Shotcrete for Underground Support in Brazil

By Pedro Boscov

Shotcrete has been used in Brazil since the 1950s, mainly in minor works of slope stabilization and repairs in concrete structures. It was only in the 1960s that it started to be used in underground work. The Furnas Hydroelectric Project had some sections of its diversion tunnels, where the ground was a highly fractured and weathered quartzite, lined with steel bar reinforced shotcrete. The good performance in Furnas led many other hydroelectric projects to adopt shotcrete lining in their tunnels, replacing previously specified cast concrete.

In 1972 the New Austrian Tunnelling Method (NATM) was introduced to Brazil in the exca vation of 12 tunnels on the Sao Paulo-Santos Imigrantes Highway (cross-section 150 m^2 (1,615 ft^2), total length 3,820 m/12,540 ft.) where about 17,000 m^3 (22,200 yd^3) of dry-mix shotcrete were used as support lining for the excavation. Another important project at that time (1976-1983) was the railroad linking Minas Gerais State to Rio de Janeiro and Sao Paulo, where 90 tunnels with a total length of 97 km (60 mi.) consumed about 400,000 m^3 (523,000 yd^3) of dry-mix shotcrete in support lining and also in final lining in small sections.

Upon completion of those projects NATM came of age in Brazil. Many large and important projects were undertaken by Brazilian contractors in Brazil and abroad, some of them quite remarkable, as the Lisbon Metro, for example. In spite of the large amounts of shotcrete employed, there was a high variation in quality, probably influenced in part by a lack of research work and also of appropriate technical standards. In 1988 CBPO, a civil construction contractor, invested in a comprehensive research program aiming at improvement of conventional shotcrete and to develop an advanced technology using non-conventional materials in Brazil at that time, such as silica fumes and fibers, to be used in shotcrete for support and final lining in tunnels. The research and development program was carried out by the Polytecnic School of Sao Paulo University on a US$500,000 funding granted by CBPO. In 1993 another R&D program was developed in partnership with Vulkan-Harex, a German manufacturer of steel fibers in Sao Paulo, addressing particularly steel fiber reinforced shotcrete (SFRS).

The R&D programs resulted in a remarkable improvement in shotcrete quality and spraying techniques, such as dry-mix pre-wetting, (by feeding the water at high pressure in the hose at a point 3 to 5 m (10 to 16 ft.) from the nozzle), new nozzle shapes and nozzleman training. In 1991 the research teams started preparation of shotcrete technical standards still non-existing at that time. All the research work was performed in the University laboratories and inside tunnels under construction. The University researchers benefited from the R&D programs as they had an opportunity to develop Master and PhD theses on up-to-date technology, to have duly rewarded extra-curricular work, to participate in seminars and congresses as authors of papers presented, and to grasp directly the operational methods of an important civil contractor.

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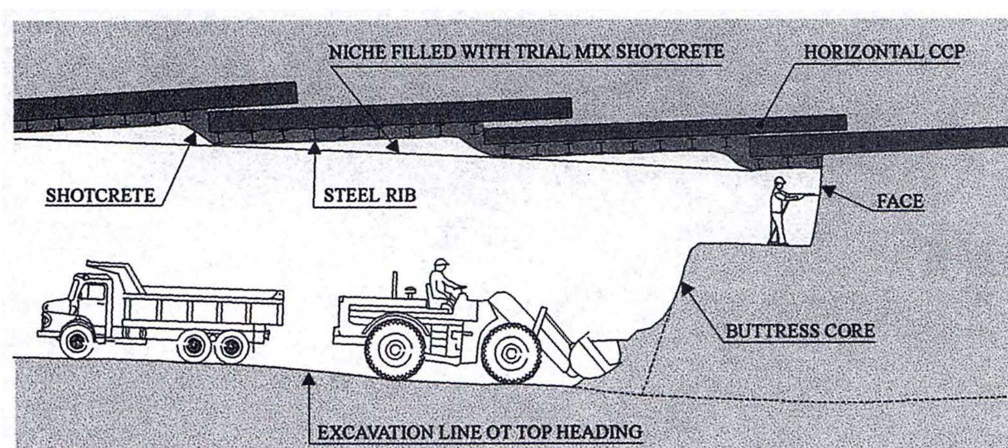
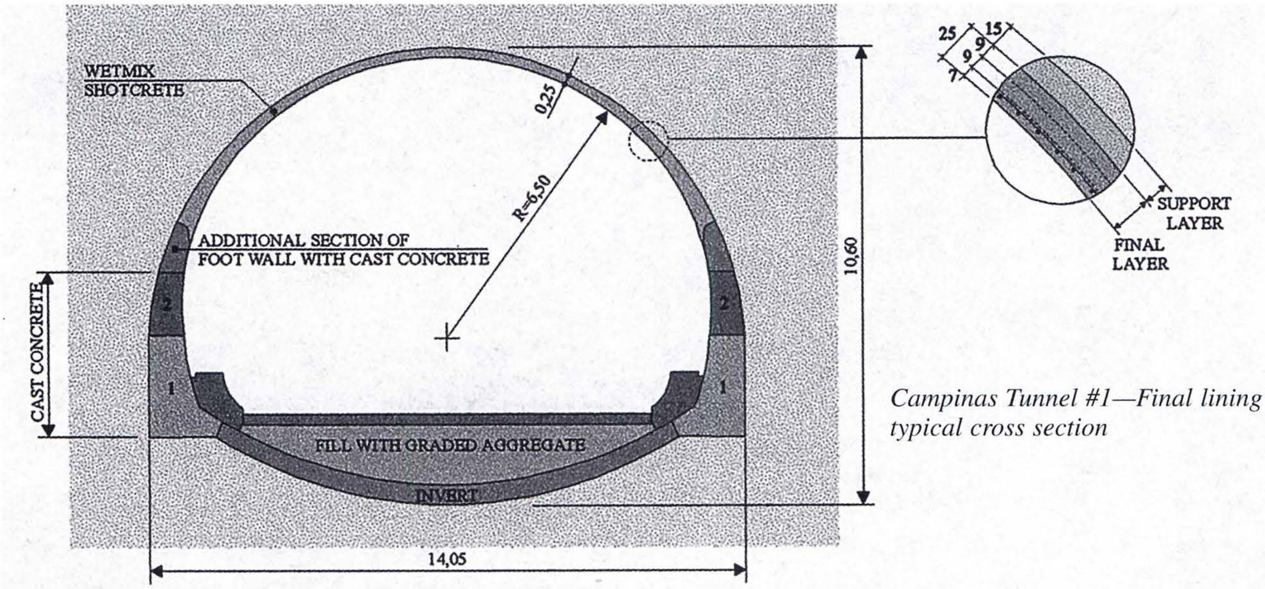


Campinas Tunnel—Ground stabilization with horizontal jet-grouting (CCP)



Campinas Tunnel #1—Final lining typical cross section

Equipment

In the beginning, dry-mix shotcrete equipment used in Brazil was made by MEYCO, Aliva and Este (Brazilian), with output capacities of 3 to 6 m^3/hour (4 to 8 yd^3/hr.) and spraying nozzles manually operated. Wet-mix shotcrete equipment included Aliva, Schwing, and Putzmeister with capacities of 6 to 30 m^3/hour (8 to 40 yd^3/hr.) and spraying nozzles operated either manually or by robot.

Recently Meyco introduced wet-mix equipment in the Brazilian market. In 1985 Aliva introduced the Duplo machines which can produce either dry or wet mixes with a capacity of 6 to 20 m^3/hour (7 to 26 yd^3/hr.) for use in the Sao Paulo tunnels. In 1993 the Brazilian manufacturer Este launched its double machine, capable of spraying either wet or dry-mix shotcrete.

Case History Examples

The case history examples summarized below are important, not on account of the size or cost of the project, but for their contribution to tunnelling development in Brazil using NATM.

Campinas Twin Road Tunnels

These tunnels, 125 m^2 (1,350 ft^2) in cross-section and 300 m (1,000 ft.) in length, were started in January1987. Work was stopped from May 1988 to September 1989 due to financial problems. The ground comprised of sandy and silty soils and water table above the tunnel had been stabilized by horizontal jet-grouting. The top heading was already completed in Tunnel #l when the work stoppage occurred. The original design specified the final lining with cast

Campinas Tunnel - Ground Stabilization with Horizontal Jet-Grouting (CCP)
Drilled cores from the finished structure showed the following results.

	TUC*	PAU-d**	PAU-s***
Density (kg/m^3)	2.24	—	—
Density—boil (kg/m^3)	2.26	2.28	2.26
Absorption—immersion (%)	7.43	—	—
Absorption—immer. Boil (%)	8.17	7.86	8.49
Absorption by capilarity (%)	2.70	2.81	2.54
Penetration under pressure (cm)	4.10	4.26	5.30
Void ratio	17.33	17.72	17.95
Compressive strength 28 days (MPa)	21.10	22.56	20.85

*TUC—Tucuruvi Tunnel
**PAU-d—Pauliceia Tunnel - double track
***PAU-s—Pauliceia Tunnel - single track

NOTE: Presently all underground shotcrete is specified with a compressive strength 30 MPa concrete. To resume the work in Tunnel #1, City Hall demanded a less costly solution for the lining, to comply with its budgetary capacity at the time. The proposition to replace cast concrete with wet-mix shotcrete, which would save the cost of the formwork, was accepted by the owner only after it was proved to be technically reliable by the research team mentioned above. Up until this time only small cross-section tunnels had been lined with wet-mix shotcrete.

The trial mixes were tested in the tunnel root filling the niches of the jagged surface formed by the sloped jet-grouted columns with 320 m^3 (420 yd^3) of shotcrete. A range of different types of cement and admixtures available in the Brazilian market were used to establish the best mix for the specified strength of 18 MPa (2,600 psi) at 28 days, with less rebound and fewer fall-downs for 90 mm ($3\frac{1}{2}$ in.) thick spraying layers. The equipment used was a pump and a robot installed on a loader. The equipment had 20 m^3/hour (26 yd^3/hr.) capacity, but spraying was kept below 8 to 10 m^3/hour (10.5 to 13 yd^3/hr.) to allow for better surface finishing and to prevent fall-downs. The final thickness of 250 mm (10 in.) was executed in two 90 mm ($3\frac{1}{2}$ in.) layers and one of 70 mm ($2\frac{3}{4}$ in.) thick layer to cover the second layer of welded steel mesh. The final lining took 2,500 m^3 (3,300 yd^3) of shotcrete. Follow-up and quality control testing were made by testing drilled cores, mix reconstitutions, and cement chemical and physical analyses.

Mix	1:2.1:1.6
Mortar ratio	0.66
Sand fineness mod.	2.3
Coarse aggregate	9.5 mm ($\frac{1}{4}$ in.)
Cement CP-IIE-32	450 kg/m^3 (760 lb./cyd^3)
Admixture	Sigunit L 20
Density	2250 kg/m^3 (*) (3,800 lb./yd^3)
Absorption-immers.	8.0 % (*)
Absorp. immer boil	8.6 % (*)
Penetration (pressure)	3.7 cm ($1\frac{1}{2}$ in.)
Void ratio	17.9
Permeability	<1 x 10 cm/s (*)
Compressive strength	22 MPa at 28 days (3,200 psi)

(*) Drilled cores of the structure

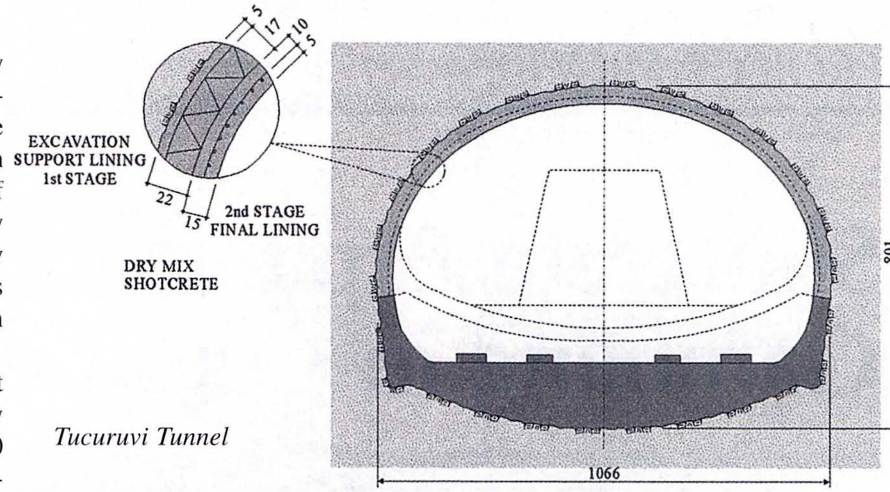
Campinas Tunnel #1

Final Lining Typical Cross Section

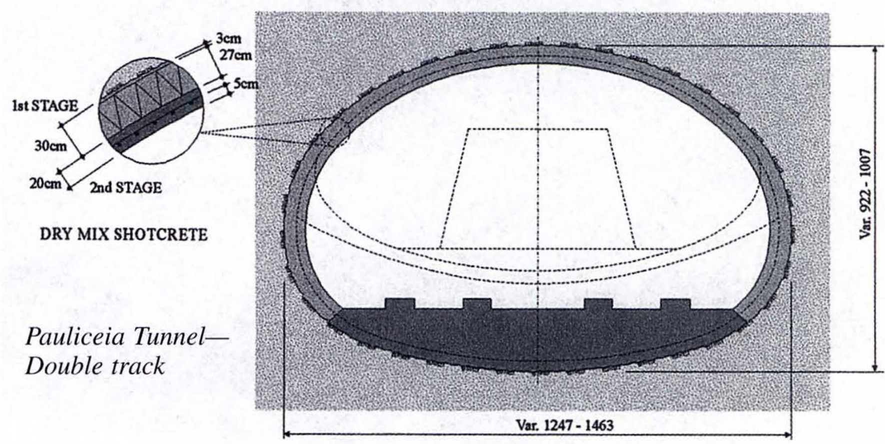
Sao Paulo Metro—Tucuruvi and Paulicaia Tunnels

These large tunnels are located in the north extension of the North-South Line of the Sao Paulo Metro. The ground is medium to hard clay and no soil stabilization was needed. The tunnelling method was NATM, with shotcrete + steel mesh in the smaller cross-sections (single track) and truss steel ribs in the larger cross-sections (double track). All the excavation was made in two stages: top heading and benching. Also in this case the dry-mix shotcrete final lining was adopted in view of the good results obtained in the R & D program. The total amount of shotcrete used in the support and final linings was 12,250 m^3 (16,000 yd^3).

Mix	1:2.21:2.14
Mortar ratio	0.60
Sand fineness mod.	2.8
Coarse aggregate	6.35 mm ($\frac{1}{4}$ in.)
Cement ARI-RS	415 kg/m^3 ($10\frac{3}{4}$ lb./yd^3)
Admixture Sigunit 22	3 %



Tucuruvi Tunnel



Pauliceia Tunnel—Double track

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