies savings in the total energy expenditure in producing the wall and a saving in the amount of binder that is used.

1.1 *Structural wall*

When additional strength or resistance to bending moments is required, the CSM wall can be reinforced efficiently with steel 'H' sections or cages. Given the rectangular shape of the panels, distribution of the steel in the panels can be designed to optimize the quantity of steel.

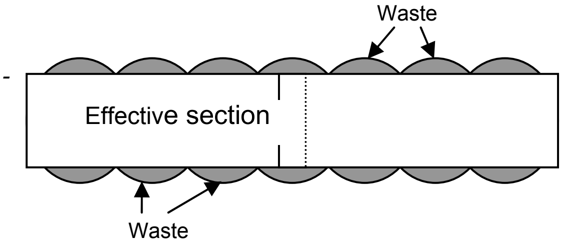

Fig 2: Comparison of mixed areas

1.2 *CSM WALL REINFORCEMENT*

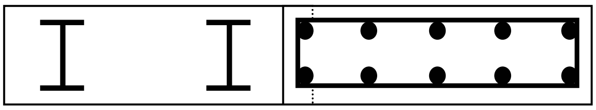

Fig 3: Types of reinforcement

If we design the wall to act as a cut-off wall, the single CSM panel is continuous over a 2200 mm (2800 mm) length whereas an equivalent secant column wall will have at least 3 joints. Clearly there is a much lower risk of leakage through the CSM panel.

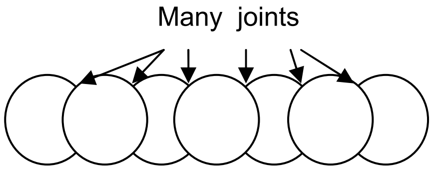

Fig 4: Secant pile wall

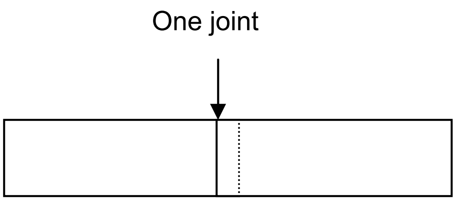

Fig 5: C.S.M. wall

1.3 *Cut off wall*

There are a number of other advantages that the CSM method and machinery offers when compared to the traditional rotating augers or paddles, notably: the only moving parts in the CSM method are the cutting wheels, as a result we can mount instruments inside the cutter gearbox support frame that give real time information throughout the treatment depth. Information such as verticality, deviations, excess pressure build-up in the surrounding soil etc. In addition, by varying the relative speeds of the two cutting wheels the operator can correct any deviation that may occur. Further as the Kelly bar does not rotate there is no energy expenditure like in the traditional DMM methods where a certain amount of energy is lost to overcome friction between the long shafts of the augers and the soil/cement mix.

2 THE FIRST TEST (ARESING – GERMANY)

In December 2003 and January 2004, in a joint effort with Soletanche – Bachy, we put the newly developed technology and machines to a test. At the Bauer testing ground we executed a series of 14 CSM panels, 2200 mm long, 500 mm wide to depths of 20 m, arranged in a circular pattern to form an 8 m diameter shaft. The perimeter panels were constructed in a primary – secondary (hard – hard) sequence, giving the primaries, that were executed using different types and concentrations of fluidifying agents and grout, time to set (2 to 23 days) before intersecting them with the secondary panels.

Across the centre of the shaft we constructed three panels, two primaries and a secondary, using a ‘fresh-in-fresh’ sequence to experiment the formation and quality of the joint. Within the shaft area we also treated two single panels, one of which we reinforced with “H” beams, the other we exhumed for a visual inspection of the effect of the treatment and to take samples of the soil/cement mix.

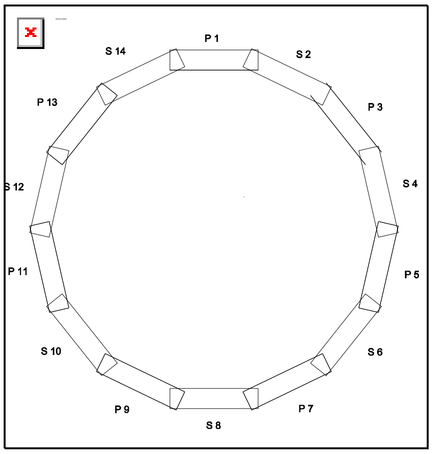

Fig 6: C.S.M. Shaft in Aresing

Most of the research effort on this first test was dedicated to finding a fluidifying agent that would give the best penetration performance during the cutting and mixing phase: we started with a water and stone powder mix and then tried other mixes including bentonite, polymers, the cement binder and finally a mix of bentonite and a fluidifier (Bentocryl) that gave the best results.

The significant parameters in the construction of the shaft are summarized in the following table:

Element Number	Surface area m^2	Excavating Time (min)	Blending Time (min)	Consumption of Bentonite mud (m^3)	Consumption of cement grout (m^3)
P1	44	126	48	10	6,6
P7	41.8	140	57	10	7.2
P9	44	135	42	14,2	7.5
P11	44	133	35	11,8	7.7
S2	44	176	55	14,5	8.2
S4	44	109	46	10	7,0
S6	41.8	153	31	10	6,0
S8	41.8	170	30	9,4	5,3
S10	41.8	130	44	9,5	6,8
S12	41.8	163	36	10.6	6,8
S14	44	185	47	12,2	6,1

The bentonite mud was made up using a water/bentonite ratio of 12 and the grout was made up using a water/cement ratio of 0,5.

The average performance rates in executing the panels that made up the shaft perimeter ring were:

Average excavating performance (Down stroke): 18.05 m^2/hr
Average blending performance (Up stroke): 62.73 m^2/hr
Overall average productivity: 13.8 m^2/hr

Two panels that were excavated using the bentonite + fluidifyer were performed at an average penetration rate of 31 m^2/hr; the average blending performance was 67 m^2/hr. This implies that an average productivity 21 m^2/hr can be achieved.

The average consumption of bentonite powder was 44,5 kg/m^3 of treated soil and the average consumption of cement was 444 kg/m^3 of treated soil.

The in-situ soil at the test site is generally a sandy gravel with a 2 m to 3 m thick clayey sand layer at approximately 12 m below ground level. The final strength of the soil/cement mix, given by compression strength tests carried out on cores taken in different panels, ranged from 5 MPa to 8 MPa.

Fig 7: Wall details and exhumed test panel

3 TEST IN JAPAN (TOKYO)

A second test was carried out in conjunction with Messrs D.K. Com in May 2004 in the Tokyo bay area in Japan where soil conditions are typically 6 m to 9 m of soft clays underlaid by fine silty sands. The object of the test, performed strictly according to normal Japanese soil mixing practice for retaining walls, was to create a series of panels of improved soil that were fluid enough to permit the problem free installation of steel beams. Other requirements were: good homogeneity of the mix, continuity of treatment throughout the panel and good quality joints; strength was of secondary importance (5 kg/cm^2 was sufficient). Other characteristics that were adopted for the test so that results could be compared with the traditional SMW methods in Japan were:

- use of compressed air, injected together with the binder, during both the downward cutting and upward mixing strokes;
- a high water/cement ratio binder and the injection of cement binder on both the downward and upward strokes.

The main working parameters used for the test were:

- depth of panels - 20 m.
- intersection of primary panels - 100 mm.
- cement content: 200 - 250 kg/m³ of treated soil.
- approx. 70 % of theoretical binder volume on the down stroke, 30 % on the up stroke.
- high speed (50 - 70 cm/min down and 70 - 120 cm/min upwards with high pump rates of 200 - 300 l/min).

3.1 *Observations.*

Levels of torque during the cutting and mixing phases were low and the speeds of penetration and extraction were sustained throughout. This was due to the nature of the soils, the large volumes of liquid that were injected into the soil/cement mix and the action of compressed air that kept the slurry in the panel turbulent and fluid throughout the process. The degree of blending and the consistency of the mix were very good; a visual check of this quality, done after exposing some of the panels, showed the mix to be very homogeneous, much better than expected.

The following table summarizes some of the parameters of the Japanese test. It shows an average productivity = 43,43 m^2/hr

Panel No.	Depth (m)	Total time (min)	w/c	Total binder (Litres)	Productivity m^2/hr
2/6	20	86’	2,2	15200	30,7
2/8b	19,4	48’	2,2	10600	53,3
2/7	18,7	44’	2,2	13300	56,1
2/9	20	64’	2,2	12900	41,3
2/11	20	55’	2,0	11000	48,0
2/10	20	71’	2,2	12650	37,2
2/13	20	63’	2,2	13355	42,0
2/12	20	72’	2,2	13300	36,7
2/5	19,4	60’	1,5	6990	42,7
2/4	20	57’	1,8	7260	46,3

Fig 8: Exposed top of CSM wall in silty clay

4 RETAINING WALL IN HOLLAND

A Dutch customer of BAUER Maschinen offered a CSM retaining wall (approx. 700 m²) as an alternative solution for the construction of a retaining wall to support 3 sides of an excavation for a 2-storey basement. The original design was for a series of contiguous, soil mix columns reinforced with steel beams. The site is located in Valkenburg (Netherlands) in a hilly area between Aachen and Maastricht.

Some of the main criteria imposed were:

- The work had to be performed from within the site, a confined area, this was particularly restrictive in some of the corners.
- There was minimum clearance to the neighbourhood buildings and structures
- The system had to be vibration-free.
- Strength was of secondary importance. The structural design assumed that horizontal loads would be transferred by the vertical steel beams (270 x 280 mm @ 1m centres).
- Backflow quantity was to be minimised to reduce the amount of cement used and the removal of spoil.

Soil conditions were generally: a fine grained soil (silty fine sand, with clayey lenses) with a stiff clay layer generally between 5 m and 6 m below ground. There was no groundwater.

The working parameters were:

- panel size 2,2 m x 0,5 m, 10 m deep
- overlap = 150 mm
- water/cement ratio: Several w/c ratios were tried in order to find an optimum mix. W/C 1,0: proved to be too dry; W/C 1,33 - 1,6. The fluidifying effect was better, but there were some concerns about final strength; W/C 1,2. was finally adopted as a good compromise between workability and strength.
- Cement content: 250 kg/m³ of treated soil.
- Use of cement slurry from start (approx. 85 % of theoretical volume downwards, 15 % upwards)

Fig 9: CSM wall (Holland) after excavation

Observations:

- high torque levels on the mixing wheels were required.
- Generally the mixing and cutting direction was outwards. Sometimes the direction was changed to inwards when extracting the tool.
- Visual check of mixing quality: very homogeneous backflow with thick, mortar-like consistency.
- Beam Installation:
  2 beams (270 x 280) had to be installed in every panel. Due to the confined size of the site, the beams were installed with the auxiliary winch of the BG 15H. Mostly they had to be pushed down with the aid of a small backhoe. The stiff clay layer proved to offer the most resistance to their penetration.
- Performance:
  The overall performance was influenced by many side activities, mainly by the installation of the beams. Nevertheless, overall performance was 86 m^2/day. The average net, cutting and mixing performance was 16,4 m2/hr.

5 SEWAGE TREATMENT PLANT – BELGIUM

The design for additions to an existing sewage treatment plant called a 4 m deep excavation that was to be supported by a temporary retaining wall. Whereas the contractor chose to use a sheet pile wall as the primary form of support, the wall had to be discontinuous in two areas where major underground pipelines existed and could not be interrupted. Sheet piles in these areas could not be used but an earth retaining structure was needed nevertheless. The contractor chose the CSM method to create an earth retaining wall in these areas and made use of one of the characteristics of the method: the ability of the machine to move sideways and under existing obstructions to produce a continuous wall.

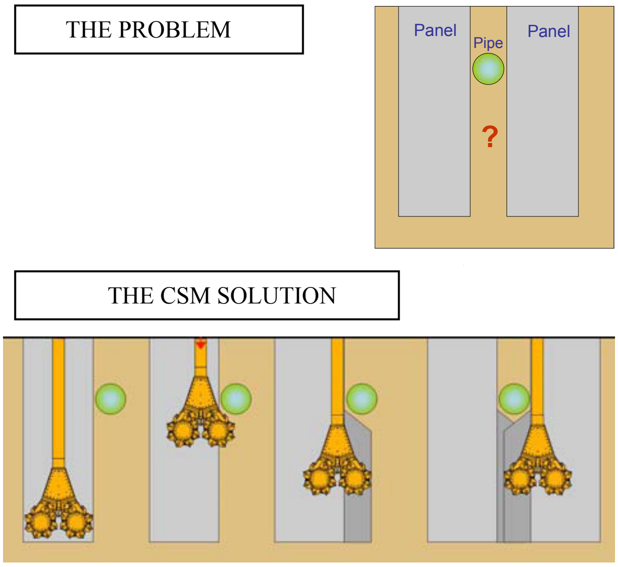

Fig 10: Forming a continuous wall underneath a pipeline with CSM

6 CONCLUSIONS

The cutter soil mixing method, CSM, is an innovative method for carrying out Deep Soil Mixing, It constitutes a new item in the Soil Mixing Methods chart (Bruce at al, 2003), its use is widespread and it offers numerous advantages over the methods of mixing soils using standard rotary tools. The method has been greeted with enthusiasm by the DMM community and promises to develop into a powerful construction tool.

The method is new, the tests described in this paper were some of the first applications of the method and there is still much to be learned. An extensive series of additional tests will be carried out in order to optimize the machinery and cutting wheels with a different geometry of the cutting and mixing blades are tested in order to improve productivity and to reduce wear. Some of our Japanese clients are applying the method in different soil conditions in Japan in order to optimize the working procedures and parameters and the concentrations of different fluids that can be used during the cutting and blending phases of the work.

There is much research to be done in this field and we invite the DMM community to participate in this