Report on IEM Evening Public Lecture by Prof Charles W.W. Ng on "Forensic Investigation of Long-Term Tunnel Settlements of Two Metro Lines in Shanghai"

by Ir. Dr Ooi Teik Aun

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The IEM Evening Public Lecture held on 24th June 2019 at the Malakoff Auditorium, Wisma IEM was on the topic of "Forensic Investigation of Long-Term Tunnel Settlements of Two Metro Lines in Shanghai was jointly organised by Tunnelling and Underground Space Technical Division (TUSTD), World Tunnelling Congress (WTC2020) and Geotechnical Engineering Technical Division (GETD), The event was managed by IEM Academy Sdn Bhd. The evening lecture was delivered by Prof. Charles W.W. Ng, President of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). Earlier in the morning, Prof Charles Ng as Guest of Honour officially declared open the First MGS-GeoSS Conference at PJ Hilton hotel and delivered his Keynote address. Due to a change of Conference Programme, there was a clash with the evening lecture. Despite the clash, a total of about 40 participants attended the evening lecture. The speaker began his evening talk by giving a brief introduction of ISSMGE and presented an ISSMGE tie to Ir. Dr Ooi Teik Aun [Figure 1]. He then gave some background history of the project. Shanghai is the largest financial centre in China with a population of about 23 millions. In order to alleviate the increasingly severe congestion problems in this city, underground metro network has been developed in stages in Shanghai.

Ever since the first metro line (Line 1) started operation in 1995, there were 11 metro lines (excluding the Shanghai Maglev airport link) and 267 stations built. All the tunnels of these 11 metro lines were constructed using an Earth Pressure Balance (EPB) machine. The tunnel outer diameter (OD) is typically 6.2 m and is located at relatively shallow depths (about 13 m below ground) in soft clay. The total length of tunnels in operation is 410 km in 2010 [Figure 2]; making the Shanghai metro network the longest in the world. A total of 510 km track was in operation in 2012 and this will be further increased to 877 km long by 2020. Since the operation of Metro Lines 1 and 2, non-uniform tunnel settlements and heaves have been observed at various stations along the two lines. Water leakages at various joints of concrete linings were observed resulting from excessive tunnel settlements along the two lines [Figure 3]. It is well-recognised that excessive tunnel settlements may lead to structural cracking and tunnel misalignment, which will greatly affect the safety of underground metro system (Schmidt and Grantz, 1979). Dalgıç (2002) monitored and reported the deformation of Bolu rock tunnel.

It was found that considerable tunnel settlement had developed in a thrust fault zone (poor ground condition) during construction. Grantz (2001) reported long-term tunnel settlements of several rectangular immersed tunnels during operation. The author suggested some possible factors could have contributed to the observed large tunnel settlements such as extraction of water gas and oil from underlying strata, poor subsoil conditions and large tidal variations. Figure 3 shows the possible causes of the settlement as presented by the speaker. Four possible settlement mechanisms including effects of tunnel construction, consolidation and secondary compression of soft clay (creep), cyclic loading due to running trains and groundwater pumping in aquifers were investigated.

Based on the results of desk study, laboratory tests and numerical Finite Element (FE) back-analysis, the speaker suggested the following conclusions might be drawn:

1. It is evident that compression characteristics of aquifers in Shanghai can change from “elastic” to “plastic” when its historical vertical effective stress (or overburden pressure) is exceeded due to a sufficient reduction of pore water pressure in an aquifer resulting from groundwater pumping. After soil yielding, noticeable secondary compression was found in Aquifer IV in Shanghai. Careful control of groundwater pumping is necessary to avoid an induction of plastic yielding and hence large secondary compression.
2. Amongst the four possible causes investigated, it is evident that groundwater pumping in Aquifer IV is the most likely principal reason for the large observed long-term tunnel settlements along the two Metro Lines in Shanghai. Controlling groundwater pumping in this aquifer is, therefore, vital to minimise further tunnel settlements.
3. Measured large long-term tunnel settlements are primarily attributed to compression of Aquifer IV. There were active discussions from the floor and the evening lecture was concluded at 7.30pm.

Figure 1: Presentation of ISSMGE Tie to Ir. Dr Ooi Teik Aun

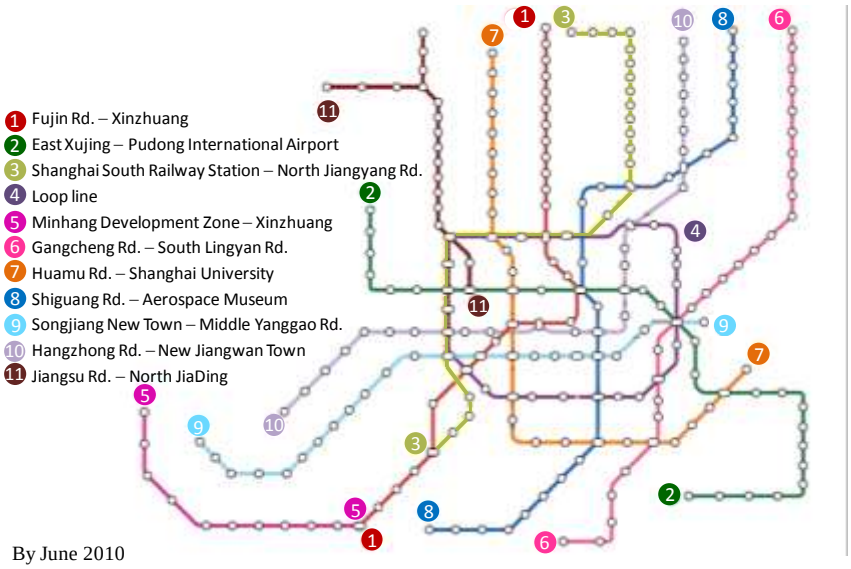

Figure 2: Map of Shanghai metro system

Figure 3: Typical leakage at concrete lining joints of metro tunnels in Shanghai

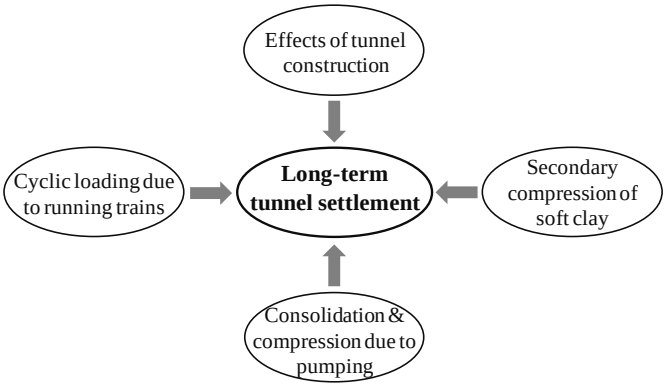

Figure 4**:** Possible causes of large long-term tunnel settlements in Shanghai