Site Report

Putzmeister Shotcrete Buffaloes

A successful working family of shotcreting machines for the wet-mix-process - well proven on the "High Speed Railways Lines: Hanover/Würzburg and Mannheim/Stuttgart"

Thanks to the advantages of the wet-mix-process:

- guaranteed quality of the wet-mix
- low rebound
- no dust
- greater performance

... in 1985 more than 150.000 m³ of wet-mix-shotcrete were sprayed by leading German contractors with the fully mechanised PM Shotcrete Buffaloes.

The new double-track railway lines are built for high speed trains, up to 250 km/h. Due to the geological situation and the high speed, nearly 40% of the railway lines pass through tunnel constructions. Most of the tunnels are built by the New Austrian Tunnelling Method (NATM), for which the carrying capacity of rock is supported by a thin shotcrete lining. NATM makes it easy to adapt excavation and safety methods to changing rock conditions and cross sections. The excavated cross sections vary between 110 and 145 m², depending on the shape if profile and the rock quality.
The usable area of the tunnel varies between 80-100 m². With NATM the tunnels are constructed with two shells. The outer shell is a protective first coat, consisting of rock bolts, steel mesh, support arches and shotcrete. The inner shell, including the tunnel floor, is constructed with a site-mixed concrete. The average quantity of shotcrete per metre of tunnel is estimated at 10 m³. However, the actual quantity used can be twice this amount if difficult conditions are encountered.
The function of shotcrete in tunnel constructions is to create a semi-stiff immediate lining on the excavated rock surface. It can be applied up to a thickness of 30 cm. The shotcrete must have a high initial strength for good adherence to the rock surface. After 28 days the shotcrete should have a strength of 25 N/mm² and correspond to B 25 according to DIN 1045. For the inner shell, site-mixed concrete is placed at approximately 14 m³/m.

Development of Shotcrete - Consumption and Prices - on the High Speed Railway Lines

The total work of excavation, rock bolts, reinforcing steel support and shotcrete as first protection, plastic sheet as sealing and the inner concrete lining. The total costs of the construction with NATM are about DM 27.000,-/m. 14 % of the total costs are due to the construction of the shotcrete lining. At the beginning of 1981 there was a great difference in price between concrete and shotcrete. In time, however, the difference was reduced from nearly 74% in 1981 to only 47% in 1984. The total amount of shotcrete needed on the new line increased from 48,000 m³ in 1981 to 237.000 m³ in 1984. During this time shotcrete for the wet-mix-process increased from 0 to 30.000 m³ - amounting to 14% of the total shotcrete. The loss of material due to the geological overburden and rebound of shotcrete, decreased from 102% in 1981 to 59% in 1984: the shotcrete in the wet-mix-process reduces rebound by 30% to 50% of the rebound of shotcrete in the dry-mix-process.
The decreasing difference between site-mix concrete and shotcrete and the reduced amount of rebound is the strongly influenced by the increasing amount of wet shotcrete - carried out by PM Shotcrete-Buffaloes.
In the past, eccentric worm pumps were used for this application. Putzmeister still offer these pumps but they are now only used for easily pumpable mixes on small jobs as otherwise wear costs could increase drastically. Compared to piston pumps, wear on worm pumps can increase 10 times if conditions are unfavourable (long distance, large aggregates, blockages etc.)

Wear Costs (DM/m³):

	Worm Pump S 8	Piston Pump BSA 1002
Natural grains 0-8 mm	8,00 - 10,00	0,60 - 0,80
Crushed aggregates 0-11 mm	15,00	1,50

approximate values

Wear costs for worm pumps can be as high as for dry guniting machines when all the parts which come into contact with the concrete are considered.

Advantages of Shotcrete in Wet-Mix-Process

The wet-mix-process with spray buffaloes is preferred to the dry-mix-process, whenever a large amount of concrete has to be sprayed, especially for large diameter tunnels. The demand for faster tunnel excavation and protection, with a shotcrete application of more than 10 m³/h, has promoted the development of the manipulated shotcrete systems: the PM-Buffaloes. There are now several types of spray buffaloes available, mounted on crawler or all-wheel drive chassis with on or two shotcrete arms. All buffaloes are equipped with robust, wear-resistant piston pumps working on the transfer tube principle.
They have been developed to such a high standard that it is now possible to spray continuously without any interruptions in the concrete flow. 10 m³ of effective spraying capacity per shotcrete line has been measured. This means that the shotcreting time can be halved. Especially for cross sections of about 70 m³, the twin shotcrete buffalo SMC 3/2 with two independent pumps and two shotcrete arms and a capacity of 25 m³/h allows most economically shotcreting work. Total construction time can be reduced by approximately 10-15%. Reducing shotcreting time reduces the whole operation period for all other tunnelling machines and consequently reduces the total hire-cost. The cleaning time for wet spraying equipment is longer than that for the dry-shotcreting process. Cleaning should be carried out before longer periods of standstill on especially reserved washing-out areas. Cleaning and maintenance of the spray buffalo takes about 1,5-2 hours and is carried out by one man while the rest of the team work continuously at other excavation, protection or covering sections. By using concrete retarders cleaning need not be carried out during operations which last longer than two hours.

A further economical advantage of the wet-shotcreting process is the much lower energy consumption. The wet-shotcreting process only needs a third of the compressed air needed for dry-mix shotcrete.

The average price per m³ of sprayed concrete is approx. DM 400,- which means that the contractor receives approx. DM 4,000 per running metre on the new railway line for the sprayed concrete.

The Spray Buffalo has paid for itself after 2,000 metres.

For the application of wet sprayed concrete in the German railway tunnels the company Dyckerhoff & Widmann, Munich, has carried out extensive trials and tests comparing dry and wet sprayed concrete.

Without taking the investments into consideration, wet sprayed concrete is cheaper by an average of approx. 50 DM/m³. Assuming that a dry guniting machine is already available and depreciated, then an investment of approximately DM 850,000 will have to be paid for a new Shotcrete Buffalo.
This amount is redeemed after 20,000 m³ of shotcrete, assuming that 50 DM/m³ are saved by using the wet-mix-process. The average "paid" consumption of shotcrete is 10 m³/m tunnel - the "Shotcrete Buffalo" has therefore paid for itself after 2,000 m of use.
As an average 10 running metres of tunnel can be driven daily, the investment is redeemed after 200 working days, i.e. in less than one year thus making it a very worthwhile investment.
The same results were reported by another company which use the "Shotcrete Buffalo SMC 3/2" in the southern part of the Dietershan Tunnel. A direct comparison could not be made with a northern part where the dry shotcrete process was used.
Due to the buffalo the driving rate increases by about 30%; 10-12 m excavation and securing could be reached per day.

As large tunnels are usually driven from two directions and also in two stages on each side, i.e. roof section and bench section, theoretically four Spray Buffaloes would be needed at a total investment of 3,4 mill. DM.

However, it is possible to use only one Spray Buffalo SMC 3/2 on each side and secure the excavation of the roof section alternatively. The excavation of the bench is normally driven 200-300 m behind the roof section.

If the shotcreting of the bench section is driven independently with a second machine one should consider using a Spray Buffalo SMR 6/1 or SMR 12/1 on wheels. Alternatively it could be done with a wet shotcrete machine BSA 1002 with accessories for shotcreting.

Water glass as setting accelerator

The German Federal Railway line has accepted this as an additive. It is also very effective in combination with super plasticizer and standard concrete retarders. As with all setting accelerators, the 28-day standard strength is reduced. In 1985 important new experiences were gained under certain conditions (cement, aggregates, accelerators).

A new and important observation is that there is no further reduction in strength if an overdose of water glass is used. Laboratory and field trials by Hochtief, Holzmann, Dyckerhoff & Widmann show that despite an increase in dosage of 5% up to 15%, practically the same standard strength can be achieved.

It is also surprising that over a hydration period of more than 28 days there is no loss in strength but a further increase. Trials carried out by Dyckerhoff & Widmann have shown that sprayed concrete containing water glass reaches practically the same strength as zero concrete without additives after 56 days.

It is important to note this fact. Experience has shown that setting accelerators based on aluminium can show a loss in strength after 28 days.

As water glass compared to aluminium based accelerators achieves a faster setting with only an intermediate short loss in strength, it is a more favourable setting accelerator than other additives. This is a very pleasing result which has been developed on many large sites and also through co-operation with laboratories of the construction companies and the Otto-Graf Institute.

Further development possibilities are offered by Putzmeister with their piston dosage pumps, electronic metering devices for the effective water glass and concrete flow and the new Dynajet spray nozzle which will be launched in 1986 as a supplementary accessory to the standard plastic Betojet nozzles (VM 85067).

Summary

The wet shotcreting method with Shotcrete Buffaloes has certainly proven successful for the large sections which had

to be sprayed in the tunnels of this new railway line. This economical method, based on wide practical experience, achieves without any problems the required strength if the rules for the concrete mix and correct operation of the machines are followed.