41 Years of Mass Transit Underground Railways

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ABSTRACT: In 1975 many cities in South East Asia were becoming congested and few had underground railways. Now several cities have underground railway systems comprising several lines and many stations, some extend above ground. Currently underground railways are being built or are being extended in many cities in South East Asia. Construction projects are often large including several sections of tunnels and stations in one contract. This paper reflects on the early days of pioneering and on some of the changes that have taken place in the planning, design, and construction of underground Mass Transit Systems during the last 41 years.

KEYWORDS: Underground, Railway, Tunnels, Excavations, Planning, Design, Construction.

1. INTRODUCTION

Construction of new underground railways, or extensions of existing systems, is widespread throughout South East Asia. There are dozens of projects and thousands of engineers are engaged in planning, designing, and building underground railway structures. There are many different skills involved. Geotechnical engineers are involved in nearly all stages including feasibility studies, planning studies, route evaluation, design, preparation of contract documents, risk evaluation, monitoring and supervision of construction, evaluation and resolution of claims. Because of the large scale of some of the projects and the short times allowed, teams of engineers are deployed and even specialized geotechnical engineers become further specialized, say in site evaluation, in numerical modelling, in risk assessment, in instrumentation and in other skills.

41 years ago, the industry was in its early stages in South East Asia. There were few underground railways under construction and the resources that were available were also few. Since then many changes have taken place that would be worthy of a book to describe. This paper addresses some of the significant milestone events along the way that have resulted in the geotechnical practices of today.

2. HONG KONG MTR

2.1 Early days

The 1975 milestone in Hong Kong was the start of high standard mass transportation system with smooth welded rails and air-conditioning in a city with then open air busses and congested streets. Planning a smart new system commenced about 1970 and negotiations started with a single consortium to build and equip a new system with three lines and eight car trains. However increases in prices of oil and steel led to a reconfiguration for a Modified Initial System (MIS) of one line from Kowloon Bay to Central to be built and equipped by a series of tenders including inviting local contractors to bid for civil engineering works. At the time diaphragm walling had been completed for only one basement in Hong Kong. Earth Lateral Support (ELS) design generally was based on Terzaghi and Peck's trapezoidal soil pressure diagram and a lot of computation was carried out by hand. A variety of ELS systems were adopted. Unusually Choi Hung Station and Diamond Hill Station used hand dug caissons to build permanent walls and plunged columns, see Figure 1. Paul Y Construction were able to mobilise more than 1,000 workers to concurrently excavate 1.5m diameter shafts for station walls and for constructing columns for top down construction.

The use of hand dug caisson was severely restricted due to the consequences of pneumoconiosis from breathing the dust when drilling silicaceous rocks such as Granite.

Soil to structure interaction analysis was pioneered using hand calculations and the Maunsell computer program "DIANA" was written in 1976. The use of computers has since increased and 2-D and 3-D finite element models are commonly used now.

Subsidence of buildings on differing foundations notably in Mong Kok in the early days led to tight control over dewatering of excavations and strict limitations on lateral movements of ELS during construction, of commonly 25mm which have remained ever since.

The early tunnels were mined using open shields and air pressure. Subsequently enclosed shields have been used with much better rates of performance.

Figure 1 Hand dug caisson walls

2.2 Financial model

The Mass Rapid Transportation Corporation (MTRC), as it was, developed a reputation for resolving claims early and delivery on time. Revenue from the very busy MIS is reported to have paid for the costs for construction in just a few years and the system has been steadily expanded. The Tsuen Wan line earned less revenue and MTRC initiated the use of rights for associated property development to finance the construction of the Island Line. This financial model has been exported to other countries.

Initially design checking in principle was carried out by Consultants engaged by MTRC, then Design and Build Contractors were require to engaged Independent Checking Engineers (ICE). For many years MTRC was exempt from the provisions for Private Building under the Buildings Ordinance but two cases of mal practice on construction sites dubbed "short piles", as well as on other sites for other developers, led to engagement with the Buildings Department (BD) and now formal submittal of record plans and records of verification are required by the BD.

2.3 Recent developments

In recent years, as the railway systems have expanded, construction of underground railways has become more complicated. Congestion in city areas and the need for new lines at different levels and interchanges have presented problems. For example, current construction will result in a multi-level interchange at Admiralty Station that will include the Tsuen Wan Line, the Island Line, the Sha Tin to Central Link and the South Island line. Because of increasing complexity a lot of costs have increased. However with some ingenuity savings can be made. For example, recently planning was carried out to construct a grade-separated interchange at Diamond Hill Station whereas the original intention was an at-grade interchange with cross platform connections. The original construction included lateral walls of steel beams and concrete "jack" arches that were intended for demolition to permit widening. A study found that with some minor improvements these temporary walls could remain as permanent walls, Chin et al. (2015).

Not only has complexity increased but also scale has increased. The High Speed Rail that is under construction in Hong Kong includes a terminal station some 240m wide and 660m long and about 30m deep being built on reclaimed land as shown in Figure 2. This is a very complicated site with many concurrent contractors. Cheuk et al. (2013)

Figure 2 West Kowloon Terminus (after Cheuk et al)

There is increasing construction of caverns mined in rock. The first was for Tai Koo Station built in 1985, Sharp et al. (1986) and recently the University Station has been completed in a mined cavern.

3. SINGAPORE

3.1 Early days

The start of underground railways (MRT) in Singapore closely followed Hong Kong in 1978 and the two systems have expanded almost in parallel. Whereas in Hong Kong the railway has largely followed corridors of populated areas, in Singapore there has been a policy to establish a network with an objective of serving the whole population providing a maximum distance of 500m to a station for everybody.

In Singapore the first technical issue was when ground water which was identified as a problem when draw down was found to follow sandy paleo-river valleys in the Quarternary Kallang Formation. However the old two-storey shop houses in these locations were found to be tolerant of quite large subsidence and whereas groundwater has been controlled, making use of recharge systems at times, lateral deflection of ELS during construction were more relaxed than in Hong Kong and lateral deflections of ELS of the order of 100mm were allowed for many years.

For passenger safety, screen doors on platforms were adopted quite early in Singapore and copied soon after in Hong Kong.

3.2 Problems

Singapore MRT encountered more soft ground and bored tunneling methods have developed. Slurry Machines and Earth Pressure Balance Machines have been used for boring tunnels since about 1980. There was a "bleak period" when escapes of slurry to the surface and local potholes due to loss of ground occurred frequently. Fortunately those problems have been overcome and for many years dozens of TBMs have been working more reliably including tunnels for drainage, sewerage and electrical power cables.

By 2000 there was over 20 years of experience of constructing underground railways in Singapore. The numbers of accidents during construction were few. However in 2004 there was a massive collapse of a 30m deep excavation for a cut and cover tunnel construction alongside the Nicoll Highway, see Figure 3.

Figure 3 Collapse of Nicoll Highway

There were four fatalities and a Public Inquiry followed that lasted many months. The lessons learned from this unfortunate occurrence were a milestone with a beneficial step forward in the procedures and control of underground construction work. There was a tightening-up of procedures. In addition there were several technical improvements that resulted.

3.3 Improvements

Probably the biggest step forward in the last twenty years has been in the use of instrumentation. By 2000 it was generally the practice to adopt a lot of instruments with frequent readings and to capture, transmit and store the data electronically. However the inquiry into the collapse at Nicoll Highway found that the instrumentation systems needed improving. Firstly the monitoring results needed to be verified and kept in order. Secondly it was recognized that the monitoring has a number of purposes. For example lateral deflections of temporary walls were often monitored with inclinometers with the protection of adjacent property in mind whereas the curved vertical profiles can be used to determine the developed bending moment in the wall in relation to the structural capacity of the wall. Also forces in struts were monitored to ensure no overloading of the struts whilst checks on the minimum forces necessary to support the walls were not considered. Often one set of limits was provided for a given instrument whereas, for staged construction limits for each stage are necessary if the performance at each stage is to be monitored and understood.

Subsequent to the collapse the use of complicated and versatile computer programs was subjected to detailed checking. However, twelve years later, the focus on satisfying procedures has run the risk of not studying the fundamentals and the complexity of numerical methods that are easy to use runs the risk that the solutions are not fully understood by the users. For example a claim arising from an instruction to adopt a drained analysis when the Contractor offered to use a coupled flow analysis reached only days before the hearing when experts on either side agreed that the coupled flow analysis had achieved almost 100% fully drained conditions and that the difference between the two analyses was not in the degree of drainage achieved but in different boundary conditions that were applied.

4. Tai Pei

4.1 Early days

Whereas Hong Kong and Singapore have varied geology and the vagaries of tropically weathered rocks, Taipei is located in a basin of very deep lacustrine and alluvial soils. The underground railway system (TRTS) was commenced about 40 years ago along with underground railways in Hong Kong and Singapore. The relatively uniform layers of clays and sands were well suited to the use of Earth Pressure Balanced tunnel boring machines and diaphragm walling.

By the early 1980's many contractors were building diaphragm walls in the relatively soft ground. However the desire to get good value led to over-engineering and widespread use of lateral joints between panels with continuity of horizontal steel reinforcement and water bars. Steel reinforcement was detailed to achieve full bond lengths sticking out horizontally through the stop- ends to overlap with steel reinforcement for the adjacent panel. To achieve this, a PVC sheet was fixed around the stop and which also enclosed a "dumb bell" PVC water stop. Excavation of the adjacent panel was intended not to damage the bond lengths of the steel reinforcement and the next cage of reinforcement was intended to slip down between the undamaged bond lengths from the first panel. The joint proved to be impractical, the stop-ends leaked, and the PVC sheets were displaced. The bond lengths of lateral reinforcement were often bent out of shape and clashed with the new cage. The consequence was that many joints that were not concreted properly with large voids leaked badly and exuded soft clay. This detail was commonly used at the time.

4.2 Milestone

An important milestone was a design review meeting for TRTS led by Jack Crooks of Golder Associates. When discussing the monitoring plans, a question was asked "if the supervisor is not the designer, what is the supervisor looking for?" Thinking of three stage traffic lights, the response was "there should be a series of limits set for each instrument. If the results are within the prediction, go ahead, if the results equal the prediction proceed with caution but if the results exceed the prediction there must be a review and likely a stop work for remedial works". This idea was modified to generate the AAA (Alert, Action, Alarm) limits of today. The milestone was recognition of the increasing complexity of underground construction and the need for people concerned to know what is expected and what should be done if what is expected does not happen.

Instrumentation is now an important activity for underground construction and there are several systems available whereby data can be accessed electronically including on a hand phone via the internet. Messages are sent out when AAA limits are breached. The user can interrogate the system asking for borehole data, results from specific instruments over specified periods of time and plotted one versus the other.

5. RISK

5.1 Risk Register

Within the last ten to twelve years Risk Management has been introduced to underground construction in the region. Quantified risk assessment relies on performance data and for many geotechnical activities there is not sufficient performance data to quantify the risks involved, Therefore a semi-quantified risk assessment with risk ratings is more generally adopted. Although a rating system runs the risk of being subjective it provides the basis by which classes of risk can be prioritised and the need for risk reduction measures can be evaluated. It also provides the lay person with a measure of the severity of the risks involved. By inviting sufficient numbers of sufficiently experienced practitioners extensive risk registers can be created and prioritized in a meaningful way. Risk registers for planning and design are taken through construction and expanded and thence into operation for maintenance.

5.2 Geotechnical Baselines

Geological risk has always been a major issue for underground construction, especially for tunnels. In the past many Employers put the whole of the geological risk onto the Contractors who, as a result, ran the risk of a big loss or of a lengthy lawsuit. Over 20 years ago Geotechnical Baseline Reports (GBR) were introduced into civil engineering contracts in the U.S.A. with the intention of providing baselines to geotechnical parameters which then are adopted as limits from which claims relating to those parameters can be considered. Objectives include making the contracted conditions more clear and to reduce the number of disputes. About five years ago GBRs were introduced to Hong Kong and to Singapore and were adopted for underground railway construction contracts. In Singapore an adaptation, a Geotechnical Interpretative Baseline Report including a more complete interpretative section, has been adopted. Some of these contracts have been completed. Some claims have already been settled making use of a GBR. (private communication). A common feature has been to reduce the risk for the Employer. For example baselines are provided for only a few geotechnical parameters. The remainder of the parameters is not baselined and therefore the extent of the improvement is limited. In some cases very large maximum limits have been adopted which considerably increases the risk shared by the Contractor. In setting baselines, one of the problems is to have enough data about the probability of exceeding values for a parameter such that the risk that is to be shared can be numerically quantified. When claims go to resolution in the Courts or by arbitration Geotechnical Engineers are often called as Witnesses of Fact or as Experts because so many cases involve unforeseen ground conditions.

6. CONCLUSION

Many projects have increased in complexity, due to interface with other underground works or structures, and due to large scale. Although more engineers are engaged, the expectations on delivery are much shorter. There have been a lot of technical advances during these four decades. Computers are widely used for design, for data management and for planning. In the past project were smaller, there were smaller teams engaged in design and they often continued to supervise the work. There were less detailed requirements and codes of practice, fundamentally the designs and construction were required to be safe but how that objective was achieved was more in the hands of the engineers concerned. Other tools such as systematic planning and risk registers enhance the work of a geotechnical engineer. Drafting GBRs often commences with the Geotechnical Interpretative Report but requires a broader view of the probability of more severe or adverse conditions being encountered on site and the means of mitigation. As a consequence, at an early age geotechnical engineers are required to specialize and focus on specific activities. Later in life the expectation of an Engineer is to be knowledgeable and experienced in many facets of planning, design, contract, construction, and resolution of disputes.

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