Site report

High-rise pumping at the Burj Dubai at over 400 bar delivery pressure

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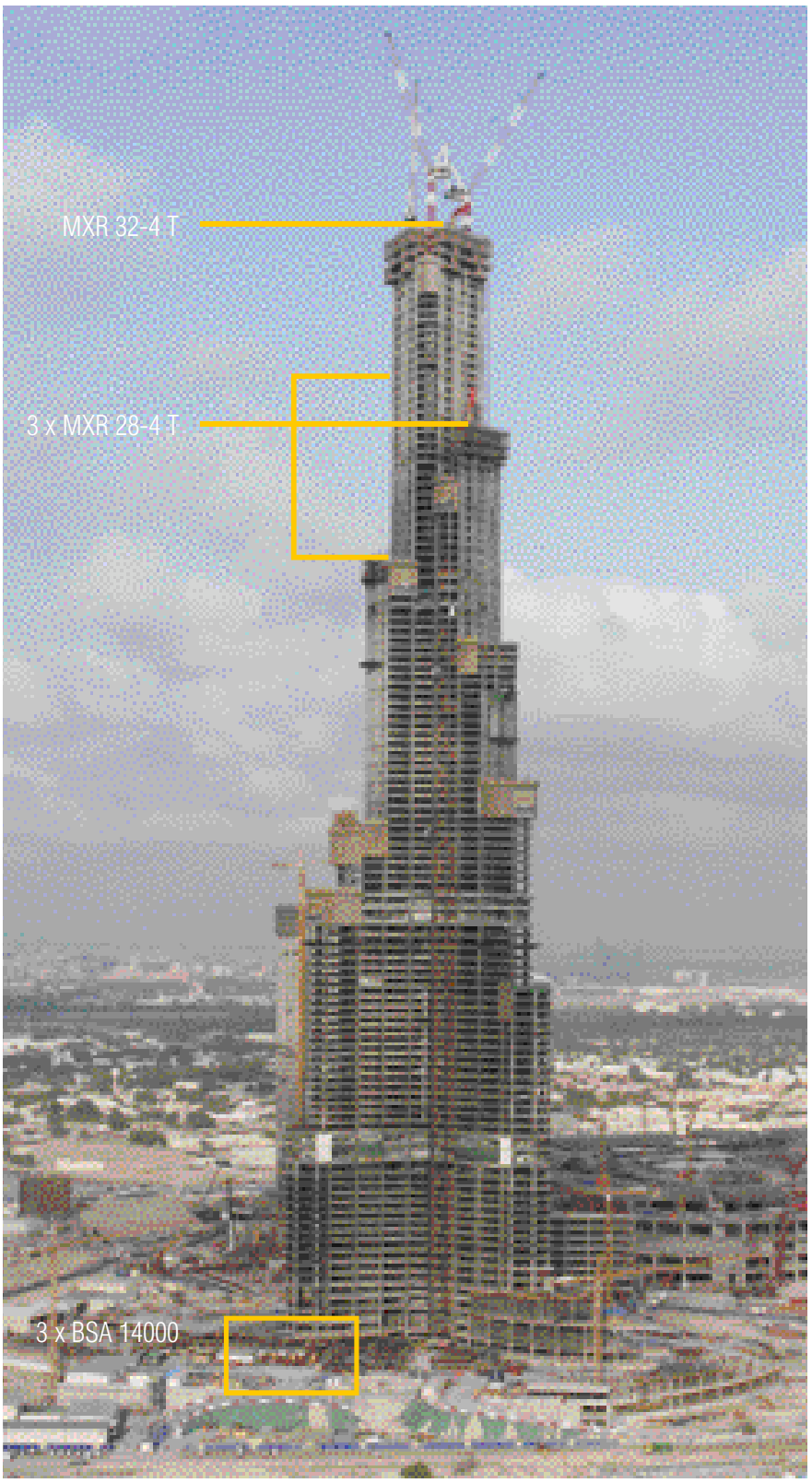

The Burj Dubai at a construction height of around 400 m

With several Putzmeister high performance concrete pumps, a sophisticated delivery line system, non-ballasted stationary booms and demanding concrete mixtures, the carcass of the Burj Dubai is currently under construction. The constructor, Emaar Properties (UAE), has commissioned a consortium managed by Samsung (Korea) together with BeSix (Belgium) and Arabtec (UAE) with carrying out the construction works on the prestigious high-rise project.
Turner Construction (USA) is responsible for the project management. The building with a final hight of approx. 800 m, will be the highest building in the world. It has not only fascinated international experts since the start of construction (excavation in August 2004), but also a wide public.

A proper amount of trust in the know-how and reliability of the partner was required when Unimix – responsible for concrete production and delivery at the Burj Dubai – decided to commission Putzmeister AG with the supply and installation of the pumps and boom systems. Putzmeister had already ascertained by pumping tests, that the concrete pumps and pipelines were suitable for delivery heights up to 570 m with a pump output of around 30 m^3/h. For static reasons, the building section towering above this should consist of a steel construction.

File under: A 1.00, BP 1.03, A 4.00, BP 4.03

High-rise pumping simulated in extensive preliminary tests

PM's preparations at the start of 2005 were correspondingly thorough as well as extremely time-consuming and human-resource intensive, both at the Aichtal Works and at the construction site in Dubai. On site, extensive tests were carried out in a large test series with horizontally placed pipelines in order to simulate the pressure behaviour and expected friction of the concrete based on the later mixture in the line and to convert it to high-rise pumping. The tests were carried out using a series produced BSA 14000 HP D high-rise pump and ZX delivery line (DN 125).

In the meantime, the base plate for the tower and the three tower wings was produced by truck-mounted concrete pumps with different boom reaches. The 7,000 m^2 foundation is supported on 200 concrete piles (diameter 1.5 m) running 50 m deep for the actual tower, and on around 650 platform piles (diameter 0.9 m) running 36 m deep for the wings. In total, 45,000 m^3 of concrete was laid at the Burj Dubai for the foundation, including base plate.

Super high pressure pumps adapted to the extreme conditions

In the Putzmeister Aichtal Works, the details of the new super high pressure pump to be developed were already fixed at this time. It had to be constructed and delivered by summer 2005 for the imminent high-rise pumping. With the BSA 14000 SHP D – the correct name for extreme pumps – the frame and hopper have been reinforced to be able to withstand the enormous forces. The S transfer tube and S transfer tube bearings have also been adjusted in respect of the expected pressures. To minimize contamination of the hydraulic fluid with water or dirt particles from the outset, the BSA 14000 SHP D also has a particularly effective filter system. Above all, however, Putzmeister engineers have modified the drive hydraulics so that the translation ratio between the hydraulic and the concrete pressure is less than i = 1 with piston side operation. Due to this hydraulic ratio concrete pressures of over 400 bar (max./theor.) are possible with the high performance pumps. Because of the expected demands for the Burj Dubai project the conveying pressure of the pump system was limited. The super high pressure pumps are driven by a standard, 470 kW Caterpillar diesel engine, which is also integrated in other BSA concrete pumps.

To simulate high-rise concrete delivery under extreme conditions, hundreds of metres of delivery line were first laid horizontally, measurement values and factors such as friction coefficients were determined and converted to high-rise pumping.

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Checking the slump during the trials

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Overview of the layout of the delivery lines at the pump station – the two super high pressure BSA 14000 SHP D pumps are shown on the left and right

Unimix has combined two of these super high pressure BSA 14000 SHP D pumps and the "normal" BSA 14000 HP D high pressure concrete pump from the test phase to form one pump station. The machines are around 70 m from the centre of the building tower.

High-strength concretes require pressure reserves

To keep the measurements of the ceilings and supporting walls as low as possible, and to be able to carry the increasing loads as height rises, only concretes with high compressive strength are being used on Dubai's most spectacular high-rise construction site. According to the original plans, the distribution of the individual concrete mixture breakdowns looked as follows:

- Base plate: C80A (maximum particle size 20 mm)
- Up to level 26 (height 95 m) for the walls: C80A (maximum particle size 20 mm)
- Up to level 126 (height 452 m) for the walls: C80 (maximum particle size 14 mm)
- Up to level 154 (height 570 m) for the walls: C60
- Concrete with compressive strength C50 is compulsory for creating the ceilings of all storeys.

Although concrete class C80A with 20 mm maximum particle size was originally only intended for installation up to 95 m height (level 26), this concrete was pumped with 50 cm spread and a w/c value of 0.3 to a height of 352 m (level 100) with a slightly modified mixture breakdown. For this height and with this material, the delivery pressure for rod side operation was just approx. 150 bar at 30 m^3/h. There were two crucial reasons for keeping the mixture: On the one hand, all those responsible were pleasantly surprised at how easily this material could be pumped even beyond the 300 m mark. On the other hand, there were clear cost advantages. This is because significantly less cement and fines are required for concrete with a maximum particle size of 20 mm than for a concrete mixture with a maximum aggregate particle size of 14 mm. Each line is also pumped with 2 m^3 grout, which is received at the top of the building in a container and can be dumped to the floor team with a crane.

Time-consuming mounting of the pump lines

Developing efficient concrete pumping for the spectacular delivery height at the Burj Dubai was just one of the many tasks for Putzmeister engineers. A particular challenge was the delivery line system, its wear behaviour and its compressive strength as well as the line routing and mounting in the structure. Putzmeister applied for several patents in connection with this.

For gradual concrete placement in the ceilings, Unimix used its stationary Putzmeister standard concrete pump, a BSA 14000 HP D, with standard ZX delivery line (DN 125) from the outset. This machine predominantly pumps concrete with a strength of C50 and has in the meantime (as at March 2007) reached a delivery height of over 400 m. This is the same BSA that was already used for pumping the test series.

At the request of the site management, pump lines with 150 mm (6") internal diameter, which are fitted over nearly the entire delivery height, were selected for pumping the particularly high strength concretes. These lines are designed for a maximum concrete pressure of 250 bar. Only in the uppermost 10 storeys were the normal Putzmeister ZX delivery lines (DN 125) installed due to easier handling. In this arrangement, they can be operated with pressures up to 130 bar.

As the flow rate drops, the residence time of the concrete in the line increases. This longer flow time should be taken into account when the concreting concept is developed. With an assumed structure height of 570 m, the residence time of the concrete in the 150 mm delivery line is around 35 minutes. Add to that the significantly higher load on the shut-off valve due to the much heavier concrete columns in the line.

In addition to the 45,000 m^3 of concrete for drilled piles and base plate, a further concrete requirement of around 180,000 m^3 is estimated for the high-rise pumping for the tower and the three wings. Due to these immense concrete quantities, the delivery pipes are of course subjet to friction wear. To ensure that they do not have to be changed, Putzmeister supplied especially long-life pump lines with an 11 mm wall thickness.

From the central pumping station at the Burj Dubai, two of these massive delivery lines will initially lead to wing "A". In the building, the two main lines divide into four legs, each of which runs to a Putzmeister stationary concrete placing boom. A further, fifth line is provided for stand-by operation.

"Thick" line has advantages and disadvantages

Increasing the cross section of the line has a direct influence on the flow rate, the wear behaviour, the pressure requirement and the period for which the concrete remains in the pipeline – given the same output per hour. In comparison with the 125 mm delivery line, the cross section for the 150 mm diameter increases by around 44 %. This results in a pressure reduction of around 25 %, and the wear also reduces accordingly.

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In the central core of the Burj Dubai, the two main lines can be folded down onto four risers in just a few movements. The risers lead to the stationary Putzmeister booms on the decks and up in the tower.

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Due to the high temperatures, concreting work is carried out predominantly at night time

Massive wall brackets hold the concrete lines which weigh over 50 tons

To support the weight of the risers (they are still full during the concreting works!), every delivery line is supported by a massive mount after transition to the vertical. These U-shaped mounts have been welded with heavy steel plates which have been concreted into the walls and bear the weight of the respective riser. With an assumed pumping height of approx. 570 m, the weights involved are immense. The combined weights of the pipes and couplings and the weight of the concrete comes to more than 50 tons!

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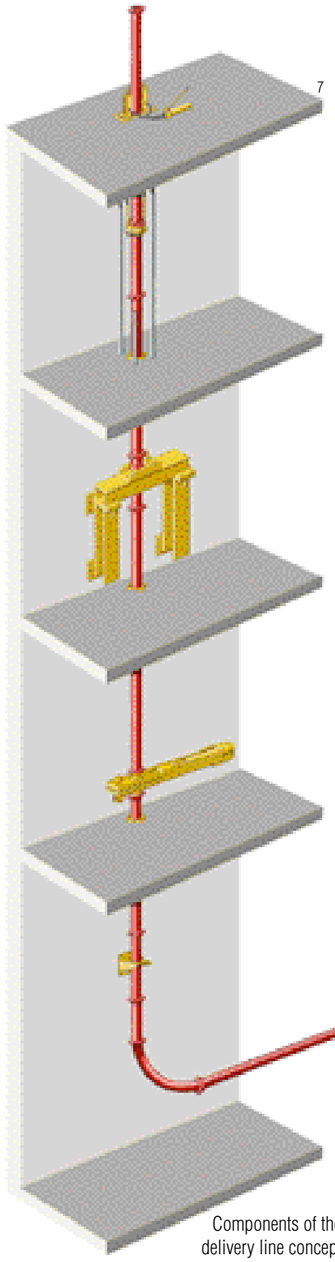

Components of the delivery line concept

The individual 3 metre pipes of the pump lines are fixed by floor fixing plates between two storeys, so that they are freely mobile in the vertical, but cannot break out or bend horizontally – despite the weight. This expensive routing and mounting of the pump lines was required as, according to Putzmeister's calculations, the stress on the pipes due to the building settlement, axial tension and temperature expansion would otherwise have been too great.

"Iron sword" for emergencies

High-rise concrete begins to set after only two hours. In order not to lose the entire line section due to setting concrete – e.g. due to problems in the mixer, failure of a pump, blockages in the 70 m long horizontal line, delays in concrete delivery or concrete placement – fast emptying of the delivery line must be possible at all times. To this end, Putzmeister engineers developed the so-called iron sword, which works like a hydraulic shut-off valve and is optimally adapted to the space conditions thanks to its low construction width. So, if the concrete batches are not placed within 90 minutes, emergency emptying would be triggered, i.e. the riser would be isolated with the iron sword, the delivery line bend beneath it would be opened, the sword would move back and the concrete could flow freely from the line.

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If individual pipes have to be replaced, the entire riser can be lifted by hydraulic cylinders

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The pump lines are routed along the sides between the ceilings so that they cannot bend horizontally, although they are freely mobile vertically

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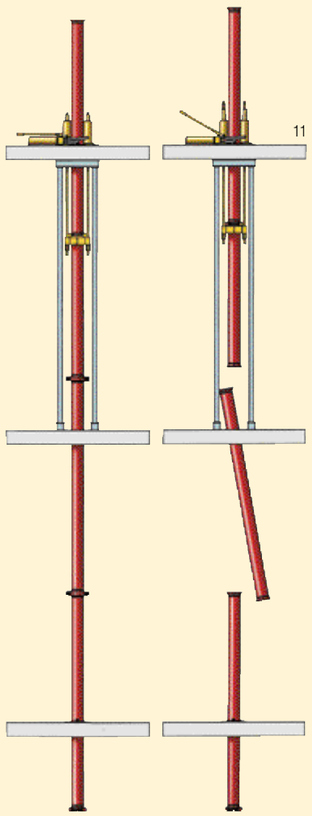
For emergencies: with the "iron sword" fast emptying of the riser is possible at all times

Hydraulic lifting device makes it easier to replace pipes

Special lifting devices were developed by Putzmeister to replace individual delivery pipes. They consist of a sleeve that is connected to the coupling of the pipe section above. Two anchor rods are then routed through the deck above and supported by it. The complete line section is lifted by hydraulic drive cylinders, that are actuated via the hand pump.



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Changing the pipeline using the hydraulic lifting mechanism

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The non-ballasted Putzmeister MX booms do not pose an obstacle to backward walls nor other cranes on the formwork

Stationary boom without ballast

The delivery lines are connected to a total of four stationary Putzmeister booms. Three of the lines are connected to MXR 28-4 T type booms, which carry out concrete placement in the wings. The MXR 28-4 T booms are secured on the platforms of the self-climbing wall formworks (Doka) and stand on 16 m high tubular columns. The concreting work in the central heart of the building is continued by a fourth, even larger, MX stationary boom with a 32 m reach. This MXR 32-4 T is set up on a 20 m high tubular column and installed on a Doka wall formwork in the shaft. The climbing processes are carried out hydraulically in several steps per storey. Three days are needed on average to complete one storey in the central tower building. Incidentally, Putzmeister supplied all four MX booms without ballast. The consortium wanted to ensure that the ballast beams of the stationary boom would not pose an obstacle to cranes and formworks.

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Structure of the cleaning station: on the right, one of the Putzmeister super high pressure concrete pumps, in the centre a shut-off valve with 90° pipe bend, which is either connected to the discharge connection of the concrete pumps for pumping operations, or to the connection for the cleaning tower

Simple but thorough cleaning

Around 100 m³ of concrete are placed in the walls of the central core for each section (there are three sections per storey). The concrete requirement for the ceilings varies in the wings from 150 m³ in the lower levels to 50 m³ for the upper storeys.

At the end of the individual concrete works, the pipelines and concrete pump are thoroughly cleaned. To do this, Unimix, on the recommendation of the PM engineers, has installed so-called cleaning towers next to each BSA. These consist of a short horizontal delivery line and a riser of about 4 m length, which is bent twice by 90° at the open end. Immediately before cleaning, the concrete line directly behind the BSA pump is interrupted by a hydraulic shut-off valve and the connection to the cleaning towers is produced by slewing a 90° angle. The machine operator can already begin cleaning his BSA 14000. Beneath the towers, an empty truck-mixer waits for the shut-off valve to be opened and for the concrete to flow from the line into the truck-mixer drum by means of gravity. A trough under the hopper collects the concrete residue.

As the pump line is not yet completely empty – there is still residue in the 70 m long horizontal line – the last of the concrete residue is pushed out of the delivery line from the top end of the pump line using a sponge ball and compressed air. To do this, two people from the concreting team remove the end hose from the top of the stationary boom, place a wet sponge ball in the line, connect a wash-out adaptor and apply compressed air. With this method, the damp sponge ball is pushed down through the riser and any concrete residue is removed. Thorough final cleaning is then carried out in a similar way, except this time a plug created from a sponge ball, water and another sponge ball is forced through the concrete line. The whole process does not take more than around 20 minutes.

Teleservice informs central Putzmeister After Sales department – own personnel are on site

Work at the Burj Dubai is carried out in three shifts. Due to the high day time temperatures – up to 50 °C – the concrete works are usually carried out during the slightly cooler night time hours. In order to always remain informed of the condition of the super high pressure pumps, the two BSA 14000 SHP D pumps are monitored by Teleservice by the central Putzmeister After Sales department in Aichtal, Germany. Important parameters, such as hydraulic pressure, control signals, oil temperature, etc. are transmitted. In addition, experienced Putzmeister service engineers attend to concrete delivery on site. These engineers were also involved in the specification of the super high pressure pumps and when working out the concreting concept. Also, during the subsequent installation of the pipelines and booms, the PM specialists were at the side of the customer Unimix and the site management to advise.

Putzmeister Products and Services
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