NATM success in Brazil

Sir, I am writing in connection with the BTS debate 'NATM is not appropriate for use in London Clay'(*T&T,* June '94, p22). Debates are useful tools for expanding knowledge in a given subject, I would like to address some points arising from the BTS debate.

Statements like "if NATM were specially suitable for London Clay it would now have been much more extensively used" do not reflect the fact that, in any area of human knowledge, innovations are resisted until their value is proved beyond reasonable and unreasonable doubts. Acquiring experience with the method and fine tuning it for optimum performance demands time, and, meanwhile, earlier established methods may present superior performance according to some traditional criteria.

The truth is that it is the name NATM that is unsuitable, not the method! A more appropriate name would be SEM (Sequential Excavation Method), as proposed by Professor Eisenstein some years ago. Sir Alan Muir Wood attempted to address the fact that a large source of ground losses (and thereby increased surface settlements) is a result of the ground moving inwards at the face. This feature can be improved in NATM using tunnel face reinforcement with jet grouted columns, soil anchors or other devices[1]. Sir Alan correctly emphasised the importance of using NATM where appropriate (e.g. varying cross sections and, especially, lower cost).

Remarks like "shotcrete . . . is a poor quality concrete which would allow steel to corrode" can be true, but today there is enough experience accumulated to enable any contractor to manufacture a high quality shotcrete if he wants to. As cited in the debate, addition of steel fibres to shotcrete improves safety, speed and economy. I should add that addition of fibreglass and silica fume can also result in remarkable improvements.

As a final comment, NATM has been a great success on the Channel Tunnel (as noted by one of the debaters), and the Heathrow Express Link trial tunnel is an impressive example of good results from NATM construction in London Clay.

As a complement to the debate contents, I would like to present some data regarding NATM tunnels built in São Paulo, starting in the '70s. NATM excavation techniques, at that time, were already in use in non-urban areas. To my knowledge, the first urban application of NATM excavation techniques was made in Germany during the '70s. The successful application of NATM in some German cities motivated São Paulo Water Company to use it at the ABV tunnel[2]. This experience led to the design and construction of an NATM double track tunnel by the São Paulo Subway Company (1984), with great success from the technical and economic points of view. This experience demonstrated that it was possible to construct large cross section tunnels in the city using NATM techniques in place of cut-and-cover methods.

As a consequence, construction of the Paulista Line was initiated by São Paulo Subway Company in 1988-1989, with four stations (Brigadeiro, Trianon, Consolacão and Clinicas) being built using NATM techniques. These stations were excavated in just two years, with no disturbance to the busy Paulista Avenue surface traffic as the tunnels portals were located in quiet streets nearby. The Paulista Line represents a milestone regarding NATM construction in São Paulo City. These NATM tunnels achieved high production rates (up to 13m per day) when high capacity roadheaders were used[3]. Current NATM tunnels built in São Paulo City also use shotcrete as secondary and permanent lining, an unusual practice in other countries until some years ago.

NATM tunnels in stiff clay

Another example (Pinheiros Tunnel) was built in a stiff, fissured clay (SPT blow count around 40), very similar to London Clay as regards excavation behaviour and geotechnical parameters. This tunnel was excavated under a large river, with a soil cover of only 4m. The successful completion of the Pinheiros Tunnel motivated the construction of a second one under the same river (begun in May '94) and two other tunnels (Sto. Amaro Tunnel, due for completion in Nov '94; and Ibirapuera Tunnel, to be completed in July '95). They are all being excavated in stiff, fissured clay.

Excavation performance parameters for the tunnels above were very good indeed. The Pinheiros Tunnel has shown remarkably good behaviour (e.g. maximum surface settlement of 12mm and ground loss of 0.4 per cent). Distortions induced by the excavation are of particular interest, since damage potential to structures and utilities nearby are strongly correlated with transversal and/or longitudinal distortions. Pinheiros Tunnel induced maximum distortions of 1:1500 (transversal to the tunnel axis). These distortions were small enough not to cause any damage to overlying buildings above the crown at the opposite side of the river, just after the crossing.

Information regarding lining design and performance are scarce in the literature. Problems arise in assessing tunnel lining performance, as lining loads are not routinely monitored. Some tunnels built in São Paulo City had their lining loads evaluated using mini-flat jack tests[4]. This kind of monitoring has shown that lining axial stresses are equivalent to 30 to 50 per cent of in situ stresses in hard and stiff clays. Soil arching significantly reduces lining stresses, as expected, and this effect is much more intense in stiffer soils. Taking this effect into account can lead to thinner and more economical tunnel linings. Also, it has been detected that longer invert installation delays lead to smaller lining loads, confirming previous theoretical studies[5].

I would also like to add that, besides São Paulo City tunnels cited above, the Brasilia Subway System is now being completed, with 6.5km of NATM tunnels. These double track tunnels were built in soft, porous clay (SPT blow count of 2 to 4), showing collapsible behaviour. No structures or utilities near the tunnels suffered any damage from the excavation, and construction proceeded successfully.

Another case worth mentioning is São Paulo City Fourth Subway Line, to start in 1995. Design is being finished, with 6km of tunnels (4km will be using NATM), and eight subway stations using NATM. Stations and tunnels will be built under a ground cover of 30 to 40m and high water pressures (the water table is 5-10m below surface).

These challenging underground works will make extensive use of ground treatment, drainage and dewatering. The use of NATM concepts in the design reflect the degree of confidence the São Paulo Company has in the ability of these techniques to deliver large cross section underground urban excavations safely, on time at low cost.

References

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Yours faithfully, Dr Roberto Kochen,
University of São Paulo,
Department of Civil Engineering,
São Paulo, SP, Brazil.