Site report

High-rise concrete pumping to 532 m – New world record for PM – Riva del Garda power station – 2nd June 1994

The pumped storage power station built in 1929 at Riva del Garda has an output of 76 MW and is fitted with three turbines and a water pump for filling the night-time storage located further up the mountain with water from Lake Garda.

A complete overhaul and operational improvements have become necessary after 70 years service. One of the most important operations was driving a new pressure tunnel for a new pressure pipe. This will supersede the old pressure pipes which are laid overground.
During the course of modernization, the turbine hall will also be moved into the mountain and a cave will have to be excavated for it.
Putzmeister set a spectacular world record with a height of 432 m in an almost identical project in the Spanish Pyrenees in 1985 (Site Report TS 1662). This record has now easily been beaten by 100 m using a Putzmeister high-pressure pump operated by the customer alone. A maximum effective concrete pressure of 185 bar was measured in the pressure pipe during this work.
Why was it necessary to pump at Riva del Garda? The main objective was the cost savings and a 30 – 40 % reduction in the project time. The project supervisors state that there was an effective saving of 4 – 5 months.
The essential advantage of concrete pumping by comparison with the traditional method of transporting concrete on cable set-ups is that it allows for the simultaneous continuous installation of the steel sections for the pressure pipe. These were hauled up in 6 m long sections through a service drift which was driven next to the pressure tunnel, and then dropped into the pressure tunnel itself and welded around their circumference.
The tunnel was driven to a diameter of approximately 3.75 m, the steel pipe had an internal diameter of 2.3 m and walls 36 mm thick.
Because the concrete delivery line was laid and concreted into the ring space between steel pipe and tunnel wall, it was possible to plan and execute concrete placement completely independently of the installation of the steel pipes. The total space for the approximately 700 m long, inclined pressure shaft took approximately 5,000 m^3 of concrete.
The service drift will also remain for the future as a transport route or is even available for a later, second power station pipe.

Concrete placement

The concreting procedure was optimized for cost. Concrete placement was carried out by a team of just 3 men.
A normal working day wlth no overtime was projected for the placement of an average of 100 m^3.
Pumping operations placed around 80 –130 m^3 per day at delivery rates of 12 – 18 m^3/h, varied according to the operator's choice. Greater delivery rates were not required. The 200 kW drive motor was only utilized to 60 – 70 %.

The concrete

Since there were no particular requirements on strength (250 kg/cm^2), the principal requirement rather being that the concrete was densely packed, it was possible to optimize the composition in respect of good flow characteristics and density of the hardened concrete. The task was, after all, for the concrete densely to fill the ring space in the drift, which inclines at an angle of 52 degrees, by natural flow without vibration.
This good flow characteristic, which also permitted no segregation, was also useful for pumped placement. Broken aggregate from local quarries was used with river sand and "fluid concrete" as

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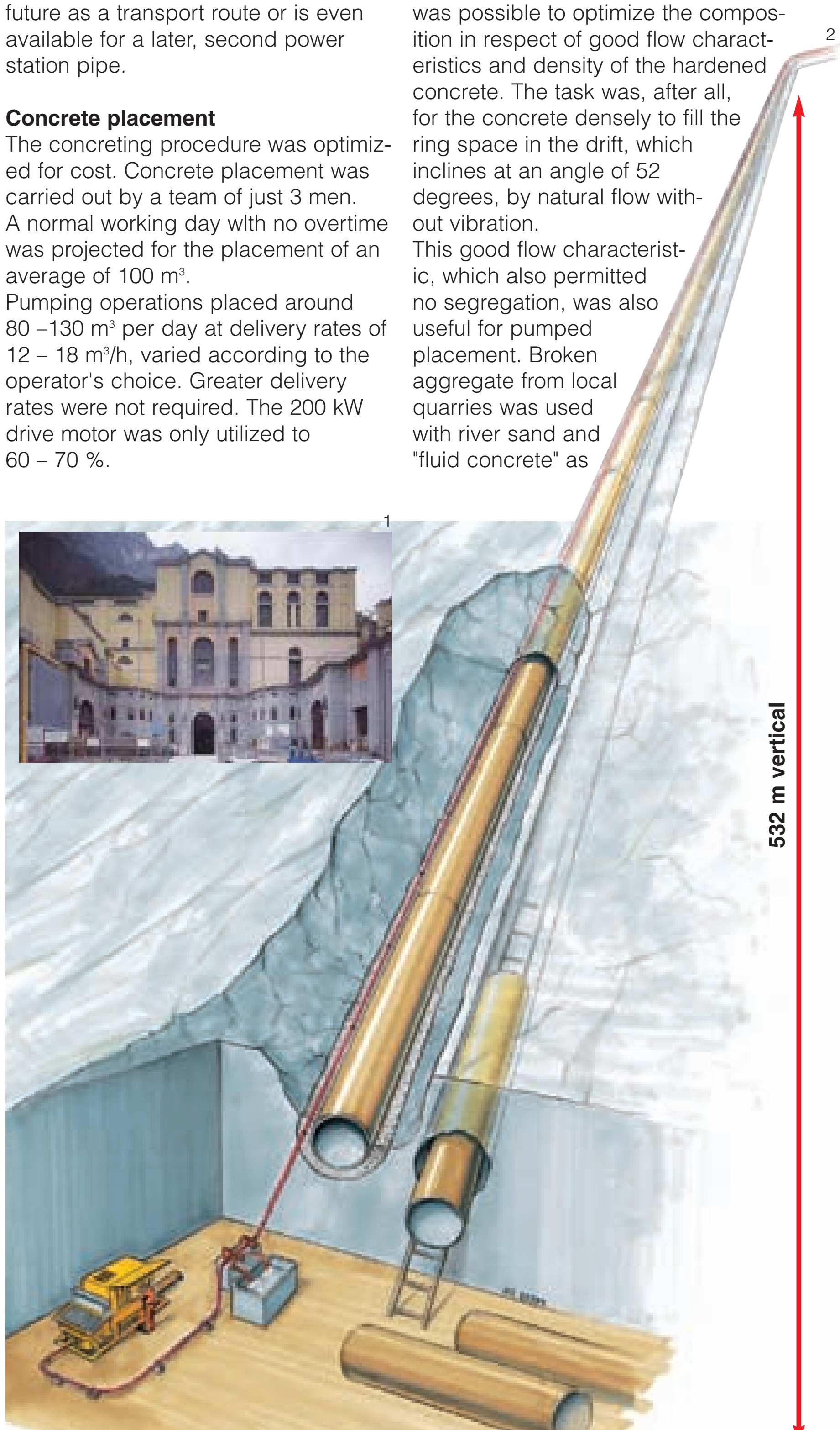

Concreted-in delivery line, 100 mm diameter, total length of 790 m.
Service tunnel with rail lift for steel pipe sections

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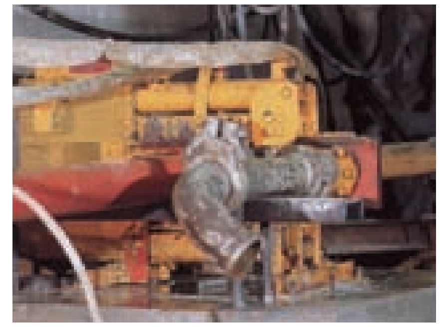

3-way gate valve for air-water cleaning using the sponge ball

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Maximum pressure in the concrete: 185 bar

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Draining the residual material by reverse pumping into a mechanical shovel for distribution in cavities

Design of the concrete pump

A long-stroke pump was the obvious choice to reduce the number of transfer tube switches. The customer thus cline the BSA 2100 HE. This has 150 mm delivery cylinders and 140 mm diameter base-driven drive cylinder, giving a transmission ratio of i = 1.15. I.e. an oil pressure of 300 bar gives a pressure in the material being delivered of 250 bar, both on the test rig and in practice; the 350 bar oil pressure which is also possible yielding correspondingly more.
Drawing on previous experience, Putzmeister decided to equip the machine with "HI-SOFT" control. This is hydraulic and electrical equipment optimizing the pump-transfer tube switch-over. Re-adjustment of HI-SOFT on site allows optimization of the hydraulic behaviour of the delivery side in the tube and the pump with the aim of achieving the greatest possible stability by avoiding pressure peaks, thus minimizing steel wear as the transfer tube switches, minimizing peaks in power consumption, etc.
The HI-SOFT device was, however, only used occasionally because of the relatively low rate of delivery. It is of greater significance for high-performance delivery with a drive output of more than 300 kW. The effects of the HI-SOFT device was, however, also clearly visible with optional switching on and off even in this Riva del Garda project.
The pump has the PM single cylinders tried and tested for high pressure delivery, and the largely cylindrical S-transfer tube S 1510.
Although the pump is very stable on its mountings, it was anchored to the floor because of the long duration of the job. It was thus absolutely fixed in relation to the concrete line, which for its part was anchored to the floor in a block of concrete a few metres from the pump. The line directly following the pump was built up from 900 large pipe bends in accordance with the regulations.

Outlook

The experience of Riva del Garda shows that heights of 800 m can easily be achieved today using the equipment currently available. The use of delivery lines with a diameter of just 100 mm is advantageous if the total quantities to be pumped are not too great, as these would weaken the walls considerably as a consequence of abrasion. If necessary, the wall thicknesses could be enhanced in the lower sections, which have to deal with large quantities of concrete. The delivery pressure is slightly higher in a 100 mm line than in a 125 mm in high-rise placement with delivery rates under 30 m^3/h. The slightly higher pressure demanded by the smaller line diameter, however, is a lesser disadvantage than the longer time the concrete requires to travel through larger diameter lines thus leaving greater volumes and greater weights of unused concrete in the line with concomitant higher costs.
Aggregate grades will not exceed 30 – 32 mm in such jobs anyway, and are more likely to be 25 – 15 mm. This is a consequence of the high-grade steel reinforcement and the good basic flow properties required of the concrete, normally demanding a liquidizer, which will also help in curing the concrete. This means that 125 mm delivery lines are preferable if delivery rates of over 50 m^3/h of normal concrete are required, or extremely high-quality concrete is being placed, as is the current practice in Japan. In these cases the normal wall frictions are several times greater than with normal concrete. No flotation effect can really be anticipated either because of the special concrete admixtures used there.
The rate of delivery can be reduced slightly if the pump pressure would increase to too great an extent at significant heights. At low delivery rates the pump pressure approaches the static pressure. This amounts to about 1 bar per 4 m height difference for normal concrete, i.e. 100 bar for 400 m and 200 bar for 800 m.

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Pump on the record-breaking day, still "as new" after 532 metres

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Renato Micolucci, pump operator (3rd from left)

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100 mm delivery line with gate valve; to the right, the service tunnel with inclined rail lift

a powder admixture. This was supplied by DRACO ITALIANA SPA. "Fluid concrete" consists principally of microsilicate.
The choice of "fluid concrete" was made on site with the aim of optimizing mix stability and flow characteristics. Enhanced strength or protection against chemical attack because of the microsilicate properties were of lesser significance here.
The concrete was supplied as normal with 22 cm slump and poured into the pump hopper. It stiffened to a slump of approximately 14 to 16 cm by the time it exited the delivery line.
As off-site mixed concrete has been specified for projects of this type in the past, we have learnt that good and precisely batched concrete with wet mixing in the truck mixer can also be used for extremely high-quality projects of this type. In addition, high-pressure pumped placement amounts to intensive re-mixing which optimizes and favours cement exploitation and thus the development of strength.
Occasional lumps of cement in the concrete could be tolerated. These were trapped in the concrete hopper grid and could be broken up by switching on the vibrator.
It was decided not to use a super liquidizer or retarder admixture for cost reasons; the small diameter of the delivery line also allowed us to make this choice.
The concrete was placed in the ring space within an average of one hour of it being mixed. It is quite certain that this would not have been possible using traditional methods with cable lifts, etc. Choice of the pumping method was decisive in achieving the advantages mentioned for this reason alone.

Delivery line – 100 mm diameter
Relatively large 125 mm lines are traditionally used when high-rise pumping concrete in order to reduce the pressure required.
On the other hand, an effort is made to use the smallest possible line diameter when pumping high and over a distance, in order to reduce the amount of concrete in the line. The aim is the quickest possible placement of the concrete, i. e. avoiding stiffening because of long pumping times or degradation of the effects of liquidizers or admixtures. As is well-known, where lines over 1,000 m in length are being used, this always demands the use of expensive long-lasting liquidizers with the aim of keeping a soft mix consistency and low pipe friction at normal temperatures for at least two hours.
Working on the basis of the flotation effect discovered in 1975 in the Frankfurt high-rise pumping project, Putzmeister again proposed, and enjoyed success with, the use of a 100 mm delivery line for the Riva del Garda project.
100 mm high pressure delivery lines with Putzmeister ZX couplings in conjunction with Putzmeister high-performance stationary pumps and concrete placement booms had been tested with success as long ago as 1985 at the Grosvenor Place high-rise development in Sydney, Australia (see site report BP 1344).
For logistical reasons at Riva del Garda, the delivery line was initially laid horizontally for 60 m before entering the inclined pressure drift. Its total-length for a rise of 532 m was 790 m. This resulted in an in-line volume of concrete of approximately 5 m³.
At the planned minimum delivery of 10 m³/h, the concrete was therefore travelling for half an hour between the mixer truck and the placement site. This time was reduced to approximately 12 minutes at the maximum delivery rate of 25 m³/h. The concrete would have been flowing for twice the time in a 125 mm line, which would have cost 15 % more.
The line itself was made from thick-walled steel pipes with an internal diameter of 100 mm and the Putzmeister ZX-6" high-pressure coupling. It is not only resistant to high pressure and playfree, but 100% centred, so that the boundary layer between the concrete and the pipe wall can develop without hindrance. This is a precondition for the friction-reducing flotation effect.
With a completely vertical line and otherwise ideal conditions, the wall friction of the column of concrete will then tend to zero, since it floats on a circumferential film of water. This effect occurs less and less with increasing inclination of sloping lines. Normal pressure values result in a horizontal line. These pressures are, by contrast, reduced by some 50 % or even more for a line inclined at 45°.
The pump and line are, however, designed as if the flotation effect does not occur.

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Protected delivery line and direct concrete pressure gauge. Pump anchored to the ground for long-term operation

Concrete gate valve and pipe cleaning
Originally, a gate valve was fitted downstream of the pump. In between, a 3-way gate valve was fitted in the delivery line for the purposes of draining the residual concrete into the truck mixer through a short stub pipe.
These are standard components from the Putzmeister range and tried and tested cleaning methods. In this procedure, the concrete is normally drained quickly and without problem using compressed air and a rubber sponge. The delivery line is then cleaned out. This is done by pushing through a sponge ball from top to bottom with water. Hard rubber scrapers can also be usefully be employed for this task as any accumulated concrete can be better rubbed off than with rubber sponges.
The on-site team, however, finally decided in favour of a simpler, completely different cleaning method: in good time before the end of concrete delivery, a last load of cheap cement mortar was pumped into the line. As soon as this mixture began exiting from the top end, the cleaning process was begun by simply reversing the pump. A simple chute was used to empty the mortar arriving in the pump's concrete hopper into the scoop of a mechanical shovel, which distributed the mortar locally in cavities and areas that were to be concreted later.
The pump operator practically never shut down the pump, even in normal operation. He merely slowed it down to the slowest creep delivery when changing over truck mixers. Neither the gate valve nor the 3-way drainage valve was required for this purpose, a truly brilliantly simple money-saving method! It does, however, assume that the operator is very familiar with concrete and pump and can handle both with great skill!
Here, too, the important lesson was again learnt that every individual truck-load of concrete must absolutely be sampled for consistency at least before it is emptied into the pump.
The use of cheap lines with a thickness of only 2 millimetres, for example, can cost dear here.
The lines concreted into the ring space can deteriorate as a result of internal wear and cause the line to be blocked. It is therefore decisive that the knowledge and rules developed from years of experience are strictly observed, in particular in the dimensioning and selection of the delivery line.
False economy can therefore cost dearly. Original Putzmeister accessory and wear parts meet the high quality standard demanded for projects of this type.

Pressure measurements
The development of the delivery pressure over the various heights and length of delivery line is shown in graph KS 68730.
At the final height of 532 m, the pump was operating at an average of 8 strokes per minute, depending on concrete supply and planned concreting time.
The effective delivery pressure in the concrete is 160 bar with a current consumption of just 210 amps.
It was possible to run the pump at 400 amps current consumption without problems, giving an effective concrete pressure of 185 bar at a stroke time of 4.8 seconds and an effective delivery of 24.2 m³/h.
The hydraulic pressure of 270 bar was here still a good 20 % below the maximum value of 300 bar, which effectively gives a delivery pressure in the cylinder of 250 bar (transmission ratio i = 1.15).
The static pressure was measured at 532 m, showing around 130 – 135 bar for a line length of 790 metres. The delivery pressure required to overcome pipe friction was only 30 – 55 bar, depending on the in-line quantity of concrete.

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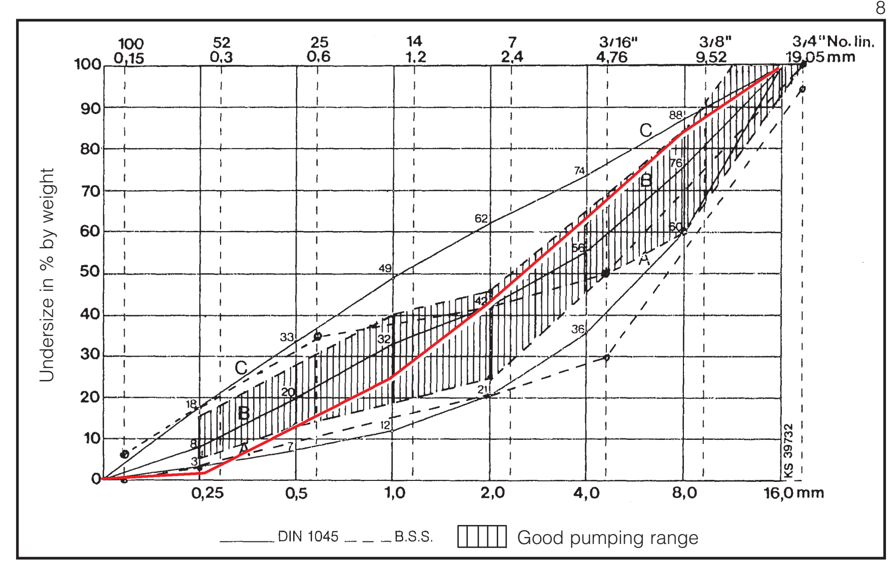

Aggregate grading graph

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Slump measurement – 22 cm

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Concrete arriving in the ring space

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Steel pipe transport through the service tunnel