CSM

Cutter Soil Mixing
Process and equipment

Process

BAUER

CSM-Process

Mixing of self-hardening slurries with native soils by using a modified trench cutter technique is a new and effective method for constructing:
Cut-off walls;
earth retaining walls;
soil improvement or for constructing foundation elements.

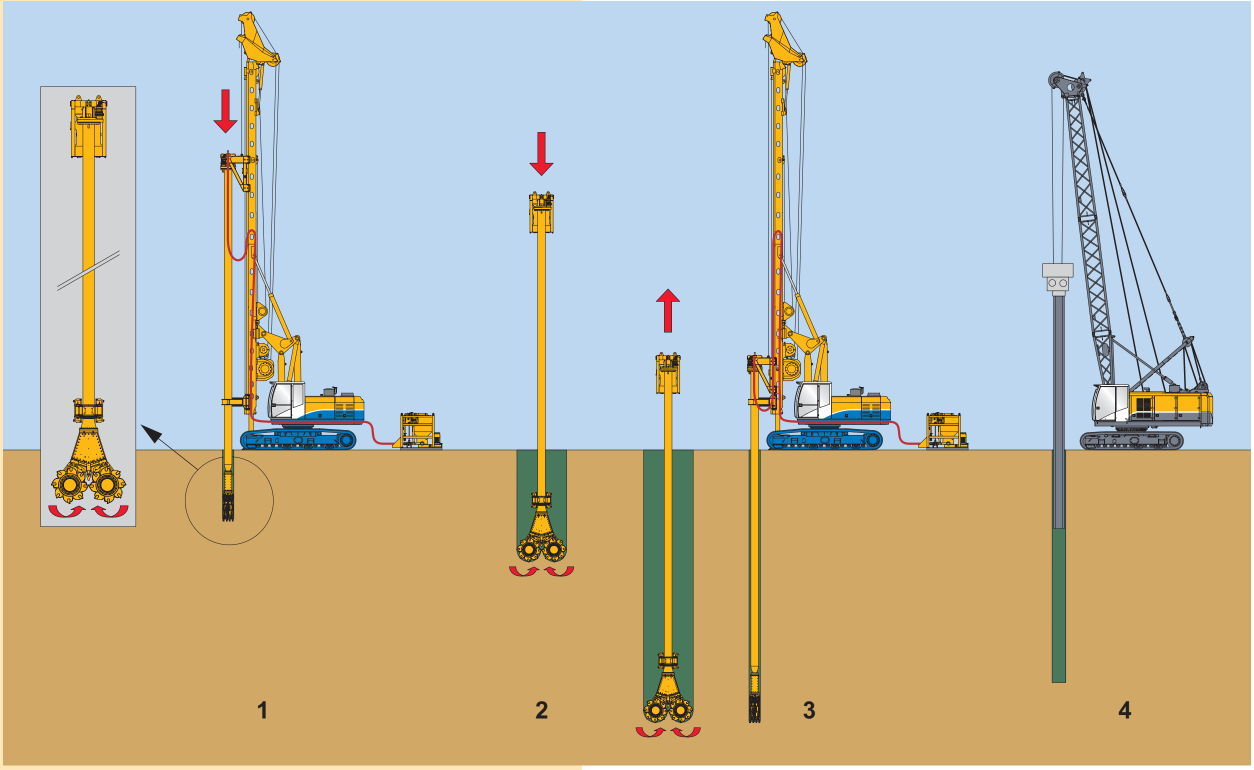
CSM is used mainly for stabilizing soft or loose soils (non cohesive and cohesive), however the machinery used, derived from Bauer's cutter technology, extends the applicability of the method to much harder strata when compared to other methods of soil mixing.

Main advantages of the method are:
- High productivity
- The in-situ soil is used as a construction material
- Very little generation of spoil (important factor in contaminated areas)
- No vibrations induced during construction
- Extended depths (up to 60 m) can be reached – when using the rope suspended units.

Construction sequence

Preparation:
Excavation of a guide trench for collecting surplus slurry

Step 1:
Positioning of the cutter head in wall axis.
The construction of a guide wall is not required.



Step 2:
The mixing tool is driven into the ground at a continuous rate. The soil matrix is broken up by the cutting wheels and at the same time a fluid is pumped to the nozzles, set between the cutting wheels, where it is mixed thoroughly with the loosened soil. Adding a compressed airstream can improve the breaking and mixing process in the downstroke phase. The direction of rotation of the wheels can be varied at any time. The rotating wheels and cutting teeth push the soil particles through vertically mounted shear plates that have the effect of a compulsory mixer. Penetration speed of the cutter and the volume of fluid pumped in are adjusted by the operator to optimise the absorption of power and to create a homogeneous, plastic soil mass which permits easy penetration and extraction of the machine. Typical speed of penetration is 20 – 60 cm/min.

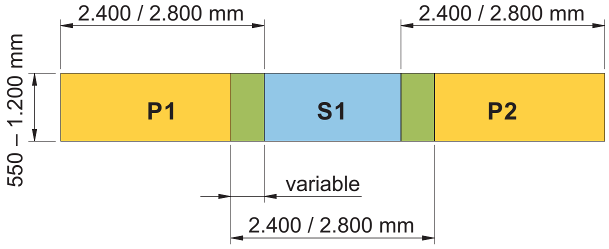
Step 3:
After reaching the design depth, the mixing tool is slowly extracted while cement slurry is continuously added. Homogenization of the fluidified soil mixture with the fresh cement slurry is ensured by the rotation of the wheels.

Step 4:
Reinforcing elements required for structural purposes can be inserted into the completed wall. A standard case is the insertion of steel stanchions. In shallow depths these will usually penetrate under their own weight; otherwise a light vibrator can be used to assist their installation. The distance of the beams and beam cross-sections are designed on the basis of the applied loads and on the results of the characteristic strength of the soil.

Construction sequence

A continuous wall is formed in a series of overlapping primary and secondary panels. Overcutting into fresh adjacent panels is called „fresh-in-fresh method“.
The cutter technique also allows the “hard-in-hard method”, whereby secondary panels are cut into the already hardened primary panels.

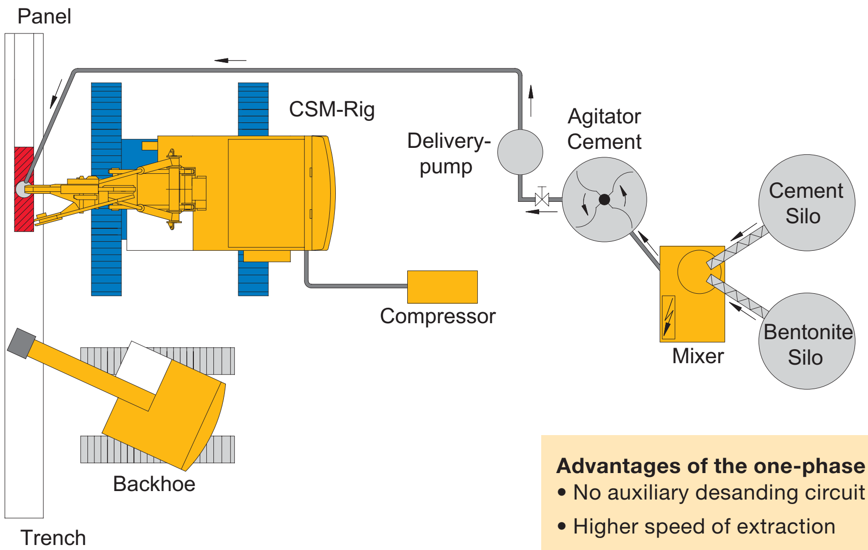
The cutting and mixing procedure can be executed in two ways:



One-phase system

During the penetration (downstroke) phase, cutting, mixing, fluidifying and homogenising is performed while pumping the binder slurry into the soil. Adding compressed air is recommended for assisting the downstroke phase. As a rule of thumb about 70 % of the total slurry volume is pumped during this phase. The backflow of soil and binder slurry is collected in the pre-excavated trench or stored in a settling pond to be removed later off the site.

After reaching the design depth air flow is stopped. In the upstroke phase the remaining volume of binder slurry is blended into the soil. The speed of extraction can be high as the majority of the binder slurry has already been mixed with the soil in the downstroke phase.

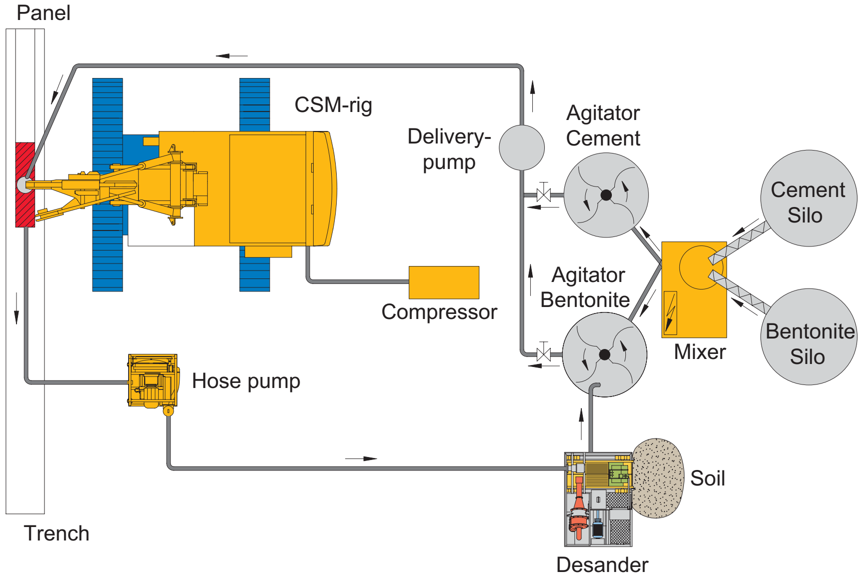


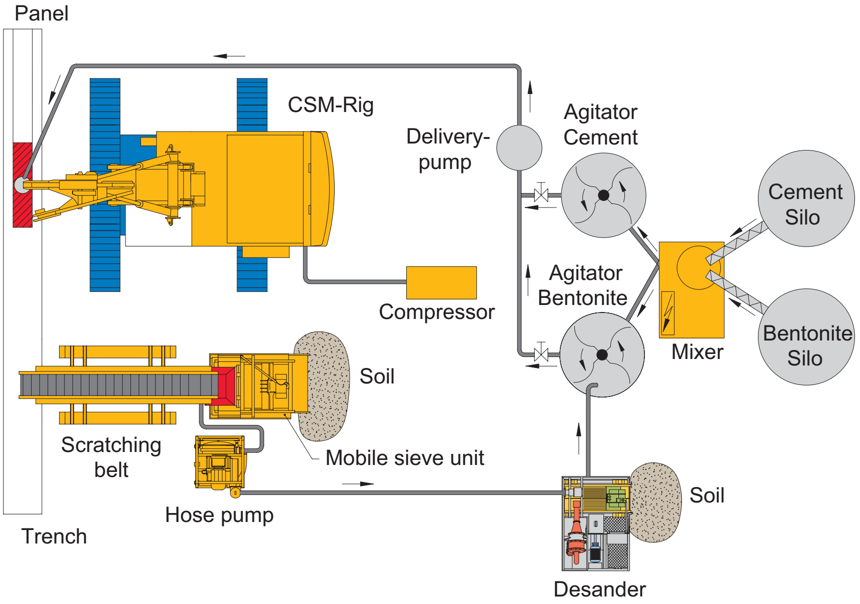
Advantages of the one-phase system are:
- No auxiliary desanding circuit required.
- Higher speed of extraction
- Preferred application in easy and uniform soils, depth range < 20 m

Two-phase system

The soil is fluidified and homogenised in the downstroke phase by pumping of bentonite slurry into the soil. The mixing process can be supported by adding compressed air.
The backflow of soil and bentonite can be pumped to a desanding plant where the sand is separated from the slurry which is then pumped back to the rig.

When the backflow becomes too heavy for pumping, it can be removed by a backhoe or a scratching belt from the trench onto a screen where primary separation occurs. Using a hose pump the fluid fraction is then pumped to the desanding plant unit for further treatment.
After reaching the design depth, the flow of bentonite is stopped and replaced by cement slurry. On the upstroke movement cement slurry is mixed thoroughly with the fluidified soil. The speed of extraction and flow of binder are adjusted to ensure that the total calculated quantity of binder is blended with the soil.





Advantages of the two-phase system are:

- Increased safety when working at extended depths or when the working process is interrupted.
- Reduced wear and tear on the cutting wheels.
- Reduced cost for removal of spoil (a certain percentage of the slurry can be reused), the remaining spoil can be easily removed as it is a dry material.
- Preferred application in difficult soil conditions and for extended depths.

Productivity factors

The average productivity is highly influenced by the following site parameters.

	favourable conditions	unfavourable conditions
Soil structure	uniform soil structure	layered soil structure
Soil type	loose to medium dense gravelly sand, silty sand	dense to very dense soil, cobbles and boulders embedded in soil, stiff or hard soil, cohesive or organic soil (reduction of the final strength)
Site geometry	long, straight wall sections	irregular wall layout
Wall depth	wall depth > 10 m	wall depth < 10 m (influence of non-productive periods such as moving, setting-up)

Slurry specifications

Components of the binder

The components of binders normally used in the construction of CSM panels are: cement (OPC or Blast furnace cement CEM III/B 32,5), bentonite, and water. When required, it is also possible to use additives (plasticizer, retarder) or admixtures (such as fly-ash).
When working with bentonite slurries for premixing (two-phase system), polymer additives have shown good results in terms of decreasing viscosity and the reduction of fluid loss.

In-situ sampling tool

Mix design

The mix design should always be determined by suitability tests prior to the start of construction.
The following tables give values for an initial design of the mix proportions. They should be used for reference only.

Bentonite suspension (for fluidifying the soil in the two phase system)

- approx. 20 – 40 kg bentonite/m³ slurry
- 400 l slurry/m³ soil (minimum quantity for fluidifying the soil)

Binder slurry (typical mix design)

		Cut-off wall	Retaining wall
Cement	kg/m³ slurry	250 – 450	750 – 1.200
Bentonit	kg/m³ slurry	15 – 30	15 – 30
w/c ratio		2,0 – 4,0	0,5 – 1,0

The mix design and the applicability of the system is highly dependent upon:

The application:

- Cut-off wall (permeability, strength, plasticity, erosion stability)
- Retaining wall (strength, permeability, plasticity of the fresh material – as precondition for installation of reinforcement)

The soil conditions:
Particle size distribution, grain size, fines content, organic content, density, SPT values, porosity, groundwater level, groundwater chemistry are the main influencing factors.

Wall characteristics

		Cut-off wall	Retaining wall
Compressive strength qu	MPa	0,5 – 2	5 – 15
Permeability kf	m/sec	ca. $1x10^{-8}$	
Cement kg/m³ soil		100 – 200	200 – 500

Site examples

Wall construction in limited conditions (Malaysia)

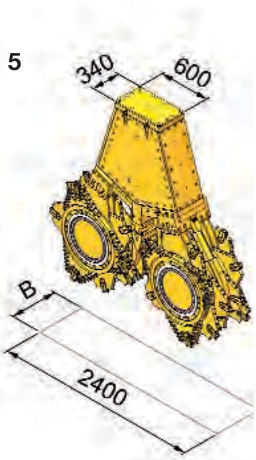
Retaining wall and underpinning for a heritage building
with CSM (Australia)

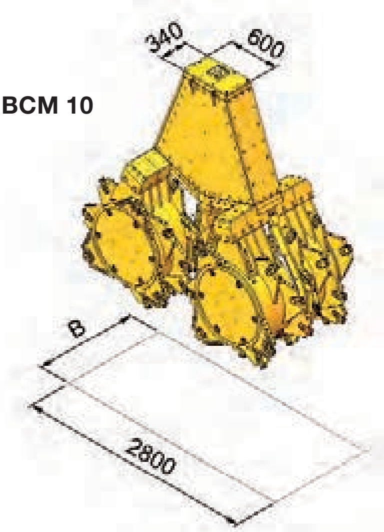
CSM-wall for start shaft microtunneling (USA)

CSM-protection wall around a
shut-down nuclear reactor building (USA)

CSM-rigs

Cutting and mixing head BCM



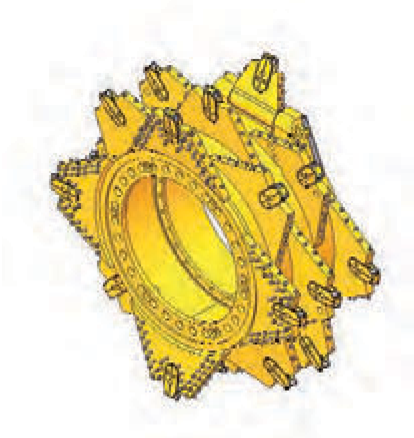


	BCM 5	BCM 10
Torque	0 – 57 kNm	0 – 100 kNm
Rotation speed	0 – 35 U/min	0 – 30 U/min
Height	2,35 m	2,8 m
Panel length	2,4 m	2,8 m
Panel width B	550 – 1.000 mm	640 – 1.200 mm
Weight (with wheels) *	5.200 kg	8.200 kg

* at min. panel width

Types of wheels

The wheels are designed to cut and loosen the soil matrix and then to mix it with the slurry. The soil type dictates whether more emphasis needs to be put on the wheel´s cutting or mixing capability. As the cutter wheels cut into the ground they break up the soil matrix and then mix the loosened soil thoroughly with the injected binder slurry. The prevailing soil type dictates whether more emphasis needs to be put on the cutting or the mixing capability of the wheels. The use of symmetrical tooth holders in conjunction with the application of DC teeth allows trouble-free breaking up and mixing of the soil in both rotational directions. A cutter wheel mixing set does consists of four identical mixing wheels. This and the application of BAUER-exclusive TungStuds result in low wear costs.



Four tooth holders in one row of teeth

• loose to dense non-cohesive soil,
• gravely soil with stones, cohesive soil
• good mixing capacity (due to four tooth holders)

Three tooth holders in one row of teeth

• dense non-cohesive soil, gravely soil with stones
• hard cohesive soil
• good cutting capacity (due to three tooth holders)

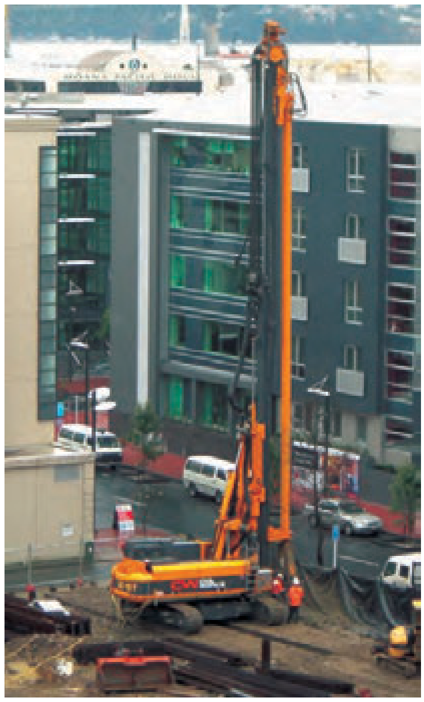
Kelly-guided CSM-rigs

Monokelly (round shaped)

The BCM unit is supported by a Monokelly system. For smaller rigs and for a maximum depth of approx. 20 m, a round Kelly bar (Ø 368 mm) is used.
Two guide sledges connect the Kelly bar to the drill rig's mast, they provide alignment, crowd and extraction forces and rotational movement. A hydraulically operated locking mechanism transfers crowd and extraction forces to the Kelly bar and a rotating arrangement incorporated in the guides enables the CSM unit to be turned +45° to -90°.

Systems with round Kelly bar
(with rotation device, without Kelly extension, further base carriers on request)

	Mixing head	Motor output (kW)	Extraction force (kN)	Operating weight (t)	Overall height (m)	Mixing depth (m)
BG 28 (BS 80)	BCM 5 / BCM 10	354	330	90,0	26,2	18,0
BG 30 (BS 95)	BCM 5 / BCM 10	403	330	92,0	26,2	18,0
RG 16 T (BS 65 RS)	BCM 5	563	200	71,0	21,5	14,5
RG 19 T (BS 65 RS)	BCM 5	563	200	67,0	24,5	17,5
RG 21 T (BS 65 RS)	BCM 5	563	260	84,0	27,5	20,0
RG 18 S (BS 65 RS)	BCM 5	563	260 / 400	80,0	23,5	17,0
RG 22 S (BS 65 RS)	BCM 5	563	260 / 400	80,0	26,1	21,0
RG 25 S (BS 90 RS)	BCM 5 / BCM 10	563	400 / 600	105,0	29,5	23,0



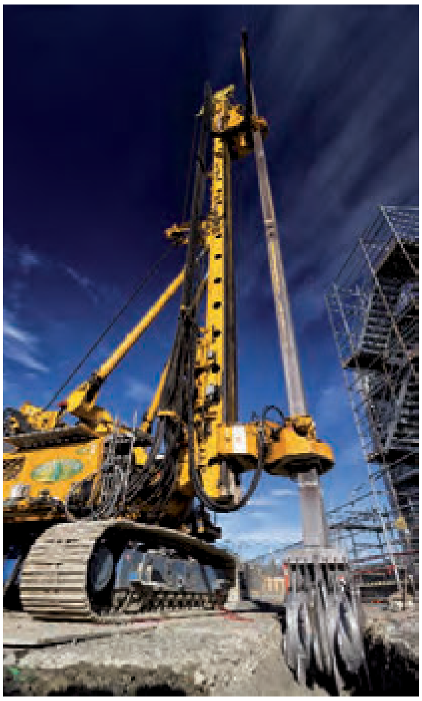
Monokelly (rectangular type)

For greater treatment depth, the BCM unit is held and guided by a Monokelly with rectangular (600 x 340 mm) cross-section. The full string length is made of sectional pipes. The Kelly string can be extended above the height of the rig mast. The connectors can transfer all forces (especially bending moments resulting from the load case “assembling”) and they are covered with protection shields to ensure a flush surface.
Hydraulic hoses, slurry pipes and air hose are located inside of the hollow kelly bar.

Systems with round Kelly bar
(with Kelly extension, further base carriers on request)

	Mixing head	Motor output (kW)	Extraction force (kN)	Operating weight (t)	Overall height (m)	Mixing depth (m)
BG 28 (BS 80) *	BCM 5 / BCM 10	354	580 / 830	130,0	42,0	35,0
BG 30 (BS 95) *	BCM 5 / BCM 10	403	580 / 830	132,0	42,0	35,0
BG 39 (BS 95) *	BCM 5 / BCM 10	403	690	165,0	48,9	43,0
BG 42 (BS 115) *	BCM 5 / BCM 10	460	750	180,0	43,4	38,0
BG 46 (BS 115) *	BCM 5 / BCM 10	570	910	190,0	49,0	43,0
BG 50 (BT 180) *	BCM 5 / BCM 10	570	860	300,0	60,5	53,0
RG 25 S (BS 90RS)	BCM 5 / BCM 10	563	400 / 600	114,0	39,0	30,5

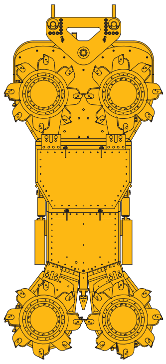
* with rotation facility as option



Rope suspended CSM-rigs

Rope suspended CSM rigs are made for big mixing depth with minimized rig dimensions.
The machine concept can be offered in four variants with the base components:
base carrier, hose handling system, boom, mixing unit.

QuattroCutter

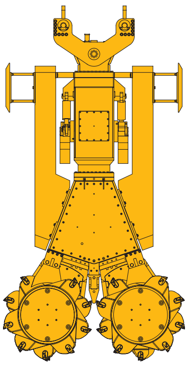


2 x BCM 5
Mixing unit
(4 gear boxes)

QuattroCutter Standard on MT 75

Quattro SideCutter on MT 75

TandemCutter



1 x BCM 10
Mixing unit
(2 gear boxes)

TandemCutter Standard on MC 64

Tandem SideCutter on MT 75

	QuattroCutter		TandemCutter	
	Standard	**SideCutter**	**Standard**	**SideCutter**
Hose handling system and boom	not turnable	turnable	not turnable	turnable
Overall height (m)	6,6 – 8,1	8,6	6,6 – 8,1	8,6
Working width (m) *	8,0	min. 4,5	8,0	min. 4,5
Max. mixing depth (m)	60	60	80 **	60
Installed power (kW)	2 x 205	2 x 205	2 x 205	2 x 205

* Width perpendicular to panel axis
** 80 m on MC 64 base, 60 m on MT 75 base

Auxiliary equipment

The list is intended as a guide for auxiliary equipment to ensure an efficient working sequence.

Mixing station

Combined mixing and pumping station

For one-phase and two-phase working sequence:

- **Slurry mixing station**
  minimum capacity 20 m³/h
- **Delivery pump**
  frequency controlled slurry pump with remote control, capacity depends on volume of panel and speed of mixing.
  (typically: 200 – 600 l/min, 12 – 15 bar)
- **Agitator tank**
  approx. 3 – 5 m³ (as buffer for cement slurry)
- **Silos**
  for cement and bentonite with screw conveyors
- **Hydraulic backhoe**
  for excavation of guide trench, maintenance of working platform, handling of backflow
- **Hoses**
  for conveying cement or bentonite slurry from the agitator to the rig. Typically 1,5" or 2" rubber hose (length to suit site requirements)
- **Air compressor** – recommended
  7 – 14 bar / 7 – 10 m³/min (for air assisted mixing)
- **Service crane and vibrator** – optional
  for inserting universal beams or other reinforcement into the panel of retaining wall. Size of crane depends on length and weight of beams and vibrator use.

additionally for two-phase working sequence:

- **Agitator tank**
  as buffer for bentonite slurry
- **Delivery pump** – optional
  pumping of reflux slurry from trench to desanding plant
- **Scratching belt** – optional
  transporting of reflux slurry from trench to primary desanding plant
- **Desanding plant** – optional
  for separating soil out of the reflux slurry
- **Mobile sieve unit** – optional
  located near the trench for pre-screening dense reflux slurry

Scratching belt
It is placed on top of the trench, immerging into the trench and conveying the bentonite/soil mixture automatically upwards into a dewatering screen. The fully automated process does not require any additional workforce.

Mobile sieve unit

Quality control

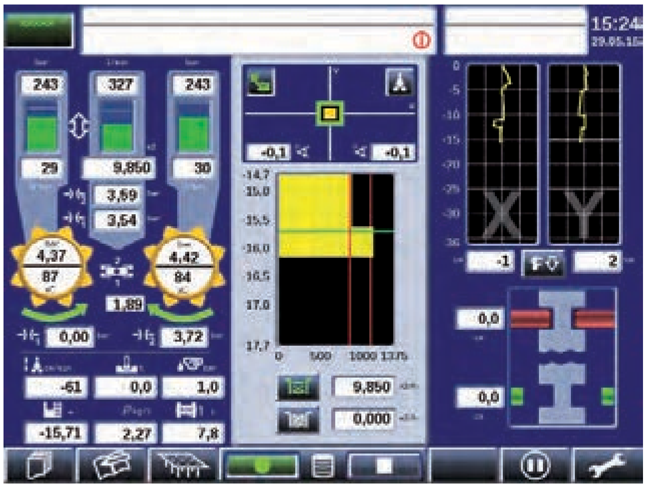
Control of production parameters

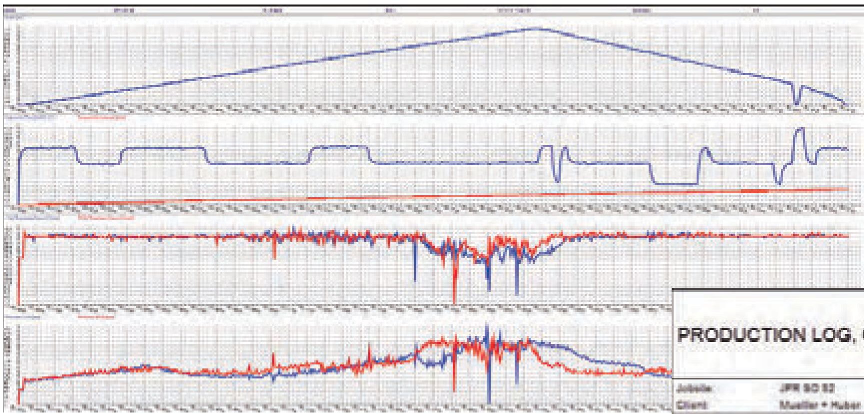
(displayed on the monitor of the rig operator)

An electronic monitoring and control system – B-Tronic – can be installed in all CSM rigs. This data acquisition system monitors and controls construction parameters as well as general rig functions.

Production data as listed below are continuously acquired, visualised and stored.

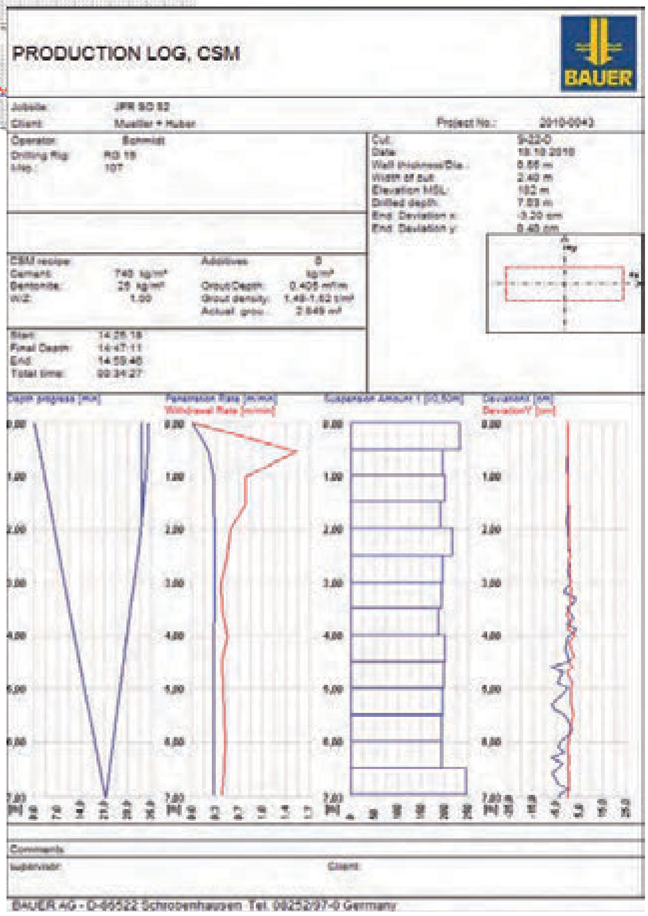
- Depth
- Volume
- Slurry pressure in hoses
- Slurry-soil pressure in trench
- Pumped volume vs. time
- Pumped volume vs. depth
- Inclination (in two directions)
- Speed of mixing tool
- General rig parameters





Documentation

All production parameters are monitored, recorded and stored inside the rig throughout the construction process and can be printed out in the form of a quality assurance record for each individual panel.



In-situ sampling of soil mix material

Quality control of the completed soil mix elements is carried out on samples obtained either before or after the soil/binder slurry mixture has hardened.

Samples of the fresh soil mix material prior to hardening can be obtained by using a special sampling tool.

Obtaining fresh samples using a special sampling tool

Horizontal core sampling with a hand-held drill

Insitu samples of hardened soil mix material can be obtained by techniques such as:

- Taking "horizontal" core samples with hand-held drills
- Drilling "vertical" core holes with drilling rigs used for exploratory boreholes
- Insertion of double-walled plastic tubes into the fresh soil/slurry mix elements and. after hardening. extraction of the inner tube together with the embedded hardened core

Cut-open inner plastic tube with hardened core

Drilling a vertical core hole with a drilling rig used for exploratory boreholes

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