Opportunities and Challenges faced by Professional Engineers in Mega Infrastructure Projects

By Ir. Dr Tan Yean Chin

As our country progresses towards developed nation status, there will be an influx of mega infrastructure projects. Most of these mega infrastructure projects will be integrated engineering in nature and may not fit the conventional contract process of detailed design carried out by an Engineering Consultant engaged by the Project Owner or Client, followed by a tender/award and finally, the Contractor in charge of carrying out the construction and commissioning. Instead, most of these mega infrastructure projects will be design and build (D&B) or turnkey contracts, with the Contractor awarded the project being responsible for both the detailed design and construction. These "integrated engineering projects" will involve professionals from many different disciplines. For example, finance, accounting, project management, architectural and engineering input from engineers of different disciplines including contractors, tradesmen, etc.

Some of the major integrated engineering infrastructure projects in Malaysia in which the author was involved are as follow:

1. Electric Train Service (ETS) which was originally called the Electrified Double Track Railway project from Ipoh to Padang Besar.
2. Klang Valley Mass Rapid Transit Line 1 (KVMRT1): Sungai Buloh–Kajang (SBK Line) which is 51km long.
3. Klang Valley Mass Rapid Transit Line 2 (KVMRT2): Sungai Buloh–Serdang–Putrajaya (SSP Line) which is 52.1km long.
4. International Airports (e.g. Kota Kinabalu, KLIA2)

The author wishes to share his experiences regarding the opportunities and challenges faced as a Professional Engineer with a Practising Certificate (PEPC) who has designed, endorsed and supervised the geotechnical and underground works for the KVMRT2 – SSP Line project. It is by no means that the author claims to have overall knowledge nor can he cover all the aspects of integrated engineering projects. The intention is solely to share his own experiences as a PEPC of the Engineering Consultancy Practice (ECP) engaged for the projects.

Opportunities and Challenges in Mega Infrastructure Projects

The experiences gained by a PEPC working on mega infrastructure projects include:

1. Exposure to unconventional analyses and new design methodologies by working together with various local and international consultants and specialists (e.g. Building Information Modelling (BIM), risk planning and mitigation, specialised designs such as tunnels, mine adits, deep underground stations, systems, etc).
2. Developing new design methodologies and design criteria for the type of infrastructure that is not commonly found in Malaysia, at the same time assimilating international practices to suit local conditions and practices (e.g. develop specifications and design requirements for MRT, high speed train, etc.).
3. Ability to design and specify materials, type of machinery, tools and equipment that are readily available in Malaysia to reduce reliance on importing them from overseas while attempting to design a construction methodology that is possible for local contractors to carry out.

The challenges for the PEPC who are responsible and liable for the design and supervision include the following:

1. Occasionally, there are no Malaysian Standards or Code of Practices available for the analyses and designs that need to be carried out for these mega projects. Therefore, reliance and reference to international standards, guidelines, or code of practices (e.g. tunnel lining design, deep excavation in urban area combined with tunnelling, railway embankment for high speed train, etc.) is common. This poses a big challenge and liability to the PEPC if there are any non-performance issues or failures in the design.
2. There are limited local case histories or experience available for analyses and design. Therefore, if any design challenges or problems arise, the PEPC has to carry out extensive literature review of journals and technical papers published in international conferences and seminars. Advice and review by international specialists in this field greatly benefits this situation.
3. Additional effort is required to assimilate and evolve the international practices with local practices and to develop customised methodologies to suit local conditions. This effort is tedious but improves the knowledge and skill set of the PEPC. In addition it exposes the PEPC to latest international practices. This is very important to further advance the engineering know-how of the Malaysian engineering fraternity.

Development of Systematic Analyses and Design Processes

For the engineering consultancy firm employed by the contractor to carry out analyses, designs, endorsements and supervision of engineering work for mega infrastructure projects under design and build (D&B) or turnkey contract, it is imperative that the key objectives listed below are achieved: -

1. Safe design (e.g. no failures),
2. Technically suitable (e.g. best engineering solution possible),
3. Cost-effective (e.g. minimal wastages of resources or no over-conservative design),
4. Construction-friendly (e.g. able to construct without difficulty following good engineering practices),
5. Minimal and ease of maintenance in the long term (e.g. to reduce the cost and effort required for long-term maintenance which if not under control, may make the project a cost liability to the operation or even the country),
6. Timely delivery of design for construction (e.g. no delays in design to ensure no delays in starting construction),
7. Construction is carried out in line with the design intent (e.g. with good co-ordination between contractor, consultant and supervision team).

The human resources (e.g. specialists, engineers, BIM operators, etc.) involved in the analyses and designs are huge, ranging from project leaders, design managers, design engineers and BIM/drafting team. The whole team may total up to 50 to 200 personnel, depending on the scale and scope of works. Therefore, it is important to have a systematic plan, streamlined analyses and design processes that ensure consistency, repeatability and efficiency.

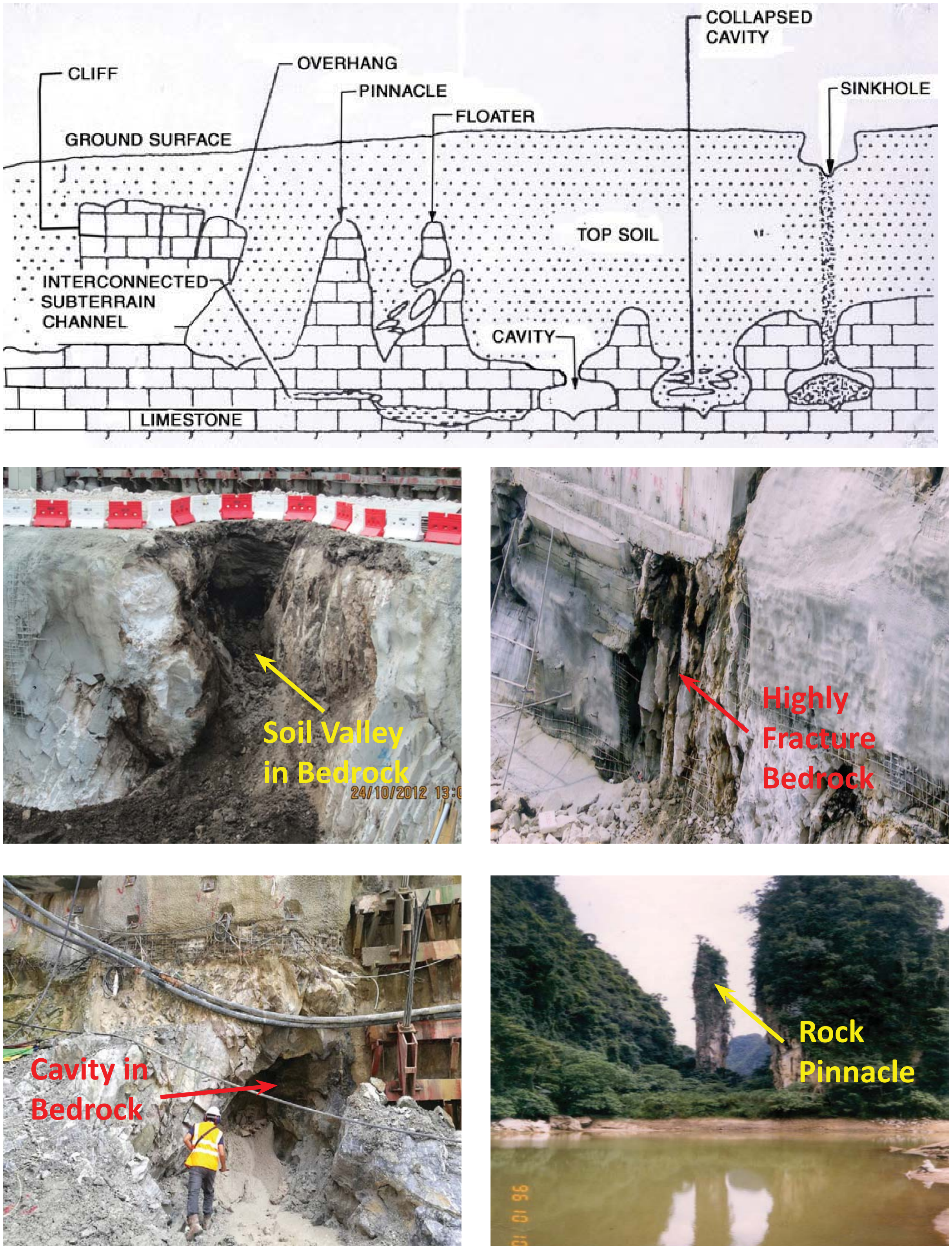

Figure 1. Karstic features of Limestone

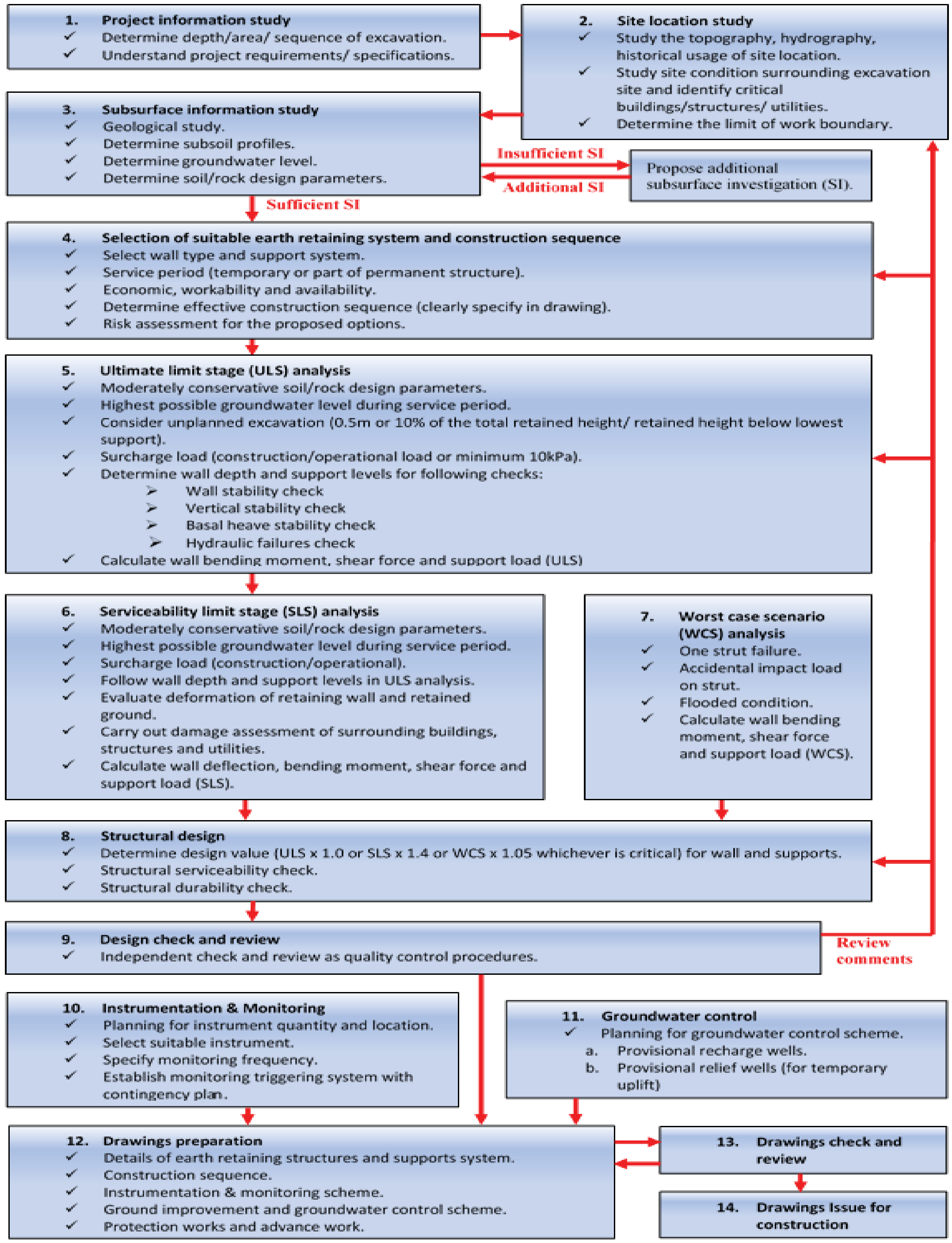

Figure 2. Flowchart for analysis and design of deep excavation works

Consistency and repeatability in the analyses and design are very important as there are many engineering personnel working on the same project, doing similar types of analyses and designs for similar structures or foundations, albeit with some modifications and at different geographical locations. The challenges are even more prominent for projects constructed in limestone with infamous karstic features as shown in Figure 1.

The standardisation of the design processes leads to a more systematic and effective training of engineering personnel to carry out their work. The trained engineering personnel will be able to produce consistent, quality works with fewer errors. This will ultimately lead to higher efficiency and ensure completion of the works in a timely manner. Efficiency will also lead to less resources required for the same task and be more economical. Without systematic and streamlined processes, there will be potential problems of resource wastages, delays or even failures.

Figure 2 shows an example of a flow chart presenting the key processes that need to be carried out by the engineers for the analyses and designs of deep excavation works (e.g. MRT underground station). There are more details and guidelines that the engineers can refer to for each process stated in the flow chart. These design processes were used to design two underground stations in KVMRT2-SSP Line, namely the Chan Sow Lin Station and Conlay Station. The photo taken by the drone operated by MMC-GAMUDA KVMRT (T) Sdn Bhd JV (MGKT) for the Chan Sow Lin underground station is shown in Figure 3 while Figure 4 shows the photo of Conlay underground station at night. Figure 5 shows the Three-Dimensional Finite Element Method (3-D FEM) modelling of a section of Conlay underground station.

These systematic processes can only be successfully achieved by a team of engineers who are properly guided and trained by the project leaders and design managers. Integrated engineering mega projects not only combine the engineers' technical brilliance and experiences, but also require them to have the following attributes to ensure success:

a. willingness to share their skills and experiences;
b. willingness to train the engineers working with them;
c. developing a systematic, consistent and repeatable design process (e.g. flow charts, checklists, list of do's and don'ts, design manuals, excel spreadsheets, software application procedures, analyses and design methodologies, verification processes, etc.) so that the engineering team working under them can perform their duty with efficiency and consistency to ensure quality of work;
d. carrying out systematic checks and reviews of analyses and designs including input parameters, modelling, analyses, results, specifications, drawings, method statements, etc. to prevent errors;
e. guiding the team on design changes or deviations encountered in the design processes and during construction.

A systematic design process is also needed to design the tunnelling works for KVMRT2-SSP Line. Figures 6 and 7 show the tunnelling works.

Importance of Innovative Designs based on fundamental Engineering Principles

One of the potential pitfalls faced by design engineers working on mega infrastructure projects is the over-reliance on existing analyses and design methodologies instead of having an inquisitive mindset to find out the fundamental engineering principles behind the analyses and designs; then trying to evolve and improve the methodologies to suit their own project requirements and local conditions.

It is important for an engineer to ensure public safety through sound engineering designs while complying to the standards or codes of practice, which are mandated by law; and to use available analyses and design methodologies developed specifically for the project (e.g. tunnelling design, underground excavation, ground treatment and embankment designs, bridges and viaducts, special structures, etc.). Engineers must also continue revisiting fundamental engineering principles to further improve and remove unnecessary conservative or obsolete methodologies. With the advancement

Figure 3. Chan Sow Lin underground station under construction (photo courtesy of MGKT)

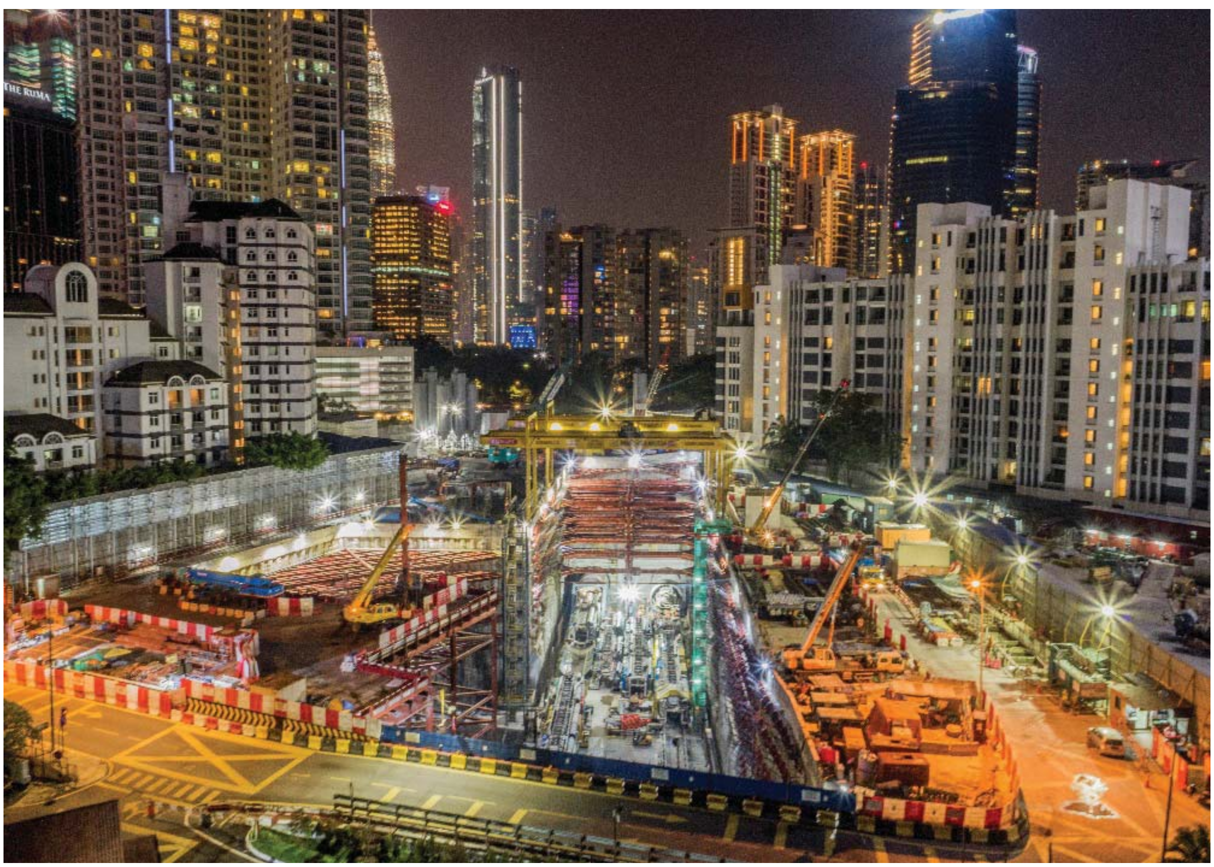

Figure 4. Conlay underground station under construction (photo courtesy of MGKT)

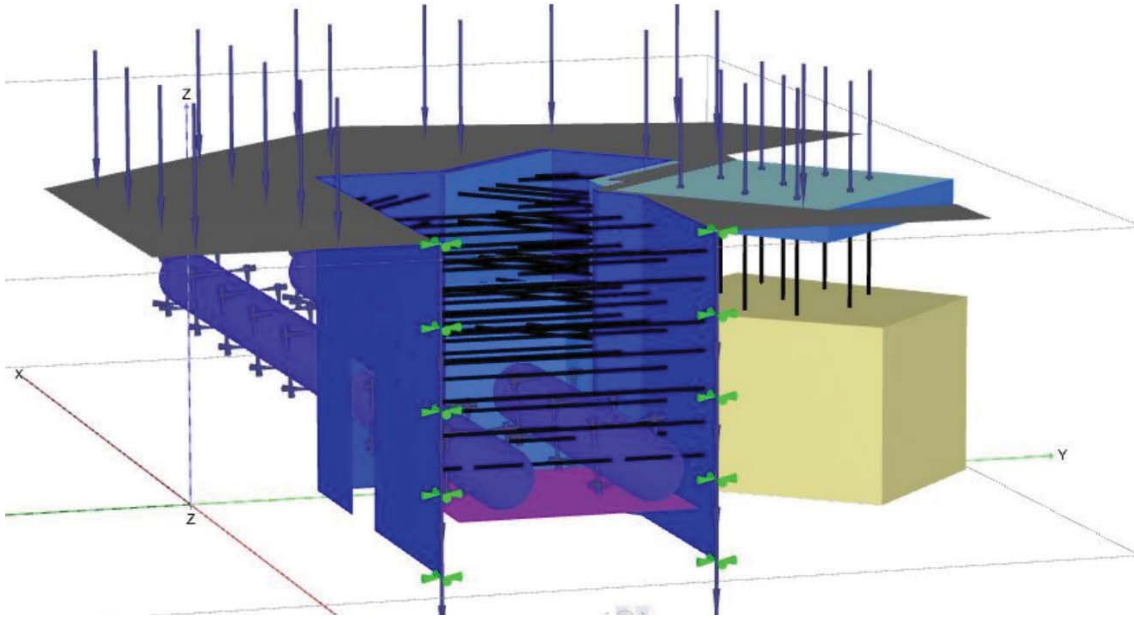

Figure 5. Three-Dimensional FEM (3-D FEM) modelling of a section of Conlay underground station

Figure 6. Tunnel breakthrough at Chan Sow Lin Station.

of computer and software capacities, many of the analyses and design methodologies not previously feasible nor possible 10 years ago are now commonplace, such as the three-dimensional (3-D) finite element method for soil-structure interaction problems.

There is a saying in engineering designs where the term factor of safety is rather a factor of ignorance; only to be used when one is not sure of one's design. While this statement is not entirely true, particularly in geotechnical engineering where much uncertainties exist in the ground, it does remind engineers that unnecessarily conservative and "overly" safe designs are not the way to go. These often result in an environmentally unfriendly design; one that requires more resources and materials and ultimately costs more. Continuous research efforts across the years internationally and the advancement of computing resources play a role in reducing uncertainties with regards to deformation mechanisms. However, it is quite often that the industry is contented with existing older methods due to familiarity, thus becoming slow to take up new approaches.

At this stage, it is also critical to point out that one can go to the other extreme, treating results from these sophisticated analysis tools as an absolute truth but forgetting that it is often only

Figure 7. Author and his team carrying out inspection of Tunnel and Cross-Passage Adit

as good as the input and coding. For example, taking results of analysis from a 3-D finite element analysis blindly and treating it as a black box could potentially be disastrous. Therefore, a good understanding of the fundamental mechanics at hand, coupled with in-depth knowledge on the analyses' limitations is critical. Ultimately, the engineering tool or computer is not the engineer nor should it be substituted for sound engineering judgement.

The usage of fundamental engineering principles helps engineers to develop their own analysis and design methodologies that suit local conditions and challenges at site. One example of an innovative design proposed by the author was used in the construction of the Maluri underground station of KVMRT SBK line. Tight regulatory requirements for rock blasting were extremely challenging given the close proximity of pre-existing and temporary steel and reinforced concrete structures. The innovative design developed by the author allowed blasting to be successfully carried with only a 1m blasting exclusion zone from the temporary king posts supporting a steel traffic decking. The innovative design was combined with an observational approach with vibration monitoring to verify the design, followed by detailed on-site inspection of the steel decking after each rock blasting to ensure that the integrity and safety of the structures were not compromised. This innovative approach expedited the construction progress with minimal traffic disruption and allowed completion on time. Figure 8 shows the steel decking in the MRT Maluri underground station during construction.

Another example of innovative design is the use of a circular shaft in the irregular karstic limestone formation for the underground shaft excavation. The MRT Line 2 Intervention shaft 2 (IVS2) was the deepest, at a challenging depth of 57.5m below ground level. Harnessing the rock strength to support itself, shafts constructed in the rock were designed to be carried out without the need for temporary support structures. A combination of ground improvement via deep soil mixing/curtain grout and rock stabilisation methods allowed for

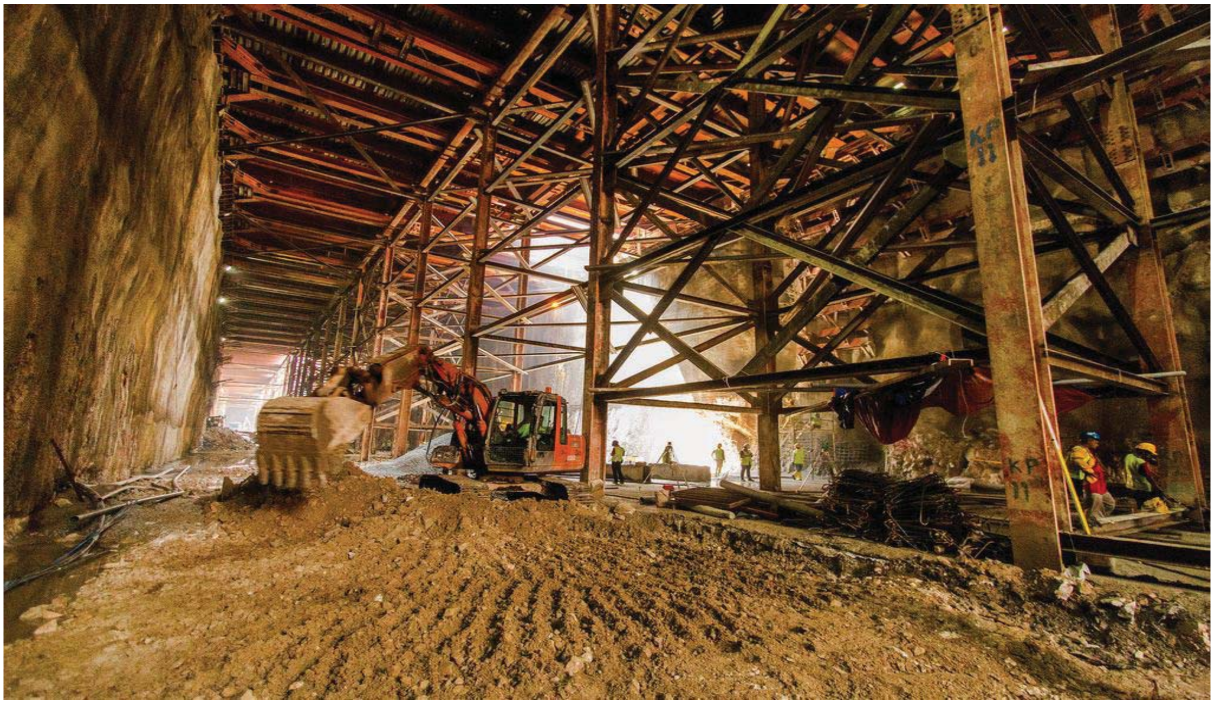

Figure 8. Controlled rock blasting was successfully carried out as close as only 1.0m away from king posts supporting a live traffic deck.

Figure 9. (a) (left) Photo taken from the bottom of the intervention shaft, (b) (right) Photo of author inspecting the shaft under construction together with his colleague Dato' Ir. Dr Gue See Sew.

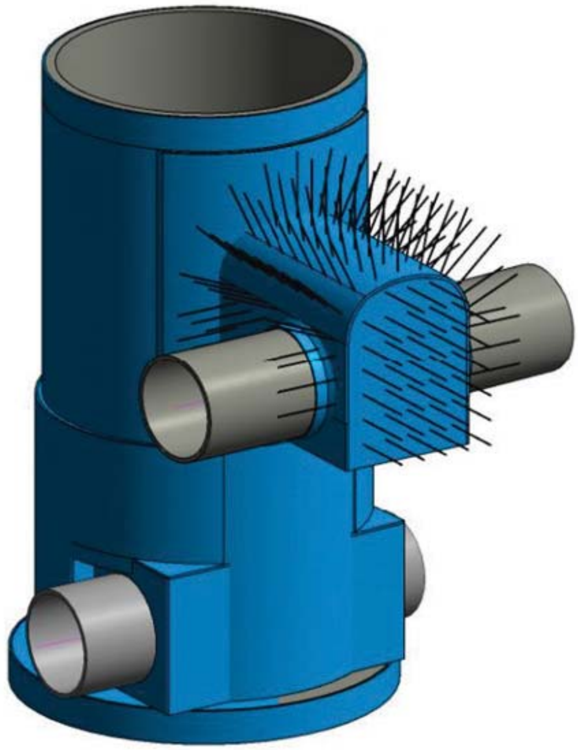

Figure 10. BIM model of Intervention Shaft 2 (IVS2) showing the tunnels and adits

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a much faster construction rate at a lower cost. Figure 9a shows the view of the shaft with photo taken at the bottom of the shaft and Figure 9b shows the author inspecting the shaft. The BIM model of the IVS2 is shown in Figure 10.

The biggest challenge of innovative designs, especially those that are unconventional and unprecedented in Malaysia, is not of a technical nature but rather of mindset to accept new things; usually caused by the human fear factor. It is inevitable that some questions and comments posed by stakeholders may be rooted in fear of change, namely :-

1. This proposal has not been used in Malaysia before,
2. Other parts of the world have not done this,
3. We do not have experience in this, and
4. Better not change the existing way.

These comments and questions remain the most challenging as they are based on fear rather than based on technical and engineering calculations, analyses or justifications. However, it is important to note that in order for engineering know-how to grow and continue to develop in our country, we must always go back to fundamental engineering principles coupled with detailed analyses, design, risk assessment and verification processes to move forward. If we wait for others to pioneer a particular engineering design and only then do we follow, we will be suppressing our innovation and risk being left behind in terms of engineering development.

Conclusion

A Professional Engineer with Practising Certificate (PEPC) involved in integrated engineering mega projects will gain extensive exposure and experiences that are not commonly available. However, the work also comes with exposure to risks and liabilities linked to the challenges inherent in mega projects. It is important to keep a positive attitude of willingness to learn new things, develop new skills, share knowledge and train fellow engineers. All decisions must be based on good fundamental engineering principles and good judgement to ensure successful implementation of the project.

The completion of some recent mega engineering projects within time and budget with a significant involvement of local engineering talents has demonstrated the capabilities of Malaysian engineers. As we move towards a developed nation status, Malaysian engineers should also move towards bigger and greater leading roles in developing our country. ■