ABSTRACT: For construction of underground railway systems in dense urban environments the main geotechnical issues nowadays concern geotechnical risks that arise from the ground conditions and the common need to complete the construction as soon as possible. Having worked on Mass Rapid Transit System (MRTS) construction in South East Asia since 1975, the author sets out and illustrates with examples current practice for mitigation of geotechnical risk and for planning rapid rates of construction.

1. INTRODUCTION

There are many large cities in South East Asia and there are many infrastructure projects. India is no exception and has many cities each with millions of population and a growing demand for infrastructure.

Characteristically densely populated areas comprise narrow streets that are usually congested. There can be a pressing need for Mass Rapid Transit Systems (MRTS) but no room for construction vehicles. Narrow streets limit the width for construction. Tight corners and orthogonal junctions are incompatible with tunnel driving radii and railway operating radii. Tunnels turn out beneath buildings.

Fortunately in many cities in India there has been little construction below ground previously. Provided that the piles can be identified and avoided, the remainder of the natural ground, as opposed to fill, generally contains no artifacts.

Many of the older areas have a complexity of structures often in the range of 1 to 5 storeys. Within the influence zone of one underground station there could be up to 1,000 structures that could be affected by the works. A key element of underground construction is monitoring of structures and prevention of damage and addressing concerns of local inhabitants.

2. REDUCTION OF GEOTECHNICAL RISK

It is well established that underground construction has a big geotechnical risk, it leads to big claims, and the big claims lead to expensive law suits.

Whereas structures built above ground can be built to order, below ground there are greater uncertainties and the consequence of encountering something that is unexpected can be very severe. For example a face collapse, or a main bearing failure at the front of a Tunnel Boring Machine (TBM) that is 150 m long, means cutting a siding and backing the TBM out of the way before any plant can reach the face to recover the collapse or to install a new bearing. In addition to the costs, some 6 months of production could be lost.

3. GROUND INVESTIGATION (GI)

It goes without saying that unless there is enough GI and it is properly interpreted then the exercise is wasted.

A few decades ago in U.K. and U.S.A. it was commonly accepted that GI for tunnels was sufficient if vertical holes were spaced of the order of 100 m apart. Assuming a diameter of 100 mm the borehole only sampled less than 1/50 of the width of ground for a railway tunnel and only 1/1000 of the length.

For some tunnels in urban areas in mixed geology boreholes can be as close as 20 m whereas in the Taipei basin, below the fill, the interbedded layers of clay (even numbered) and sand (odd numbered) do not change substantially between nearby sites and for some projects boreholes could be more widely spaced.

In Hong Kong, the Government has set up an archive of old GI reports. On a recent tunnel project we were able to obtain copies of borehole logs for over 32,000 boreholes. This provided a fund of information. On the other hand, we have just completed Horizontal Directionally Controlled Coring (HDC) for 26% of the length of 19.6 kms of deep sewer tunnels. High percentage of recovery has provided a lot of information about the ground prior to tunnelling. The combination of a large number of records of vertical boreholes, a number of inclined boreholes and HDC provides a lot of geological data which reduces the overall geological risk.

There is no doubt that accurate and representative GI is a fundamental need for any underground project. Unless GI is properly interpreted into a worthwhile geological model then
the exercise can be worthless, or worse, it can be misleading and consequentially very expensive.

4. PERFORMANCE DATA

In the past Contractors could build up their experience of the ground conditions and of performance of their equipment and labour, and were jealous to guard their knowledge for commercial reasons when tendering the next contract.

However, in recent years Information Technology (IT) has permitted the recording, sorting and analyzing massive amounts of performance data in the field. In Hong Kong performance data for the first stage of the deep sewer tunnels was stored on a Tunnel Data Management System (TDMS). This includes the geological logs for the ground that was encountered, rates of progress, logs of probe holes, rates of inflow of water, amounts of grout used, and residual rates of inflow after grouting.

Detailed information of this kind permits a quantification of the time and effort taken for tunneling activities which can be classified according to the types of ground. Such data can be used for estimating rates of production and costs for similar work in similar ground for new projects. As more work is undertaken below ground and the data is collected, the greater is the data base and the wider is the application of the data. By taking into account detailed records and performance data the uncertainty regarding performance can be substantially reduced and geotechnical risk can be reduced.

5. CONTRACTUAL PROVISIONS

5.1 Lump Sum or Re-measurement

For purposes of financial planning, many clients prefer awarding lump sum contracts. Lump sum contracts can be fine for manufacturing by which I include construction above ground construction where there are few unknowns.

Re-measurement contracts are often used for piling whereby the contractor gets paid for what he builds. For example re-measurement can be according to the length of the piles, or the lengths in different categories of ground such a soil or rock, or for overcoming obstructions. However, for underground construction where the impact of changed ground conditions can be far more severe, clients in many cases have been reluctant to shoulder all of the geological risk. The Client’s concern is that in accepting geological risk the Client may find that he runs out of money.

Experience tells us that tendering on a basis of awarding a lump sum contract to the lowest bidder leads to a contract with low provision for risk of any kind and, in particular, it often results in inadequate funding for the geological risk. Unless large contingencies are reserved, on a lump sum the Contractor may run out of money and on re-measurement the Client may run out of money. Neither result is satisfactory. The geotechnical risk is not adequately provided for and all too frequently large claims arise. Take only one example; according to the Press, nine years ago in Hong Kong a financial settlement of about UK$90 million was made on a deep tunnel project.

6. GBR

One of the responses of the industry has been to design contract documentation to reduce exposure to risks. Driven by an intention to reduce disputes, Geotechnical Baseline Reports (GBR) have come into use in some countries. Their purpose is to make clear what is included within the expectations of the contract, whether it is a lump sum or schedule in the Bill of Quantities, and what is not included in the expectations of the contract and should be reimbursed by another means. In a GBR the types of ground are baseline. For example it might be the case that a tunnel is expected to be wholly in rock. If soil is encountered, it is deemed to be a changed ground condition and the changed conditions is dealt with accordingly. For example the Contractor may be entitled to more money or more time or both. The GBR is not only informative for the tenderers but it also provides a clear basis for resolution of claims. By providing a clear statement to the Tenderer of what he is to base his price on, and how changed conditions will be dealt with under the contract, the risk of costly disputes arising from geotechnical risk is considerably reduced.

7. QUALIFIED SUPERVISION

Underground construction requires skill and expertise. Mistakes happen during construction. For many projects, including deep excavation, in Hong Kong, qualified supervision is a requirement by Geotechnical Engineering Office (GEO) of the Government. There are three levels; full time supervision on site by a Chartered Engineer; regular site visits by a Senior Engineer and input at critical stages from a specialist. There are two roles, one role is to verify the geotechnical assumptions made in the design, the other role is to ensure that the works are progressed in accordance with good practice. Qualified supervision is aimed at reducing geotechnical risk.

8. OBSERVATIONAL METHOD

The observational method is not new. It was introduced by Ralph Peck some, 50 years ago. The objective is to reduce uncertainty, and to control the works. The method commences with a prediction as a baseline for performance, monitoring of the work, and qualified supervision to interpret the monitoring and conduct back analyses if performance differs from the expectations. There also needs to be sufficient provision lest the site conditions turn out to be worse than expected and contingency measures are adopted and the methods being used are altered accordingly.

On the other hand, if the conditions on site turn out to be better than expected, some economies can be achieved. First example of the use of the observational technique in Hong Kong was in 1976 at Choi Hung Station when the deflections of
diaphragm walls were less than expected and a back analysis of the deflections and strut forces allowed the deletion of the lowest level of struts which not only saved the cost of the struts but also permitted normal plant to be used at faster rates of production instead of reduced headroom plant that had been planned, see Figure 1.

9. FAST CONSTRUCTION

It is commonly held that time is money. Moreover construction of infrastructure is often clouded by politics and prestige may be attached to early completion. At times political interference can lead to setting impossibly short programmes for construction. Notwithstanding these two reasons, engineers usually aim for quick construction.

10. BIG PLANT

Given no other restraints, rates of production and unit operating costs are generally better when using large plant. For example the earthworks for Chek lap Kok Airport included 200 tonne trucks, the largest at the time that were in regular production, see Figure 2. Currently Tunnel Boring Machines (TBMs) of the order of 15 m in diameter are in use. Near Shanghai, the Chong Ming road tunnel is designed to accommodate three lanes of road. The 7.5 km long drives were completed at average rates of up to 510 m per month at a diameter large enough to accommodate an underground railway station comprising two rails and a narrow platform, see Figure 3. In fact the design was modified to accommodate rail transport in the void beneath the road deck. This tunnel was driven under the sea so face loss and subsidence of the ground was not critical. Closed face TBMs are heralded as reliable means of preventing settlement by controlling face loss. Controlled settlements during construction are reported but these can be at the cost of high face pressures which leave behind excess pore water pressures which drain away and result in on-going consolidation settlement. It is found that subsequent settlements can be sometimes double the immediate settlements. TBMs are designed for mining in urban areas and can result in rapid rates of tunnelling but estimates of settlements due to their operation should be regarded with caution.

For large projects, especially in urban areas, hauling away the excavated materials can be a problem. For the proposed High Speed Rail Terminus in Hong Kong it is proposed to use road going trucks on site for the majority of the haulage, about 3 million cubic metres, from a large pit where bottom up construction will commence.

11. PLANNING

Removal of spoil is always difficult in busy urban areas. Planning for the West Island Line in Hong Kong adopted long adits for removal of spoil to close to a barge loading point. The adit could be used later as a long pedestrian subway entrance.
Planning for the Delhi Metro at Chawri Bazaar considered mining the station because the area was too busy for removal of spoil and import of building materials. A mined railway station is shown in Figure 4.

Similarly in Singapore, Contract 825 Bras Basah Station of the Circle Line 1, required 35 m deep excavation in mixed soil conditions close to historical monuments. This was achieved safely and with minimal impact on the monuments with careful use of diaphragm walls up to 1.5 m thick, ground treatment, top down construction and close monitoring and use of recharge wells when required.

Not all planning can adopt such fast methods. For example, at North Point Station in Hong Kong mining in rock beneath operating station could only be carried out during shut down of the system at night and was necessarily slow.

12. ORIGINAL IDEAS

Geotechnical Engineers can also achieve value with innovative ideas. This can be especially effective when working with a Contractor for Design and Construct contracts. For example, it is now commonplace but in 1975 in the early years of MRTS construction contractors proposed construction by cut and cover from the top down to save the costs of strutting and provide a robust means of strutting the walls apart. Likewise adopting an open roof using main beams to span between the walls permits ease of access for plant and shortens the time for construction. Contractor’s design can optimize the design and construction methods and lead to savings in time for construction.

13. CONCLUSION

For infrastructure projects involving underground construction, good GI goes a long way in mitigating the geotechnical risks. Geotechnical Baseline Reports could be used as a useful tool to balance the risk sharing between Employer and the Contractor.

Adoption of observational methods backed by a well-conceived monitoring regime and responsive supervision helps in mitigating the geotechnical risks and achieve faster construction rates.

Rapid progress on complex urban infrastructure projects can often be achieved using the right plant and equipment with innovative construction schemes.