One-Day Seminar on “Underground Construction: Design, Technologies and Recent Findings”

GEOTECHNICAL ENGINEERING TECHNICAL DIVISION

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THE one-day seminar on “Underground Construction: Design, Technologies and Recent Findings” was organised by the Geotechnical Engineering Technical Division on 5 January 2012 at the Tan Sri Prof. Chin Fung Kee Auditorium, Wisma IEM. The seminar consisted of six lectures which were delivered by Prof. Lee Fook Hou (three lectures), Ir. Dr Toh Cheng Teik (two lectures) and Ir. Dr Leong Kam Weng (one lecture). A total of 100 participants attended the seminar.

In his first two lectures dealing with finite element modelling in deep excavations and tunnelling, Prof. Lee from the National University of Singapore shared some insights into the Nicoll Highway collapse using a three-dimensional (3-D) finite element analysis. The findings include:

1. Maximum movement of the south diaphragm wall was larger than that of the north diaphragm wall due to the breakup of the south wall inter-panel joints under tension (no continuous walers). The breakup of the south wall inter-panel joints might have led to the twisting of the struts causing the struts to buckle and the transfer of load from the 9th level strut to the 8th level strut. A possible contributory factor to the collapse was the absence of continuous or global walers.
2. Soil arching is not an effective means of redistributing strut loads as it requires a large ground deformation to take place. In such situations, some struts would have failed before the redistribution became effective. This accentuated the likelihood of a progressive buckling of struts.
3. Location of maximum movement coincided with where the marine clay is thickest, suggesting that the 3-D variation in soil profile had a significant effect on the location of the maximum movement.
4. There was significant non-uniformity in the strut loads, even within the same strut layer, due to non-uniformity in ground conditions and preloading sequence.
5. There were very significant 3-D effects in the problem, but many of these might have been quite subtle and would not have been immediately self-evident. The curvilinear wall alignment might not have been in plane strain even for a large radius of the curvature.

In a study to examine the effect of unsupported tunnel length on ground surface settlement during the construction of the Fort Canning Tunnel using the NATM tunnelling method, Prof. Lee used a 3-D finite element analysis to demonstrate that the maximum ground surface settlement had not been reached at the tunnel heading. Instead, it was reached at some point above the bench or towards the tail end of the bench. The reasons are:

1. Ground movement around the tunnel occured over a period of time. As pore pressure dissipated, the load from the ground was gradually transferred to the primary support system, i.e. shotcrete.
2. The shotcrete did not harden instantaneously.
3. The interaction between the steel pipe umbrella arch (also known as “All Ground Fastened” or AGF), shotcrete, partially excavated tunnel and ground was three-dimensional. The AGF behaved like a roof beam spanning between the supports located somewhere in front of the heading and behind the bench.

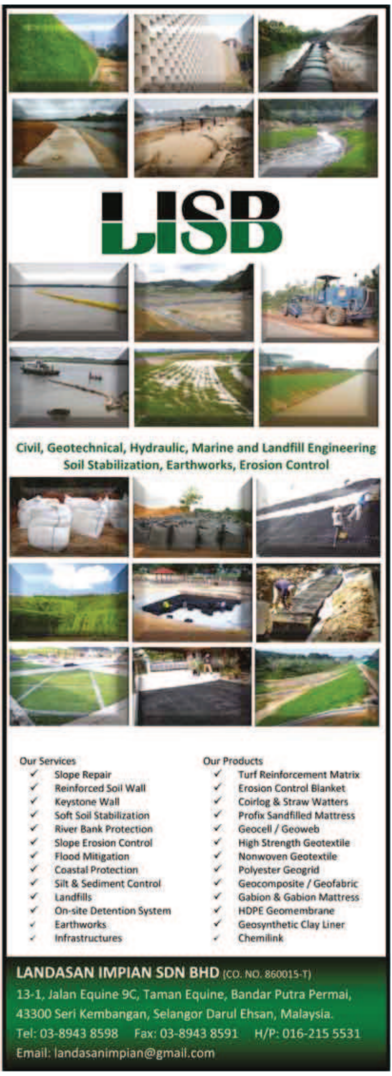
With regard to the finite element modelling, the following conclusions and recommendations were made by Prof. Lee:

1. It is important to understand real soil behaviour and which aspect of soil behaviour is critical. For instance, in the case of the Nicoll Highway collapse, strength was important, thus a simple constitutive model, e.g. Mohr-Coulomb soil model with the adoption of accurate undrained shear strengths, could be used. Using a very sophisticated soil model might be unnecessary, unfeasible and possibly risky due to the lack of knowledge of the material parameters.
2. It is difficult to lay down simple rules-of-thumb on what is conservative and what is not; this depends on the problem and the variables in question. One set of parameters may be conservative to some variables (e.g. settlement, wall deflection) but not to others (e.g. pile bending moments). Setting hard-and-fast rules for complex problems may lead to false confidence and an increased risk for errors. The recommended safeguards are to have a thorough consideration of the physics of the problem and to conduct parametric studies.
3. Most structures are designed to behave elastically under loading, and therefore, should often be analysed as such. Modelling the structure as an elastic system also often maximises the load on the structure. However, there are exceptions, for instance, when recreating a collapse or damage scenario, and for components which are conventionally not subjected to structural design, e.g. inter-panel joints in diaphragm wall and the joints between successive lining segments in a tunnel. Engineers may need to be more careful about whether one should analyse these components using an elastic model (without yield and failure) or to assume that they will undergo damage and cracking.

4. Is 3-D analysis useful for most problems? This is the wrong question to ask since all real problems are 3-D. The correct question should be whether a two-dimensional (2-D) analysis is sufficient.
5. 2-D analysis is not always conservative.
6. Most geotechnical analyses are still 2-D. The danger with doing exclusively 2-D analyses is that engineers get used to, not only doing, but also thinking 2-D, which in some situations can be dangerous.
7. It is true that a 3-D analysis takes a long time to perform, but hardware and software improvements have continuously reduced the required durations significantly.

In his third lecture entitled “Cement-Soil Treatment in Underground Construction: Some Issues and Recent Findings”, Prof. Lee concluded that:

1. The yield surface of cement-treated clay has a compression cap similar to that of soft clay. The main difference is that the cap is much larger, i.e. the yield stress is much higher, due to cementation.
2. At lower effective stress, cement-treated soil tends to fail along the tension cut-off, similar to unconfined compression test.
3. At a higher pressure, undrained specimens show peak strength at yielding followed by strain softening and positive excess pore pressure. On the other hand, drained specimens show strain hardening behaviour with large volumetric compression, until a very large shear strain level, at which point shear banding occurs.
4. Microstructural examination shows progressive loss of structure as shearing continues after yielding.
5. Regardless of cement-water-soil ratio, curing pressure and time, the initial yield locus of cement-treated marine clay can be represented by the same generic curve.
6. Towards the later stages of drained shearing, the shape of the yield locus shows a progressive evolution from a steep arch to a final elliptical shape.
7. Two main parameters affecting the uniformity of cement-soil mix are:
    (a) Unit weight of cement vs unit weight of soil – it should be approximately equal to minimise heterogeneity.



(b) Blade rotation number, which is a function of the number of mixing blades per meter depth, rotational speed of mixing tool and jack-in/withdrawal rate. An adequate mixing would require a blade rotation number of approximately more than 400. It was found that the unit weight effect is proportionally more significant than the blade rotation number effect.

The second speaker, Ir. Dr Toh, presented various case histories of deep excavations in his first lecture entitled "Deep Excavations with Finite Elements". The case histories presented included circular cantilever diaphragm walls, cantilever contiguous bored pile (CBP) walls, cantilever secant pile wall, top-down construction, preloaded struts, wall with permanent soil nails, etc. Ir. Dr Toh informed that the measured wall deflections range between 0.2% and 0.6% of the excavation depth for cantilever walls (low support stiffness), compared to 0.3% to 0.8% observed by Clough and O'Rourke (1990). For walls associated with the top-down construction method (high support stiffness), the measured wall deflections range between 0.12% and 0.36% of the excavation depth, compared to up to 0.3% observed by Clough and O'Rourke (1990). Ir. Dr Toh concluded that the comprehension of soil behaviours, mechanics of excavation and soil structure interaction coupled with the practical knowledge of construction methods and excavation logistics would enable an economical and safe design.

In his second lecture entitled "Soil Mixing and Jet Grouting as Excavation Support", Ir. Dr Toh shared his experience in grouting using three case histories. The case histories presented are:

1. The use of jet grout behind a strutted CBP wall to reduce ground movements (caused by excavation) to a negligible level.
2. Soil-cement mix to form an embedded wall for a relatively low height excavation in very soft marine clay.
3. Jet grout slab with diaphragm wall and top-down construction for a deep excavation in soft clay.

The last lecture entitled "Applications of Deep Soil Mixing (DSM)" was presented by Ir. Dr Leong. He concluded that to ensure reliable and successful applications of the DSM technique, the following aspects of design and operation must be properly considered:

1. Design considerations:
   - (a) Suitability of soil;
   - (b) Design and analysis of DSM;
   - (c) DSM pattern and treatment depth.
2. Operation considerations:
   - (a) QA/QC in mixing process;
   - (b) Degree and uniformity of mixing;
   - (c) Sequence of mixing;
   - (d) Coring and testing.

At the end of each of the lectures, the relevant speaker answered questions from the audience. Lastly, a token of appreciation was presented to each of the speakers. The seminar ended with loud applause from the floor. ■