# CSM Cutter Soil Mixing Process and equipment

PROCESS DESCRIPTION 8/2011

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.

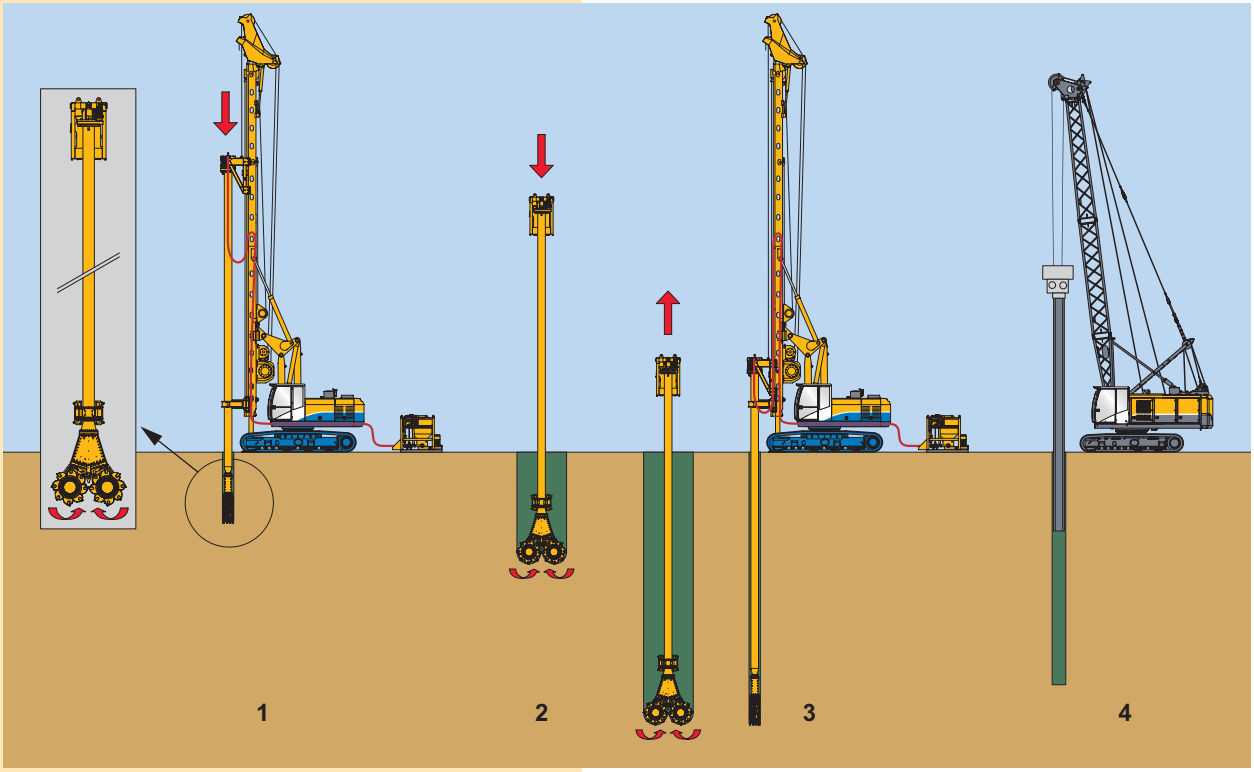
# Construction sequence

**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.

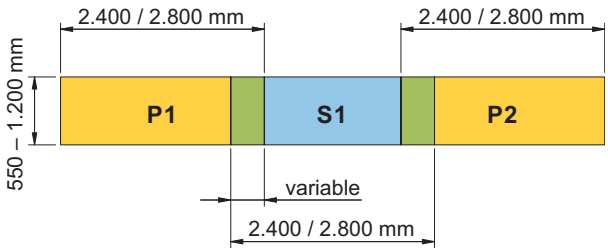
**Step 4:**

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.

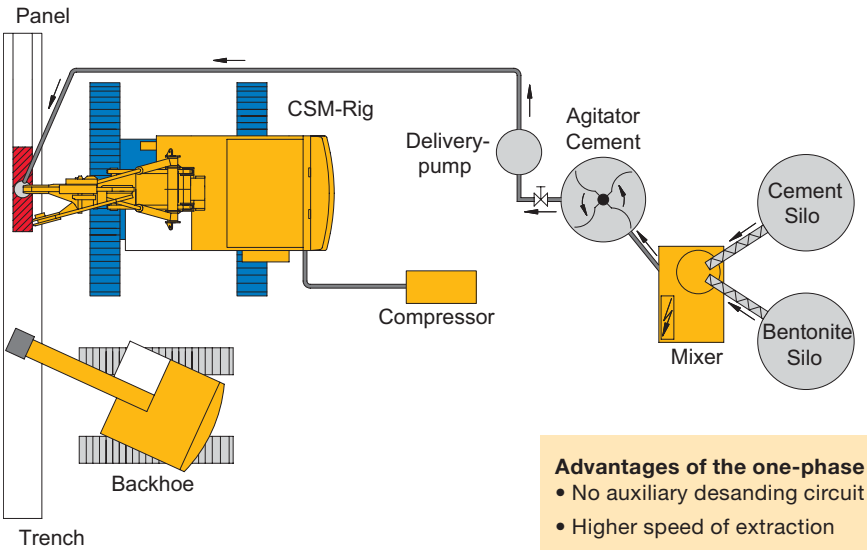
The cutting and mixing procedure can be executed in two ways:




## 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.

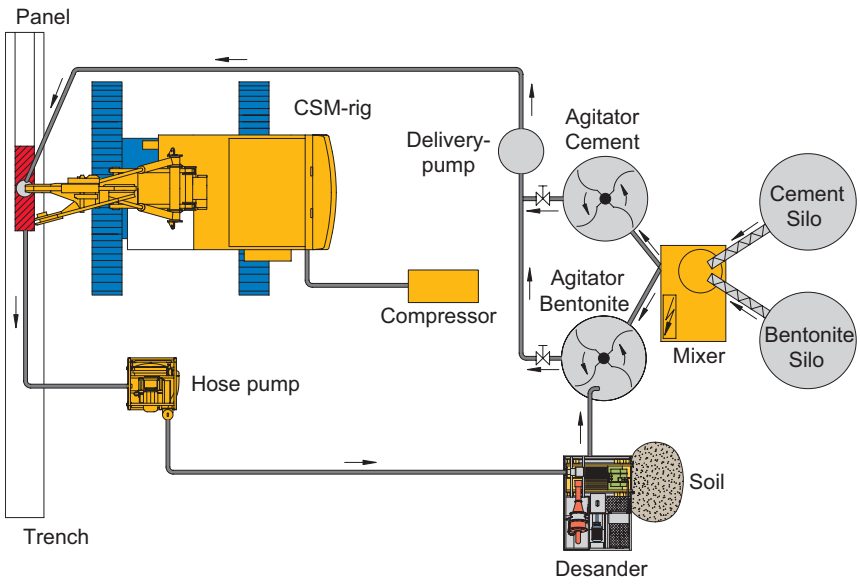


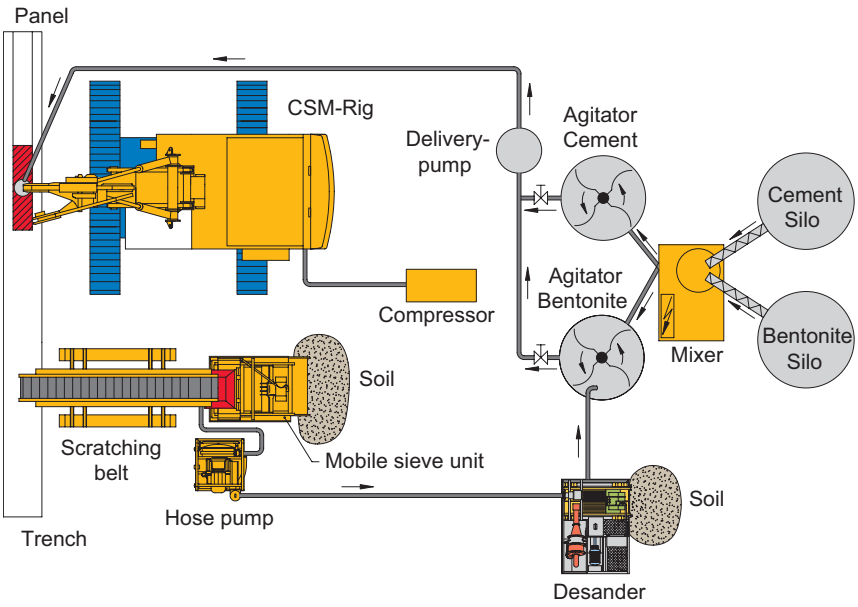

**Advantages of the one-phase system are:**
- No auxiliary desanding circuit required.
- Higher speed of extraction
- Preferred application in easy and uniform soils, depth range < 20 m, construction of retaining walls

## 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, extended depths or for cut-off walls.

# 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)
- > 40 kg bentonit/m³ slurry
- 400 kg 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

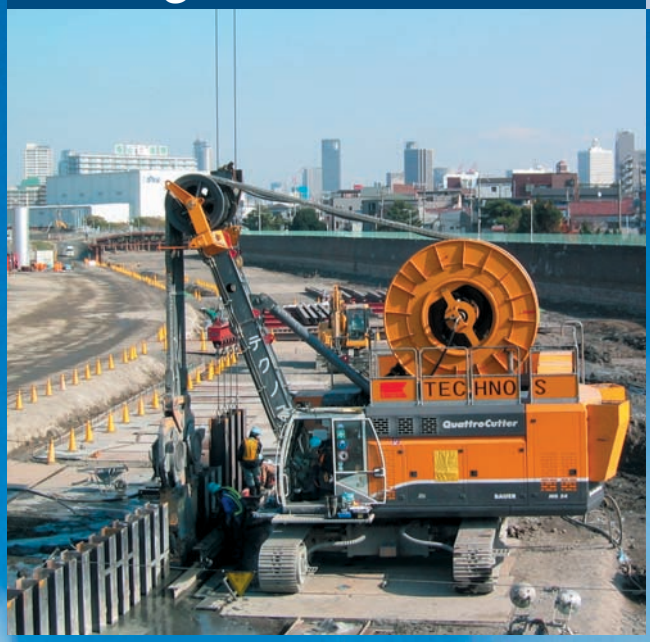
CSM-wall with props (Netherlands)

Wall and uplift retention panels with CSM (Italy)

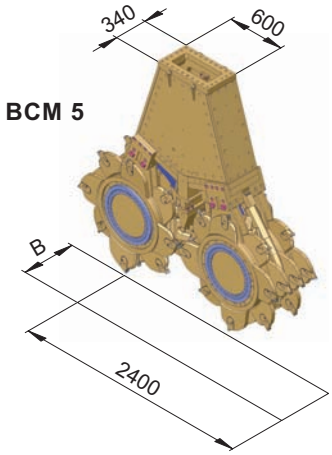
CSM-wall (Netherlands)

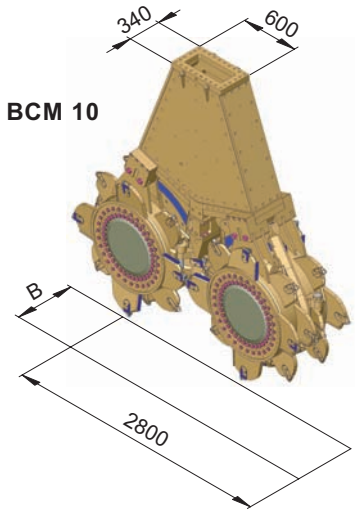

CSM-wall for start shaft microtunneling (USA)

## CSM-rigs




## Cutting and mixing head BCM



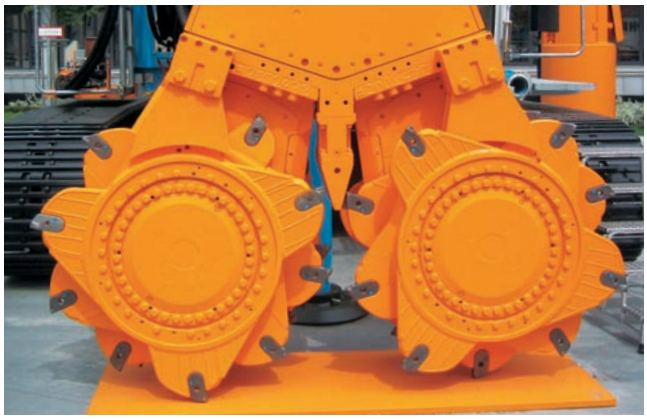

| | BCM 5 | BCM 10 |
|---|---|---|
| **Torque** | 0 – 57 kNm | 0 – 100 kNm |
| **Rotation speed** | 0 – 35 U/min | 0 – 30 U/min |
| **Height** | 2,35 m | 2,8 m |
| **Panel length** | 2,4 m | 2,8 m |
| **Panel width B** | 550 – 1.000 mm | 640 – 1.200 mm |
| **Weight** | 5.100 kg | 7.400 kg |
| **with wheels** | 550 mm | 640 mm |

## 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. Two wheel types as shown below are covering the majority of soils.

**Type 3-1** (**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)



**Type 3-2** (**three** tooth holders in one row of teeth)

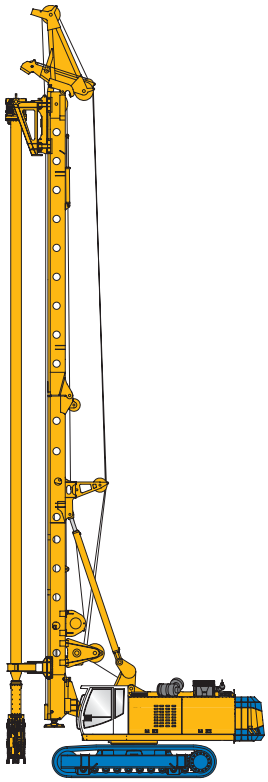
- dense non-cohesive soil, gravely soil with stones
- hard cohesive soil
- good cutting capacity (due to three tooth holders)

# CSM-rigs kelly-guided

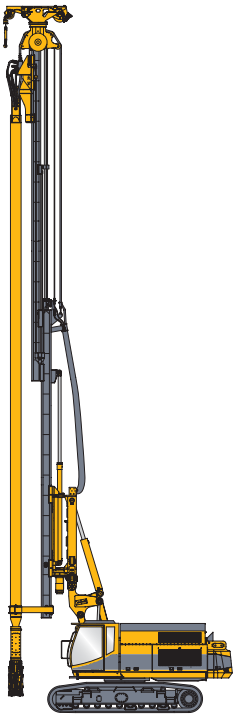
## Monokelly (round shaped)

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°.

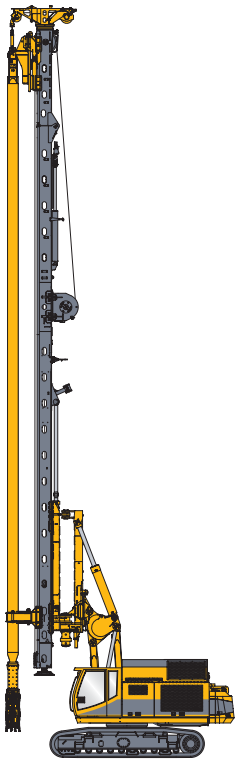
**Typical rig configurations**



BG 28



RG 19 T



RG 22 S

| | BG 24 / BG 28 / BG 30 | RG 16 T / RG 19 T / RG 21 T | RG 18 S / RG 22 S / RG 25 S |
|---|---|---|---|
| **Panel depth** | 13,4 – 18 m | 14,5 – 20 m | 17,5 – 23 m |
| **Engine output** | 261 – 403 kW | 470 – 570 kW | 470 – 570 kW |
| **Overall height** | 22 – 26,2 m | 21,5 – 27,5 m | 23,5 – 29,5 m |
| **Op. weight** (approx.) | 80 – 92 to | 71 – 84 to | 80 – 105 to |
| **BCM** (recommended) | BCM 5 / BCM 10 | BCM 5 | BCM 5 |
| **Kelly bar** | circular or rectangular | circular | circular |
| **Rotation facility** | rotation facility | through mast rotation | through mast rotation |

## Monokelly (rectangular type)

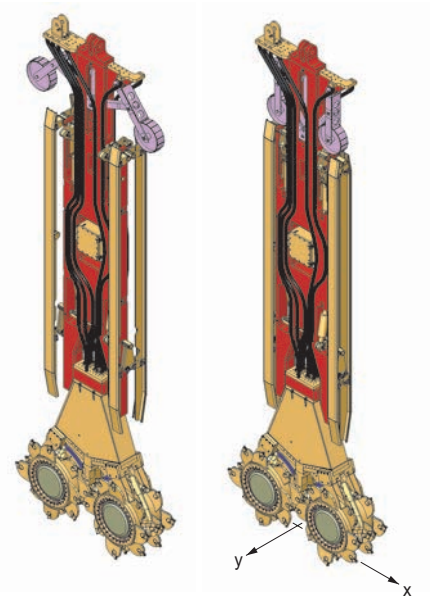
For greater treatment depth, the BCM unit is held and guided by a Monokelly with rectangular (600 x 340 mm) cross-section. The full string length is made of sectional pipes. The Kelly string can be extended above the height of the rig mast. The connectors can transfer all forces (especially bending moments 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.
The **weight** of a 30 m kelly bar (incl. hoses and inlet guide) is approx. **18 tons**, for a 40 m kelly it is approx. **23 tons**.

**Typical rig configurations**

BG 30 | BG 40 | RG 25 S

| | BG 28 / BG 30 | BG 40 | RG 25 S |
|---|---|---|---|
| **Panel depth** | up to 35 m | up to 43 m | up to 30 m |
| **Engine output** | 354 – 403 kW | 433 kW | 570 kW |
| **Overall height** | 35 m | 48 m | 36,6 m |
| **Op. weight** (approx.) | 127 – 132 to | 173 to | 114 to |
| **BCM** (recommended) | BCM 5 / BCM 10 | BCM 5 / BCM 10 | BCM 5 / BCM 10 |
| **Kelly bar** | rectangular | rectangular | rectangular |
| **Rotation facility** | rotation facility | –– | through mast rotation |

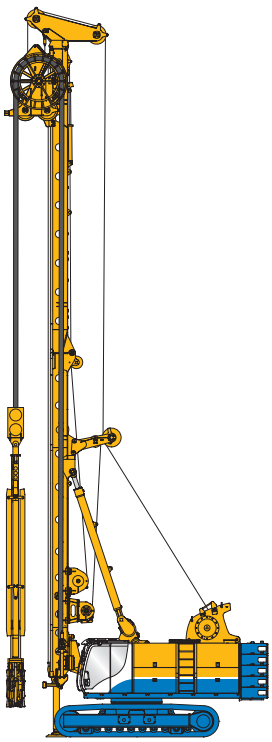
# CSM-rigs, wire rope suspended



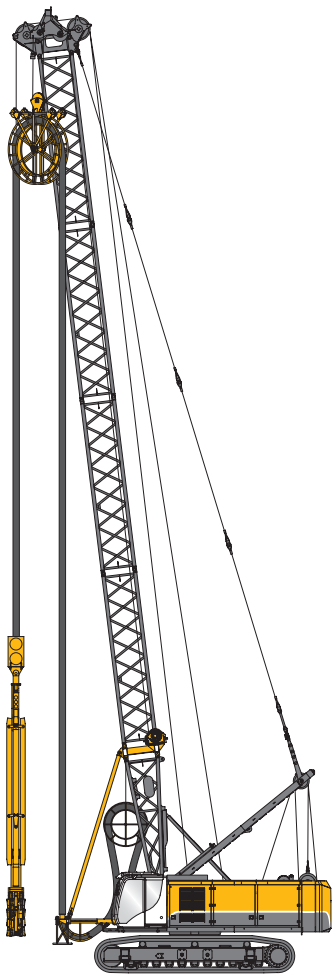

## with guide frame

For constructing deep panels, the mixing head BCM 5 and BCM 10 can be mounted at the bottom of a wire rope suspended guide frame (overall height 9 m). For stabilising the unit side plates of the frame are extended during lowering of the unit (left picture). They are retracted during extraction of the unit for minimizing friction resistance in the mixed panel (right picture).
For verticality control in x-direction the rotation speed of the wheels can be varied. For controlling the y-direction the inner frame can be tilted relative to the outer frame.

The unit can be mounted on a BG rig or on a crawler crane.
Before mounting the system on a standard crawler crane, the suitability of the base crane has to be checked and confirmed.



BG 30

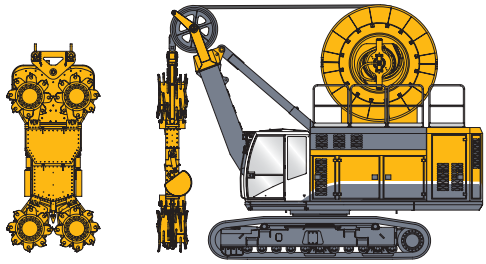


MC 64

| | BG 28 / BG 30 / BG 36 / BG 40 | MC 64 |
|---|---|---|
| **Panel depth** | 36 – 48 m | 50 m |
| **Engine output** | 354 – 433 kW | 447 kW |
| **Overall height** | 26,5 – 27 m | 33 m |
| **Op. weight** (approx.) | 85 – 130 to | 120 to |
| **Hose handling system** | HSS | HTS |
| **BCM** (recommended) | BCM 5 / BCM 10 | BCM 5 / BCM 10 |

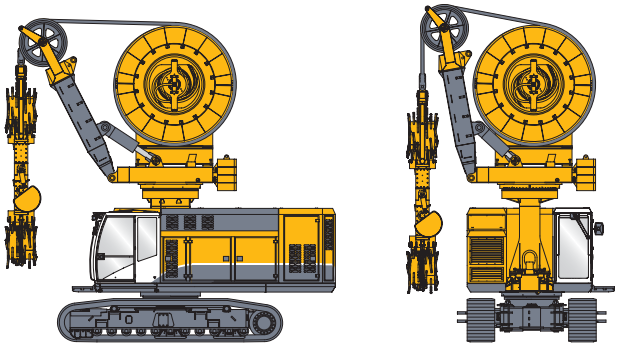
## QuattroCutter

The **"QuattroCutter"** is a new development for CSM Soil Mixing. It is formed of a frame and of two BCM 5 units (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 big depth. The hydraulic hoses and the wire ropes are mounted on one hose winding drum.
The QuattroCutter is suitable for a maximum panel depth of 60 m even for works in limited height conditions of 5 m.



## SideCutter

The **SideCutter** is a further development of the QuattroCutters. Due to ist turnable superstructure it allows a minimum working width of only 4,5 m.




| | QuattroCutter | SideCutter |
|---|---|---|
| **Panel depth** | 60 m | 60 m |
| **Engine output** | 2 x 260 kW | 2 x 260 kW |
| **Overall height** | 4,8 m | 8,6 m |
| **Op. weight** (approx.) | 85 to | 90 to |
| **Working width** | 8,0 – 9,0 m | 4,5 m |

# 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

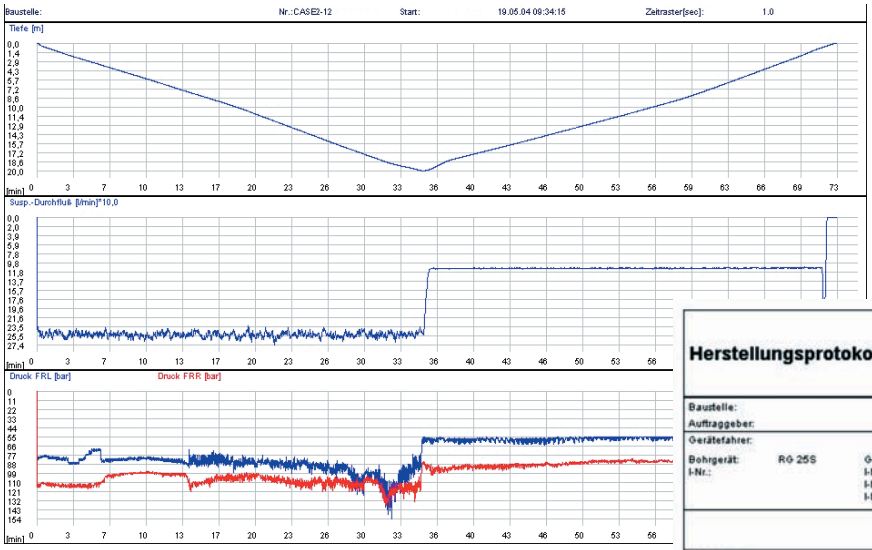
## Control of production parameters

(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.

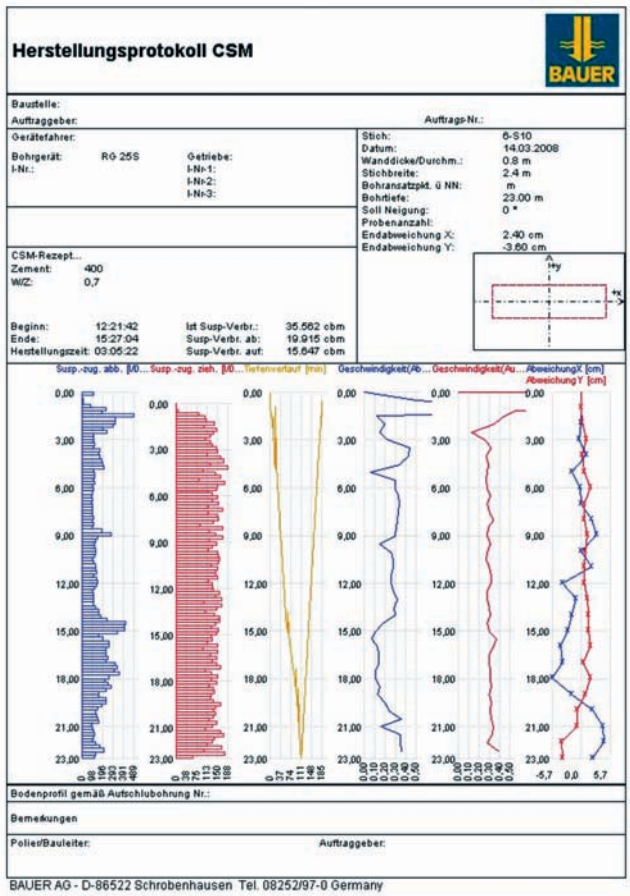
Production data as listed below are continuously acquired, visualised and stored.

- 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.




BCM 5 rope suspended on BG 28 (Bologna, Italy)

BCM 5 with rectangular monokelly on BG 36 (Brazil)

RG 25 S with extended rectangular kelly (USA)

BCM 5 with round monokelly on BG 24 (Italy)

**BAUER Maschinen GmbH**
**BAUER-Straße 1**
**D-86529 Schrobenhausen**
**Tel. +49 (0)82 52/97-0**
**Fax +49 (0)82 52/97-11 35**
**e-mail: BMA@bauer.de**
**www.bauer.de**



**905.656.2 8/11**