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This year's Intertunnel (Europe) 98 (8-10 December 1998) promises to be the largest yet in this series of Swiss-based shows. For further details see p. 23.

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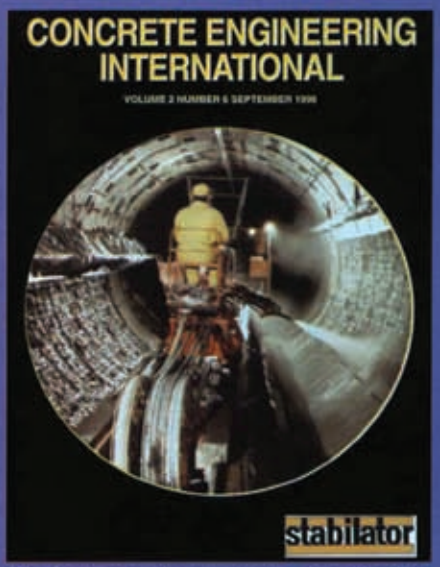

The front cover shows concrete repair work in progress on the Mass Transit Railway Tunnels in Hong Kong by Swedish based contractor Stabilator. Specialist in the fields of foundation engineering, rock support, concrete repair, post-tensioning and ground mechanics, Stabilator has been operating under its present name for more than 30 yrs and is a fully owned subsidiary of the Skanska Group. With approximately 25% of its turnover outside Scandinavia, the company has been operating in Hong Kong since the early 60s, establishing a representative office for the Far East region there in the early 80s. For the full COVER STORY see p. 24.

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UNDERGROUND

September is our underground issue, including tunnelling and piling projects, information on products and techniques as well as two conceptual projects for the future. We also have a closer look at the use of sprayed concrete for tunnelling with a special focus on the JLE project in London as it nears completion.

Thin stream conveying can also be used with a premixed wet concrete mix, but no water is added at the nozzle.

Whatever it is called, sprayed concrete is still popular in tunnelling. It remains a relatively cost-effective method of providing support. Some civils have demonstrated that in certain circumstances sprayed concrete can provide permanent rather than temporary linings.

JLE 104

Some of the most recent innovative uses of sprayed concrete have been carried out by CTW, which is currently working on Contract 104 of the Jubilee Line Extension (JLE 104) in central London. Contract 104 forms a very short part of the JLE from Green Park to Stratford but what it lacks in length is, according to the contractors, "made up for by its complexity".

The new Jubilee Line station connects with the existing Northern Line Underground station and the existing Railtrack main line and suburban line station. The Northern Line station has been extended with a new platform and associated running tunnels, and there are cross passages and connecting tunnels to the Jubilee Line.

There are five new escalator shafts, two ventilation shafts, two passenger escape shafts, a new ticket hall beneath Borough High Street, an extension to the existing underground ticket hall and a miscellany of alterations to existing infrastructure.

The majority of the running tunnels, station tunnels and ventilation tunnels were constructed with a shotcrete primary lining to provide the initial ground support. The ventilation tunnels and the running tunnel step plate junction used steel fibre reinforced sprayed concrete for the permanent lining.

When sprayed, the concrete must, of course, stick to the excavated surface, and not fall onto the floor of the tunnel. Once the concrete has 'stuck' it needs to gain strength rapidly if it is to provide the initial ground support it is supposed to do. Something needs to be done to the concrete mix to achieve these requirements.

"That something has traditionally been an alkali based accelerator", said Mr. Sharrocks. "It reacts rapidly with the cement in the mix to provide a virtually instant initial set. This instant reaction does adversely affect the long term strength and durability of the shotcrete. It has led to shotcrete being regarded as a temporary material with a design life of 2-3 yrs until some form of permanent lining is installed." According to Mr. Sharrocks JLE 104 has demonstrated that alkali free accelerators can be used to enable sprayed concrete to be considered a permanent material.

Richard Young, a Regional Sales Manager for Grace Construction Products, an international manufacturer and supplier of concrete admixtures and cement additives has a similar view. "All accelerators reduce the strength of shotcrete compared to a non-accelerated control. In my experience the new generation of alkali free accelerators have less dramatic strength loss compared to the aluminate type."

More significant is that alkali free accelerators have been widely used on such a prestigious project. Publicity might encourage their wider specification. Health and safety managers would probably prefer their use with NATM workers complaining of chemical burns, attributed to the use of aluminate accelerators.

Some civils are reluctant to use accelerators at all and most agree that the quality control of sprayed concrete has long been a cause for concern. According to Mr. Sharrocks and Ed Pilkington, a Materials Specialist who has been working for CTW on JLE 104, control at the point of application has advanced considerably over the last 5 yrs. Changes to the mix design, changes to the accelerators, the use of integrated accelerator dosing and concrete pumping plant, as well as the use of robojets have all helped to improve quality control. The training and management systems are also much better; spraying concrete is now a recognised NVQ (UK specialist skill certification) activity.

The increased mechanisation,

Table 1. Summary of concrete mix design results

	Supplier	Mix description	Free w/c ratio	Target Slump (mm)	Cement type	OPC	Cement replacement	Maximum aggregate size (mm)	Coarse aggregate (kg/m³)	Fine aggregate (kg/m³)
PERMANENT WORKS	Pioneer Willment	Underground works structural concrete	0.37	150	OPC / PFA	246	164	20	1012	767
	Tarmac Topmix	Surface works structural concrete	0.39	125	OPC / GGBS	200	200	20	1090	725
	Costain | Taylor Woodrow	Permanent sprayed concrete wet method	0.4	n/a	RHPC / PFA / MS	320	80 kg PFA 20 kg microsilca	10	875	950
	Supplier	**Mix description**	**Free w/c ratio**	**Target Slump (mm)**	**Cement type**	**OPC**	**Cement replacement**	**Maximum aggregate size (mm)**	**Coarse aggregate (kg/m³)**	**Fine aggregate (kg/m³)**
TEMPORARY WORKS	Costain | Taylor Woodrow	Temporary sprayed concrete dry method	0.45	n/a	RHPC	420		10	840	950
	Costain | Taylor Woodrow	Temporary sprayed concrete wet method	0.42	n/a	RHPC / PFA	350	60	10	840	950

enhanced control and greater skills of the operatives have led to an improvement in the quality of sprayed concrete and a far higher standard of finish. The use of robojets and associated shotcrete pumps has eliminated some of the access problems inherent in the construction of large diameter tunnels. Machines have also increased the application rate. This is a great benefit when large working areas are available for the construction of sprayed concrete permanent linings.

Recalling HEX

Quality control was also high on the agenda for the Heathrow Express (HEX) project where sprayed concrete linings have been widely used. According to Tony Deane, Mott MacDonald's Tunnelling Director, "the combination of modern accelerators and better quality control allowed 'permanent' shotcrete to be used at Heathrow."

Robojets were employed to meet the high level of quality control for the sprayed concrete required by the client, BAA plc, and contractor Balfour Beatty. However, perhaps the most significant achievement is that the HEX team has satisfied itself that fears about the long-term strength of sprayed concrete are unjustified.

Both aluminate and alkali free accelerators have been blamed for causing long term reductions in durability and strength of sprayed concrete. One way to allay such fears is to simulate ageing using accelerated tests. "A few such tests exist", explained Mr. Deane, "but they are not easy. It is a complicated long-term chemical reaction and there are disputes about how accelerated tests should be done."

In fact, the Heathrow Express tunnels are among the few projects which have used data from the latest ageing tests. Although these tests are limited in number, their results provided sufficient evidence to convince the HEX team that sprayed concrete could be used to provide permanent linings on the HEX tunnels for the 120 yr design life required. The use of sprayed concrete on this project suggests that linings made from the material should no longer be considered sacrificial.

In addition to the improved chemistry, the designers had to consider the specification of the structural reinforcement required. Rebar and steel mesh were ruled out because most tunnels contain some water which combines with air to corrode the untreated steel. "Rather than put steel in the mix in the form of rebar, we used zinc plated carbon steel drawn fibres", explained Mr. Deane. "Each fibre was 0.5 mm in dia. and 30 mm long. We believe these fibres will give the 120 yr design life specified by the client. As they are very small, they do not affect the constituency of the shotcrete when it is sprayed." Mr. Deane added that the alkali free accelerator which was used is not

"sprayed concrete has been used to eliminate the need for awkward and expensive shuttering."

expected to adversely affect the fibres. Due to the small diameter of the fibres, any corrosion which does take place will not give rise to the development of stresses which could cause cracking in the shotcrete.

The steel fibre reinforced sprayed concrete was the final finish. It was used in non-passenger areas, such as the turnouts (one tunnel widening to approximately two train widths, splitting into two tunnels so allowing trains to branch off in two directions). The very few fibres projecting from the surface were covered by a thin screed where maintenance access was required. For most of the surfaces, particularly in the roofs, nothing further was applied.

Shuttering

Sprayed concrete application has developed in parallel at Heathrow and on the Jubilee line and there are many common features. On both projects sprayed concrete has been used to eliminate the need for awkward and expensive shuttering.

On JLE 104 a lot of the tunnel lining has been carried out using conventional in-situ reinforced concrete, but there has been some creative thinking to minimise the cost of shuttering. The main Jubilee Line tunnels

Additives	Number of test results	28-day mean compressive strength result (Mpa)	28-day standard deviation of compressive strength (Mpa)	56-day mean compressive strength result (Mpa)	56-day standard deviation of compressive strength (Mpa)	Quantity used (m^3)
4.1 l Conplast SP 337	1235	51.3	5.2	58.4	5.82	28 000
5.6 l Conplast SP 337	550	55.2	7.0			26 000
20 kg Emsac 500 s microsilica 4.2 l Delvocrete stabiliser (retarder) 8.2 l Rheobild 2000 PF superplasticiser 4 % / wt Cement Meyco SA 145 accelerator	37	51	8.1		3600	

Additives	Number of test results	28-day mean compressive strength result (Mpa)	28-day standard deviation of compressive strength (Mpa)	56-day mean compressive strength result (Mpa)	56-day standard deviation of compressive strength (Mpa)	Quantity used (m^3)
7.5 % / wt Cement Delvocrete S51 activator	115	19.0	7.0	29	5.9	10 000
4.2 l Delvocrete stabiliser (retarder) 8.2 l Rheobild 2000 PF superplasticiser 6 % / wt Cement Delvocrete S51 activator	135	21	4.4	32	5.9	20 000

Investing in New Accelerators

Advances in lining materials and techniques have been demonstrated on JLE 104 at London Bridge. Dave Sharrocks charts the change from dry to wet methods and explains why a new accelerator was used.

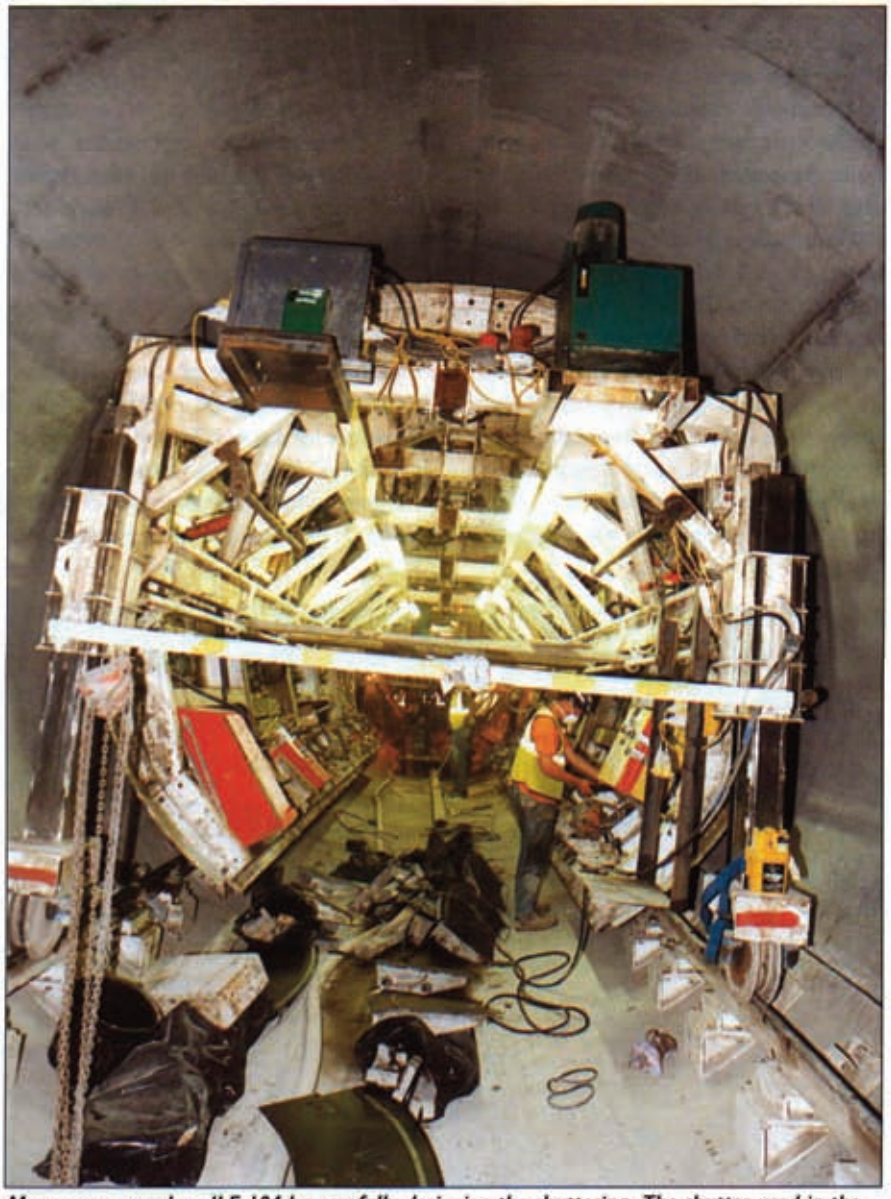
Contract 104 started to use sprayed concrete as a means of providing temporary support in tunnels in January 1994. Initially a dry process method of application was chosen. This was familiar technology as it had been used extensively in the Channel Tunnel and A27 tunnel on the Brighton and Hove bypass.

Approximately 10 000 m^3 of dry sprayed concrete was used for temporary tunnel linings on JLE 104 in tunnel diameters ranging from 2 - 11.3 m. In July 1995 a wet spray process was adopted as a means of applying temporary linings and 20 000 m^3 was applied.

In August 1996, CTW started to use concrete as a secondary (permanent) lining material applied inside a temporary sprayed lining. Significant changes were made to the sprayed concrete mix ingredients to enable it to be used as secondary lining material. In particular, Delvocrete S 51, a sodium aluminate based liquid accelerator supplied by Master Builders Technologies, was used throughout the temporary lining works. Aluminate based accelerators react instantaneously with the C_3A of the cement to form ettringite. This rapid set is a requirement when applying sprayed concrete overhead.

There is a price to pay for the decrease in setting time and that price is an overall reduction in the rate of hardening of the concrete. At London Bridge, CTW found that 28 day strength can be reduced by as much as 50% when comparing accelerated and unaccelerated mixes. Over time this difference decreases, but the periods required for recovery are years not days.

To overcome this problem of strength decrease CTW used a new accelerator called Meyco Sa 145 supplied by Master Builders Technologies. Sa 145 is an aluminium hydroxide based accelerator. The reaction between the cement and accelerator is slower and is less detrimental to the hydration phase of the C_3S, the phase of the cement hydration where



Money was saved on JLE 104 by carefully designing the shuttering. The shutter used in the 4.35 m dia. Jubilee Line Running Tunnel with the extension pieces fitted in the crown and at the bottom of the side panels is shown.

are 500 mm larger than the Northern Line ones. Instead of using two different sizes of shutter CTW designed the shutter as a number of panels with joints and hinges between panels as in normal practice. "However, instead of making the panels to the theoretical radius of the tunnel", said Mr. Sharrocks, "they were a compromise between the radius for the larger tunnel and the radius of the smaller one."

CTW used the shutter first in the smaller tunnel and then inserted extra make-up panels before using the shutter in the larger tunnel. In each case the shape of the shutter inevitability differed from the design shape of the tunnel, but the maximum deviation between the shutter profile and the theoretical profile of the tunnel did not exceed 10 mm.

Another way that CTW improved efficiency of the in-situ work on JLE 104 concerned the invert pours. "Something which is a little bit unusual was the traveller beam used to support the invert shutter", pointed out Mr. Sharrocks. "It was twice the length of the shutter. The beam straddled two pours and enabled us to fix the steel on pour two before stripping the shutter for pour one."

Conclusion

Pouring of in-situ concrete has, over the last 12 months, presented contractors working on large tunnelling

Table 2. London Bridge: tunnels and shafts with concrete primary or secondary lining	
Running tunnels: 4400 ID, 2 No., 1200 m long	Precast concrete segmental driven with Dosco Shield
Running tunnels: 4350 ID, 6 No., average 160 m long	NATM primary – in-situ reinforced concrete secondary
Station tunnels: 7700 ID, 2 No., 140 m long	NATM primary – cast iron secondary
Station concourse: 10 000 ID, 1 No., 80 m long	NATM primary – cast iron secondary
Step plate junction: 4350 - 10 000 ID, 1No., 60 m long	NATM primary – reinforced concrete /sprayed steel fibre reinforced concrete secondary
Ventilation tunnels: 6500 ID, 2 No., average 80 m long	NATM primary – sprayed steel fibre reinforced secondary
Cross passages: 4800 wide, 8 No. & various sizes 4 No.	NATM primary – reinforced concrete rectangular section secondary
Ventilation shaft: 11 500 ID & chimney 37 m deep	Bolted precast concrete segmental by underpinning & contiguous piled box
Ventilation shaft: 4 cell, 4000 x 4000, 33 m deep	Diaphragm wall & underpinning. Slipformed secondary lining
Escape shaft: 10 670 ID, 32 m deep	Bolted precast concrete segmental & partial NATM primary lining
Escape shaft: 4700 x 10 550, 26 m deep	Contiguous piled box – in-situ reinforced concrete secondary
Other shafts: 6 No., various diameters/depths	Diaphragm wall/NATM/segmental by underpinning/segmental by caisson/piled

the majority of strength is gained.

To assist in applying what is a less reactive material Sa 145 also contains polymers that cancelled out the effect of the superplasticiser in the concrete. This is an instantaneous reaction often referred to as 'slump killing'.

Sa 145 has not reduced the 28 day compressive strength by more than 15%. Another benefit of using Sa 145 was the relatively harmless pH of 5.5 as opposed to 12 for S 51. This property contributes to a much safer working environment.

Enquiry no: 3

projects with some problems they had never encountered before. However, sprayed concrete technology presents arguably the most fertile area for further improving non precast types of concrete in tunnelling.

One pass, permanent linings are now feasible. Wet sprayed concrete has made the addition of steel fibre reinforcement commercially viable in producing reinforced sprayed concrete linings.

References

1. ANDERSON J., MANNING R. F., SNEE C. P. M., 'Improvement of safety in sprayed concrete linings by good construction and thorough testing', *Proceedings from Tunnelling '97*, Institution of Mining and Metallurgy.

JUBILEE LINE EXTENSION - PROJECT OVERVIEW

CONTRACT 101
Green Park station
WORKS CONTRACTOR: *Tarmac Construction Ltd*
CONTRACT SUM: *£11m*
TECHNICAL CONTRACTOR: *L G Mouchel & Partners Ltd*

CONTRACT 102
Green Park to Waterloo Tunnels, Westminster and Waterloo Stations
WORKS CONTRACTOR: *Balfour Beatty - Amec (Jubilee Line) JV*
CONTRACT SUM: *£158m*
TECHNICAL CONTRACTORS: *G Maunsell & Partners (Civil/Structural), Michael Hopkins & Partners (Architectural - Westminster)*
IN-HOUSE DESIGN: *JLEP Team (Architectural - Waterloo)*

CONTRACT 103
Waterloo and London Bridge Tunnels, Southwark Station
WORKS CONTRACTOR: *Aoki - Soletanche JV*
CONTRACT SUM: *£64m*
TECHNICAL CONTRACTORS: *Babtie-DHV (Civil), MacCormac Jamieson Pritchard*

CONTRACT 104
London Bridge Station
WORKS CONTRACTOR: *Costain Taylor Woodrow JV*
CONTRACT SUM: *£76m*
TECHNICAL CONTRACTORS: *Mott MacDonald (Civil), Weston Williamson (Architectural)*
IN-HOUSE DESIGN: *JLEP Team (Architectural update)*

CONTRACT 105
London Bridge to Canada Water Tunnels, Bermondsey Station
WORKS CONTRACTOR: *Aoki-Soletanche JV*
CONTRACT SUM: *£70m*
TECHNICAL CONTRACTORS: *Sir William Halcrow & Partners Ltd (Civils/Structural)*
IN-HOUSE DESIGN: *JLEP Team (Architectural working details)*

CONTRACT 106
Canada Water Station
WORKS CONTRACTOR: *Wimpey Construction Ltd*
CONTRACT SUM: *£22m*
TECHNICAL CONTRACTORS: *Benaim-Works JV (Civil/Structural)*
IN-HOUSE DESIGN: *JLEP Team (Architectural working details)*

CONTRACT 107
Canada Water to Canary Wharf Tunnels
WORKS CONTRACTOR: *McAlpine-Wyass & Freytag- Bachy JV*
CONTRACT SUM: *£32m*
TECHNICAL CONTRACTORS: *Sir William Halcrow & Partners (Civil), Ian Richie (Architectural)*
IN-HOUSE DESIGN: *JLEP Team (Architectural update)*

CONTRACT 108
Canary Wharf Station
WORKS CONTRACTOR: *Tarmac-Bachy JV*
CONTRACT SUM: *£31m*
TECHNICAL CONTRACTORS: *Posford Duvivier (Civil/Structural), Sir Norman Foster & Partners (Architectural)*

CONTRACT 110
Canary Wharf to Canning Town Tunnels, North Greenwich Station
WORKS CONTRACTOR: *McAlpine-Wyass & Freytag ñ Bachy JV*
CONTRACT SUM: *£71m*
TECHNICAL CONTRACTORS: *Mott MacDonald (Civil-tunnels), Benaim-Works JV (Civil/Structural-station), Alsop & Störmer (Architectural)*
IN-HOUSE DESIGN: *JLEP Team (Architectural - below ground structures)*

CONTRACT 111
Canning Town to Stratford formation, Canning Town, West Ham and Stratford stations
WORKS CONTRACTOR: *John Mowlem Construction plc*
CONTRACT SUM: *£49m*
TECHNICAL CONTRACTORS: *WSP Consulting Engineers plc (Civil-Canning Town station; Structural and Architectural throughout), Mason Pittendrigh (Civil-formation, West Ham Station and Stratford Station)*

CONTRACT 112
Stratford Market Depot
WORKS CONTRACTOR *John Laing Construction Ltd*
CONTRACT SUM: *£18m*
TECHNICAL CONTRACTORS: *Acer Consultants Ltd*

CONTRACT 113
Trackwork
WORKS CONTRACTOR: *Tarmac Montcocel TR JV*
CONTRACT SUM: *£20m*
TECHNICAL CONTRACTORS: *JLEP Team (subconsultants Acer Consultants Ltd, Getzner Chemie GmbH, R T James and Partners)*

CONTRACT 114
Service Control Centre
WORKS CONTRACTOR: *John Laing Construction Ltd*
CONTRACT SUM: *£4m*
TECHNICAL CONTRACTORS: *Arup Associates*

CONTRACT 115
Canary Wharf Station Advance Works
WORKS CONTRACTOR: *Christiani-O'Rourke JV*
CONTRACT SUM: *£8m*
TECHNICAL CONTRACTORS: *L G Mouchel & Partners Ltd*

CONTRACT 117
Stratford Station Redevelopment
WORKS CONTRACTOR: *Trafalgar House*
CONTRACT SUM: *£15m*
TECHNICAL CONTRACTORS: *Acer Consultants and Ove Arup and Partners*