GEOTECHNICAL INNOVATIONS IN THE TUNNELLING INDUSTRY

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ABSTRACT

The Australian tunnelling industry has been thriving. In Sydney alone there have been 11 major projects in the past decade: the M2 widening, Metro Northwest, NorthConnex, Sydney Opera House forecourt, Wynyard Walk, City East Cable Tunnel, WestConnex (M4 East, New M5, M4-M5 link, Rozelle Interchange) and Sydney Metro. All this work within the same geological environment has enabled much innovation in terms of geotechnical and hydrogeological understanding, analysis of primary support, waterproofing, geological mapping and recording of observations during construction. This presentation documents some of these innovations and suggests where the industry may be going in the short to medium term.

1 INTRODUCTION

"Innovate" is defined in the Macquarie Dictionary as *'to bring in something new'*. Innovation is sought and claimed by many in our engineering profession. One just has to look at any number of industry publications to see numerous headlines and advertisements featuring the word innovation (Figure 1). Interestingly, the word innovation is both loved and loathed having been included in the publisher Merriam-Webster Word of the Year list in 2014 but suggested by the news website Crikey as the worst word in 2016.

Figure 1: A recent edition of Engineers Australia's create magazine contained numerous references to innovation

This paper presents the "new somethings" that have been brought into Australian tunnelling over the author's 30 years in the industry and attempts to peer over the horizon to see where the industry might be going.

2 INNOVATIONS THAT HAVE WORKED

Many successful innovations have been brought into the Australian tunnelling industry by contractors, suppliers and designers since the 1990s. In rough chronological order these have been:

- A stacked alignment was used on the Eastern Distributor (1996-1999) to limit the impact of substratum acquisition (Figure 2). Its tunnel contains two separate traffic directions. An interesting aside to Australian tunnelling, is the stormwater management and road tunnel (SMART) in Malaysia (2007) (Figure 2). While this extraordinary tunnel is specific to Kuala Lumpur's needs, it and the Eastern Distributor provide examples of multi-function tunnels.

- Increased design life of bolts. Cement-grouted black steel bolts were used in the mid-1990s as ‘permanent’ support for the M2 road tunnels at Epping, Sydney. At about the same time, epoxy coated bolts were used in the Sydney Opera House Carpark and the CT-bolt was developed by Norwegian company Orsta Stal (Figure 3). Epoxy coated and sheathed rock bolts were used on the Eastern Distributor for its 50-year design life. CT-bolts and other similarly sheathed and cement grouted rock bolts, are deemed to have a 100-year design life and are the “default” bolt used.
- Remote bolting with the use of multi-boom rubber-tyred equipment removed the need to expose workers to the potentially unsupported ground as they manually installed rock bolts (Figure 4).
- Almost hand-in-hand with remote bolting, was the development of the handle-bar face plate (Figure 5). This plate provides a robust structural connection between the rock bolt and subsequently applied shotcrete layers while still fitting into the carousel of the remote rock bolter.
- Work procedures to deal with major risks associated with tunnelling, e.g. changed ground conditions or unsuitable support types.
    - The permit to tunnel (PTT) procedure is a process that allows geotechnical conditions, the performance of construction, the behaviour of the excavation and the documented design to be considered for upcoming work by the group of people most involved with tunnelling.
    - Similar to the PTT, a work procedure for installing appropriate groundwater control is enabling a targeted solution to be installed.
- Geophysical tools for recording geological structures encountered in boreholes. The acoustic televiewer (ATV) (Figure 6) enables greater clarity of structures that otherwise may be missed.
- Three-dimensional geotechnical and hydrogeological models are increasingly used to develop better understanding of ground conditions for tunnelling (Figure 6).

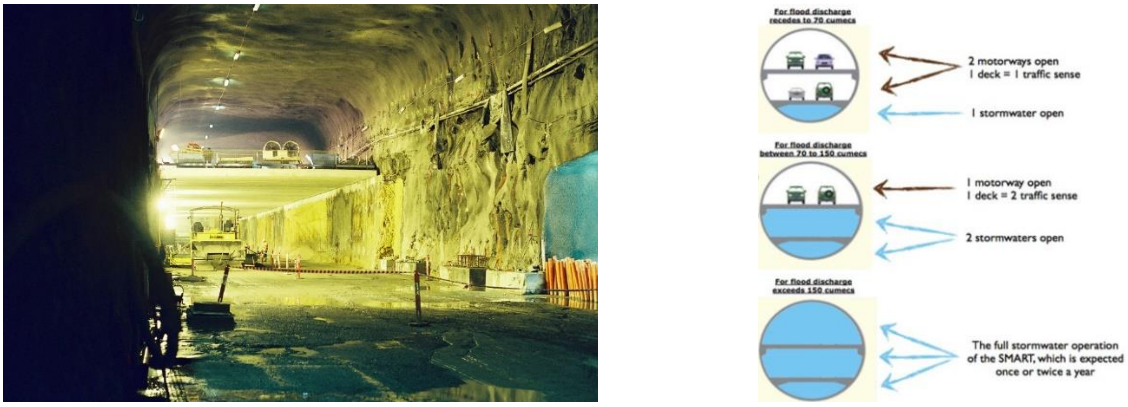

Figure 2: Double-deck Eastern Distributor (1999) – left; SMART, Kuala Lumpur, Malaysia (2007) – right

Figure 3: The CT-Bolt increased the design life to 100-years

Figure 4: Hand-installed (left) and remote bolting (right)

Figure 5: Handle-bar face plate for rock bolts.

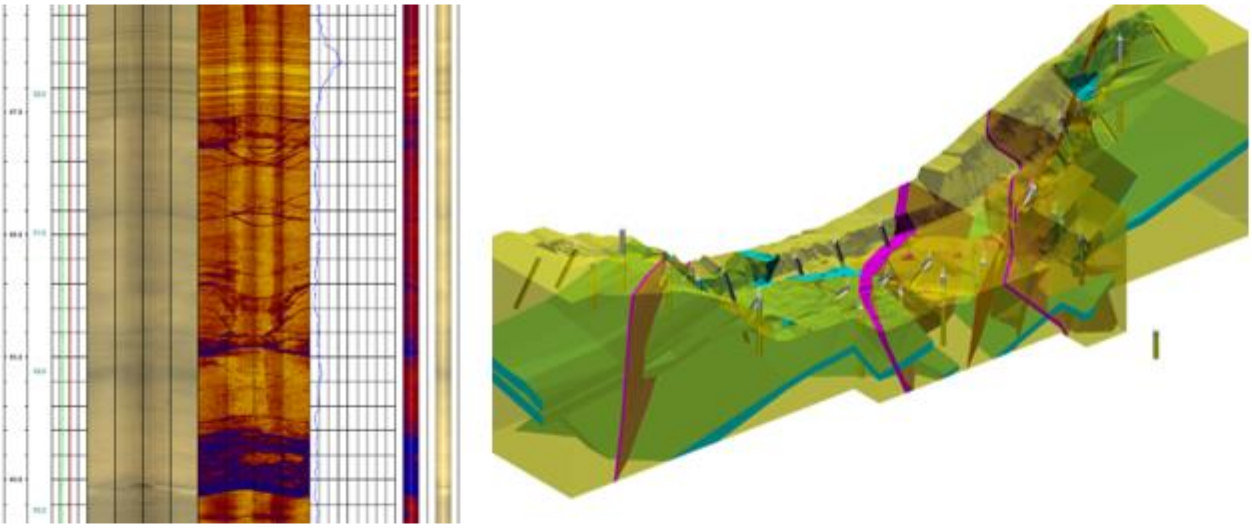

Figure 6: ATV borehole image on left. 3D geotechnical model on right

3 IDEAS THAT HAVE NOT SEEN THEIR DAY YET

This section documents a few ideas that have yet to be realised. The first two may seem frivolous but when they were mooted, it was with full intention of being the trump card to a tender win. The point of including them here is to acknowledge that innovations in our tunnelling industry are often attempted but many, maybe most, don't materialise for whatever reasons.

- Changes to road alignments are *de rigueur* during tenders for road tunnels. Realistically, most are minor tweaks to the reference design (with no offence to our road alignment colleagues), but the author is aware of a few more radical suggestions.
  - Rather than creating substratum issues and potentially affecting new third-party properties, an option of expanding capacity by tunnelling vertically beneath the existing road tunnel had been considered (Figure 7).
  - A helix / roundabout to provide connections between mainline tunnels to multiple entrances and exits without complex lane merging and under the 'one roof' (Figure 8).

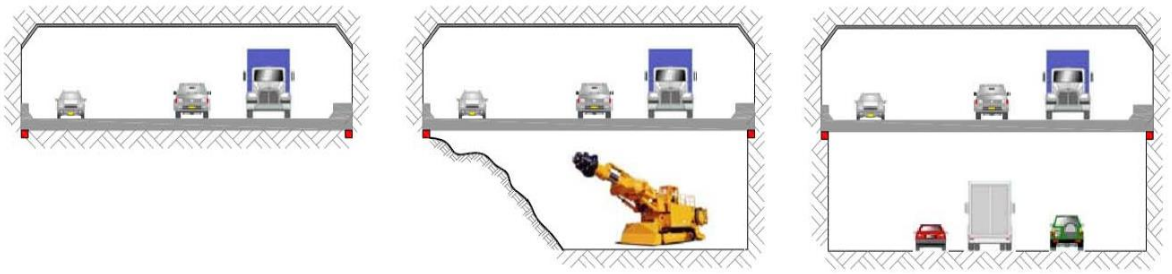

Figure 7: Expanding the capacity of existing tunnels by excavating beneath them

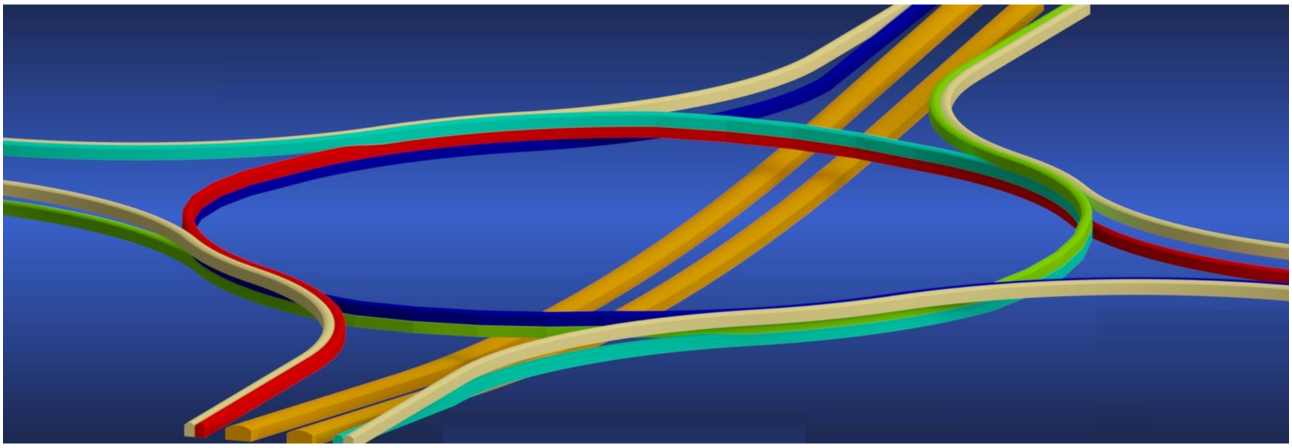

Figure 8: A helix that allows multiple entry and exit ramps without complex lane merges and underneath the one supported roof

It is unfortunate that the next two ideas have yet to find a firm footing in Australia.

- The Geotechnical Baseline Report (GBR) evolved in the USA in the mid-1990s to mid-2000s. '*The primary purpose of the GBR is to establish a single source document where contractual statements describe the geotechnical conditions anticipated to be encountered during underground and subsurface construction. The contractual statement(s) are referred to as baselines. Risks associated with conditions consistent with or less adverse than the baselines are allocated to the contractor, and those materially more adverse than the baselines are accepted by the owner.*' While the GBR concept had garnered initial interest here in the late 2000s, it has not really been embraced. In fact, recent Australian projects have taken the polar opposite view by passing the all the risk associated with the investigations which had been procured by the owner, to the contractor.
  The proponents of tunnels tend to be government agencies, who may consider a GBR offers more to the contractor by introducing uncertainty, and thereby risk, to themselves. It is noted that recent projects, notably Snowy 2.0, are trying to use it.

- Simplifying the design / review process. Bertuzzi & Rouvray (2014) addressed the design / review process and its associated cost that was in practice at the time. Disappointingly, things may have worsened rather than improved. This is further discussed in Section 6.

4 EXPECTATIONS

There is a trend for increasingly more complex geometries in underground excavations. Tunnels in the 1990s were mainly of uniform section, with no underground merges / diverges e.g. the Sydney Harbour tunnel, M2 road tunnel in Epping (Sydney), Burnley / Domain tunnels in Melbourne. Today, the Rozelle Interchange, which is part of the WestConnex project in Sydney, is a complex network of large span road tunnels. The complexity is not restricted to road interchanges as the reference design of an underground metro station shows (Figure 9).

No doubt the enviable conditions provided by the Hawkesbury Sandstone plays a major part in these designs. Such complexities can be entertained because of that rock mass. But it does raise the question are they necessary? Is the increased cost and risk justified?

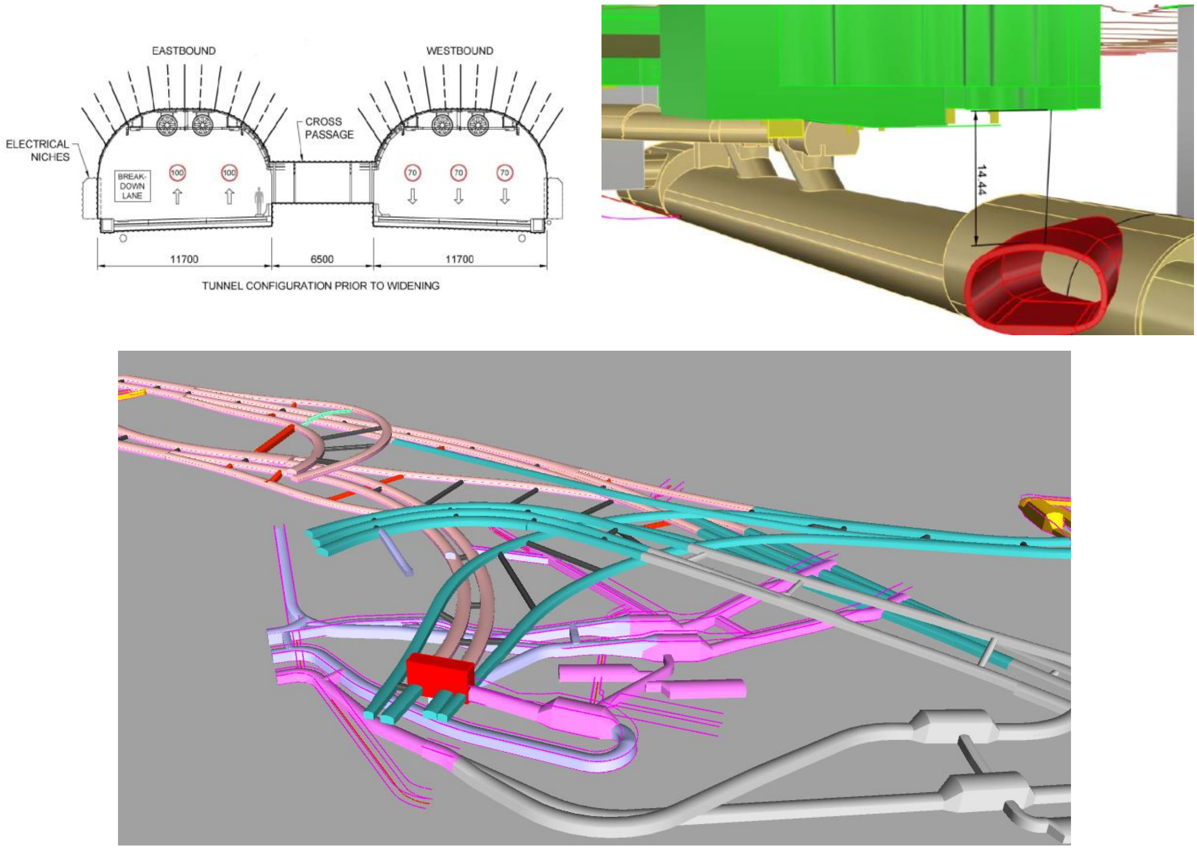

Figure 9: Increasingly complex underground geometries (top left) the M2 road tunnel in Epping (1995), (top right) metro station reference design (2017), (bottom) the Rozelle Interchange (2019)

What is acceptable in terms of the operation and maintenance (O&M) of underground infrastructure appears to be changing. For example, what was perceived acceptance of a limited but controlled groundwater inflow in the 1990s became a requirement to limit inflows a decade later, to now not allowing drips in road tunnels and for undrained rail tunnels. But along with the tighter restriction comes increased design and construction costs, not only from the additional loads and materials but also from the greater excavation volumes and construction time (Figure 10).

Counter-intuitively with more complex geometries and tighter O&M requirements, the expectation is greater productively and faster construction. Four roadheaders were used on the Eastern Distributor tunnel, 21 roadheaders were used for each of the four separate tunnelling projects that form WestConnex; 11 roadheaders were used from the one site (the Cintra site on the M4East).

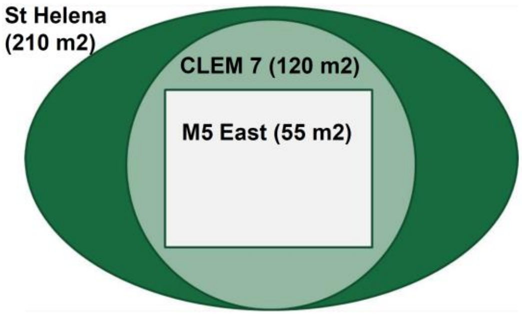

Figure 10: Undrained tunnels require greater excavations and longer construction time

5 DEVELOPING IDEAS

A few innovations are currently being introduced into our tunnelling industry, largely driven by the increase in spans but also by the continuous need to improve efficiency and productivity.

- The merge and diverge of multiple lanes in road tunnels demand very wide span excavations. As too, do station platform caverns and interacting concourse caverns. Interestingly, the spans of the 90 large underground excavations listed in the seminal text book by Hoek & Brown (1980), ranged from 11.8 to 33.5 m with most between 15 and 20 m. By comparison this is now the standard width of road tunnels in Sydney. The important distinction is that the large underground excavations are at specific locations, whereas road tunnels are long linear structures and the risk of encountering unforeseen unfavourable conditions increases. Further, the merge/diverge caverns associated with the standard road tunnels are over 30 m wide and those of station platform caverns over 25 m wide.
- The support of these very wide span excavations is being achieved with a mix of cable and bar bolts (Figure 11). The mix attempts to maximise the use of the rigid bar bolts which currently can be installed much more efficiently than cables.
- The analyses of the capacities of bolts and of relatively thin layers of shotcrete is continuing to be pushed to achieve these very wide spans designs.
- Coupled with this, is the remote installation of cable bolts. Equipment design is continuing to develop a system for installing cable bolts that is as efficient as that for installing rigid bolts (Figure 12).
- Tele-remote equipment is available and proven in mining (Figure 12) but the tunnelling industry hasn't yet fully adopted it. Tele-remote equipment could provide opportunity to re-address the issue of unsupported ground.
- Laser / optical scanning for survey, material quantities (e.g. shotcrete thickness) but also for geological mapping and convergence monitoring (Figure 13).

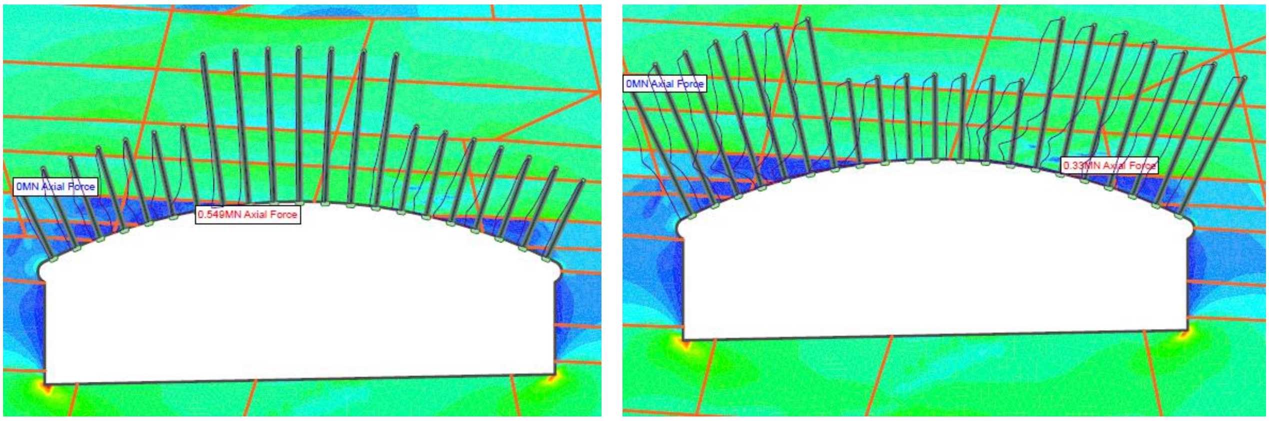

Figure 11: Alternatives to supporting very wide spans: longer bolts / cables in the centre (left) or longer bolts / cables in the shoulders

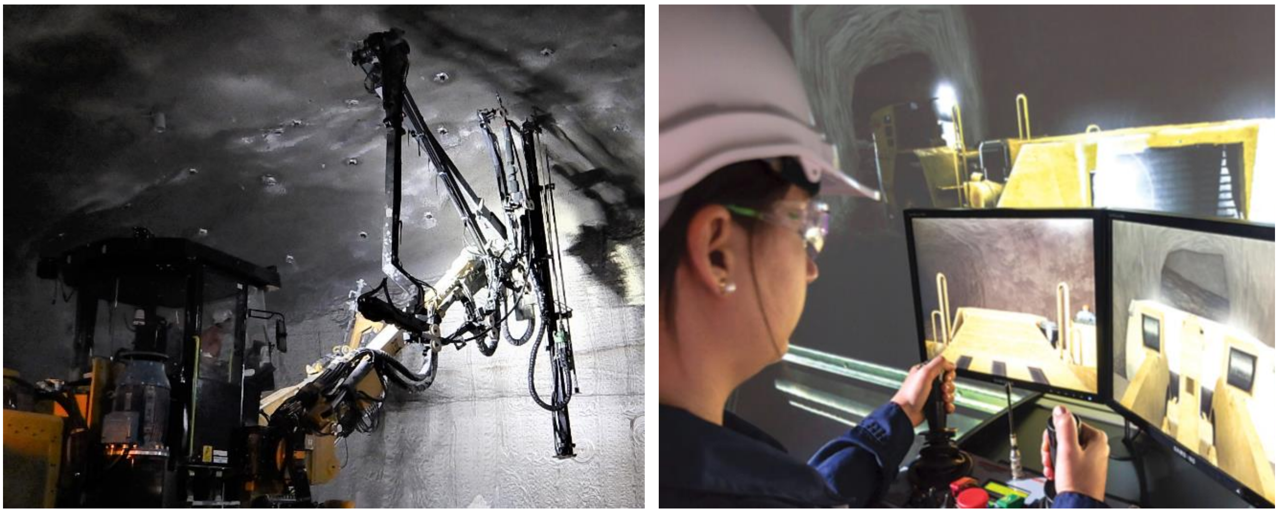

Figure 12: Left: The cable bolt rig which was used in Sydney's WestConnex M4 East road project had limited success. Right: The technology to remotely operate roadheaders, bolting rigs, shotcrete rigs, etc.

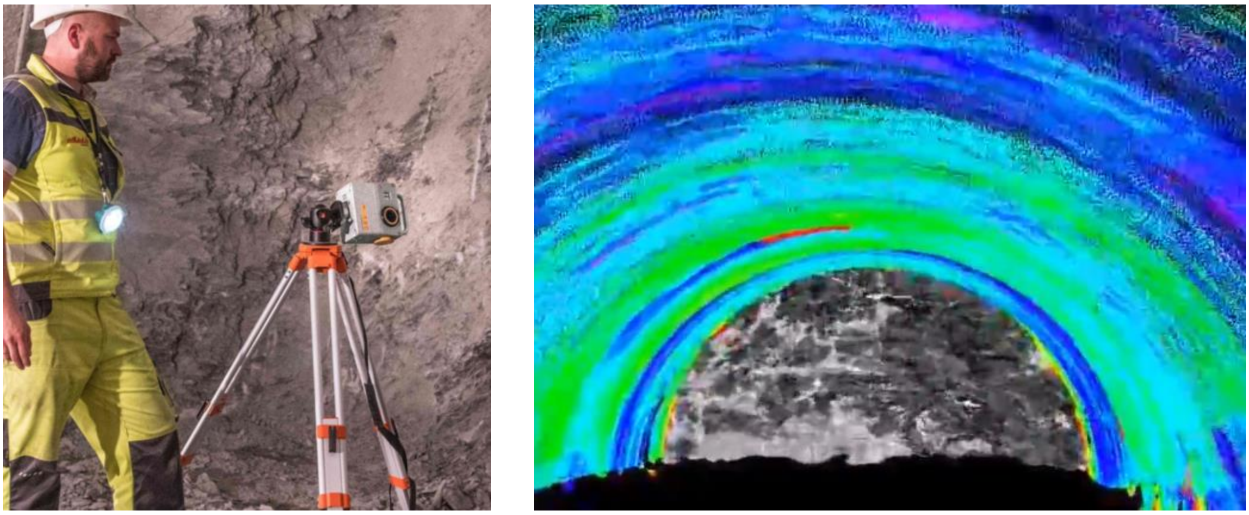

Figure 13: Scanners for surveying, geological mapping and convergence monitoring

6 WHERE INNOVATION IS NEEDED

Undoubtably this section will prove to be controversial, but in this author's opinion there are two areas that desperately need innovation: the design / review process and the timeframes for large infrastructure projects. Both of these areas require both contractor and client innovation, i.e. essentially the government agencies need to *'to bring in something new'*.

Figure 14 presents the flowchart explaining the design review process for recent tunnelling projects. That the process requires a flowchart at all, is telling. Then add the complexity of the flowchart. Then appreciate that the process passes through this flowchart four times before the design is complete and construction can start. Is it any wonder that the cost of the design / review process is now some 20 times more expensive than it was for the Eastern Distributor? Normally, it would be reasonable to expect that the item becomes cheaper the more it is made. There was approximately 1 km of road tunnels in Sydney when the Eastern Distributor was being constructed. There is now over 100 km.

As the design / review process has become unwieldly, the timeframe for projects has shortened considerably. An outsider to our industry would think that site investigations would proceed the development of a geotechnical and hydrogeological model which in turn would proceed design and construction would follow. Modern infrastructure tunnelling projects has turned this logical sequence on its head. In recent projects these naturally sequential events have overlapped so much that it is not unusual to see site investigations continuing as construction starts.

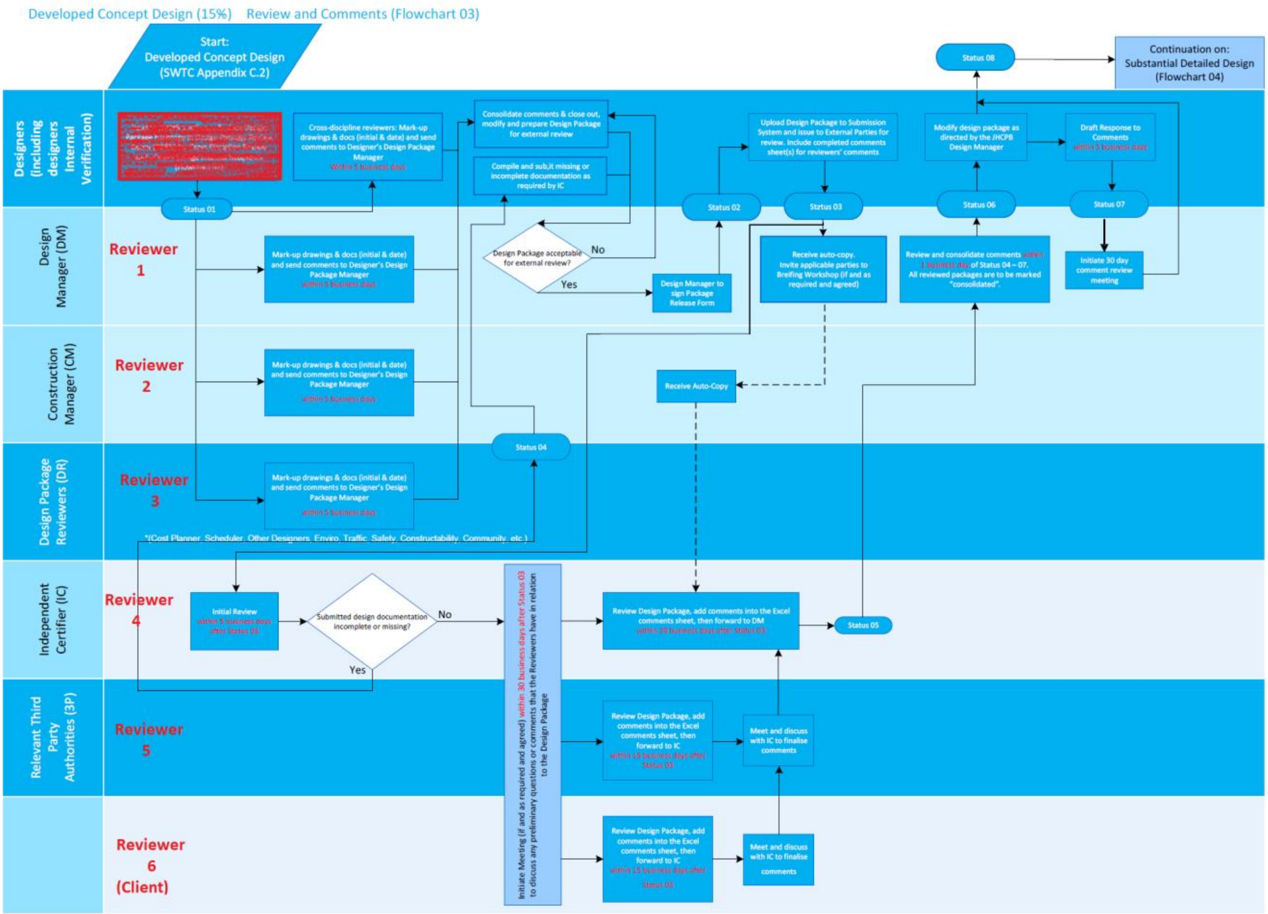

Figure 14: Flowchart of the review process for a recent project

7 CHALLENGE

One of the next tunnelling projects expected in Sydney is the F6 Extension road tunnel. It is wholly within the Hawkesbury Sandstone. So, the challenge is to the client and contractor: can we curtail the tender, how about the design / review process? Can a single cross-section be adopted for the twin tunnels? One that fits within precedence of the >100km built in Sydney. We all know what the support will comprise. How about introducing a GBR so that the risk of encountering unforeseeable conditions can be shared? Imagine the benefits of such innovation not just to our industry but to the wider community.

8 ACKNOWLEDGMENTS

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9 REFERENCES

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