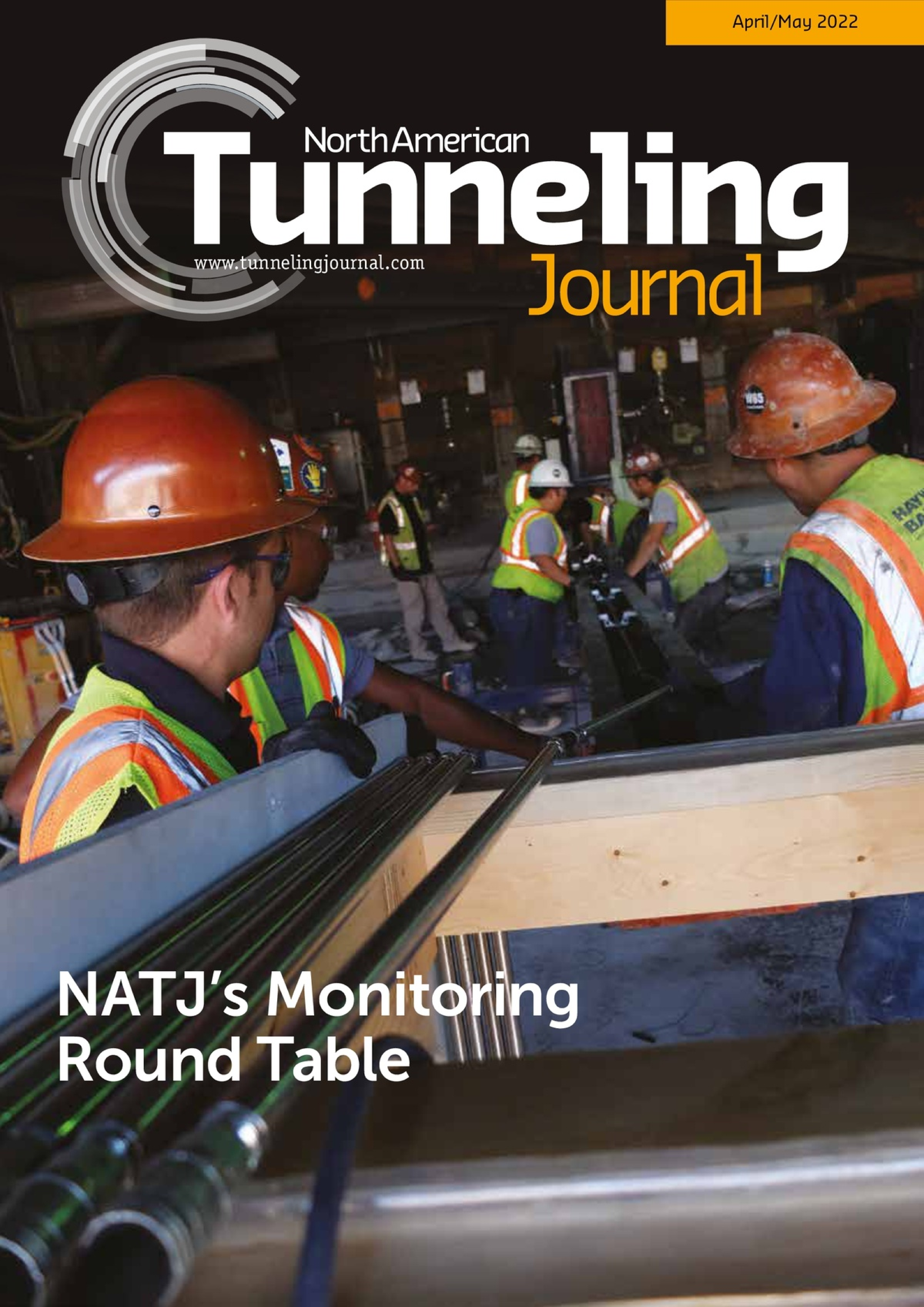
April/May 2022

North American Tunneling Journal

www.tunnelingjournal.com



NATJ's Monitoring Round Table

NATJ's Monitoring Round Table

Monitoring and Instrumentation are experiencing wider usage and acceptance in tunneling, while also rapidly changing to integrate with the latest technology. In this year's annual monitoring round table, NATJ spoke with experts Loic Galisson, Vice President USA & Canada for Sixense Group; Angus Maxwell, Director and CEO of Maxwell Geosystems; and Paul Thurlow, western-region Vice President at Geo-Instruments to get their take on the latest trends in the industry.

Loic Galisson, Vice President USA & Canada for Sixense Group

Angus Maxwell, Director and CEO of Maxwell Geosystems

and Paul Thurlow, western-region Vice President at Geo-Instruments

In the past year, what has changed for monitoring, in terms of either software or how data is collected and used?

Galisson: There is a shift happening because the manufacturers are actually pushing their products' ergonomics much further than in the past—some are turnkey solutions that don't necessarily require experts to operate them. Contractors, Geotechnical Consultants, and others may now do their own monitoring without going through specialized companies. This has both good effects and bad effects. The good is that many companies now can operate in an independent way. It helps the monitoring culture spread to more people. However, on the other side, people tend to believe they will get what they need just by pushing a button. They don't always have the experience or the judgement to assess what is good data and what is not good data. As an integrator, I'm a bit concerned by the fact that monitoring is gradually becoming a commodity, potentially endangering the quality and the value of the monitoring data.

Thurlow: I think the perception of remote monitoring has been bandied about a great deal, but someone has to install it in the first place and ensure that it is maintained, batteries are changed, and obstructions removed. Software has improved, it always does, but how data is being used is probably static in its development now.

Maxwell: There is more focus now on putting monitoring into the proper context by including information about the progress of the works and the activities and ground conditions which might affect results. This is requiring software to absorb more information from the wider construction teams. This includes combining the monitoring into BIM (Building Information Modeling) and digital twins.

There is also more interest in automating feedback against design predictions at every stage of construction, which will enable more proactive tunneling.

What would you say is the strongest trend in monitoring right now? Is it the same in North America as it is for other markets around the world?

Maxwell: In terms of types of monitoring, the use of satellite INSAR is becoming widespread. Wireless remote monitoring is now standard on most contracts and we are starting to see more embedded monitoring systems looking at asset performance. Concrete technology is also using a variety of embedded sensors for measuring curing temperatures and strains in lining. Thermal and LIDAR scanning of linings are also becoming more common globally although I haven't seen this yet in North America.

Data management is starting to be taken on by the contractor directly and in some cases directly by the owner who specifies interface requirements for the main contractor. This enables the owner to combine data more effectively in a common data environment and engage their engineers to achieve more positive outcomes.

One driver for this is a definite desire to improve the feedback processes, in particular against design predictions. To do this effectively needs high quality data and this is seldom the cheapest. The monitoring industry is starting to push back against the 'low bid wins' culture in North America.

Galisson: The younger generation is showing much more interest in technology, specifically on the owner's side now. We are very close to the point where the approach to monitoring is going to change. New technologies will be more welcomed and used in upcoming programs. By technology, this could mean anything from new sensors or communication systems to a wider use of satellite telemetry. That is good news overall.

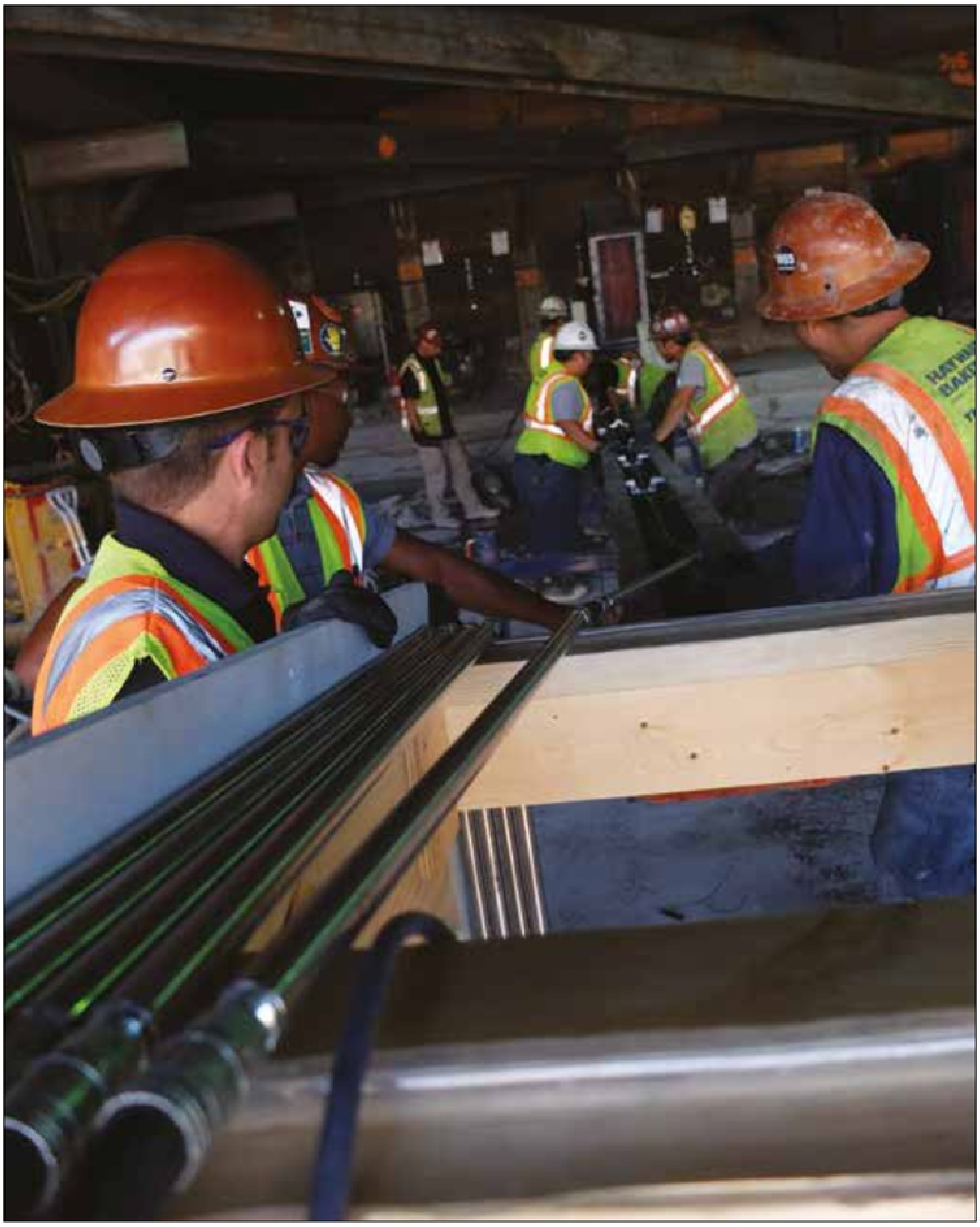
Thurlow: Wireless and InSar technologies are the trends again this year with structural health instrumentation being introduced at a faster pace than previous years.

In the past several years we've seen a big shift to remote work and with it, remote monitoring capabilities. How has this changed monitoring programs, if at all? Do you think the change is permanent?

Thurlow: No, I don't think it is a permanent change. All of these systems require some initial setup and maintenance so none of them are totally plug and play and 'I'll come back in 10 years'. Monitoring programs are embracing the wireless technology more and more and the use of automated methods of monitoring. However, there is still a long way to go.

Maxwell: I don't think the remote work is driving the way jobs are monitored. The move to automated wireless monitoring and INSAR/LIDAR is mainly cost driven with wireless hardware costs starting to reduce and satellite scan frequencies increasing. The demands on software are increasing though, with more integration of remote monitoring (e.g., CCTV, terrestrial radar, drones and LIDAR) being combined within the monitoring software.

Galisson: Remote work hasn't changed monitoring significantly, as we were already pushing for automated systems. The pandemic has instead confirmed the use of those automated systems and accelerated the transformation. People are ready to embrace more sophisticated systems.



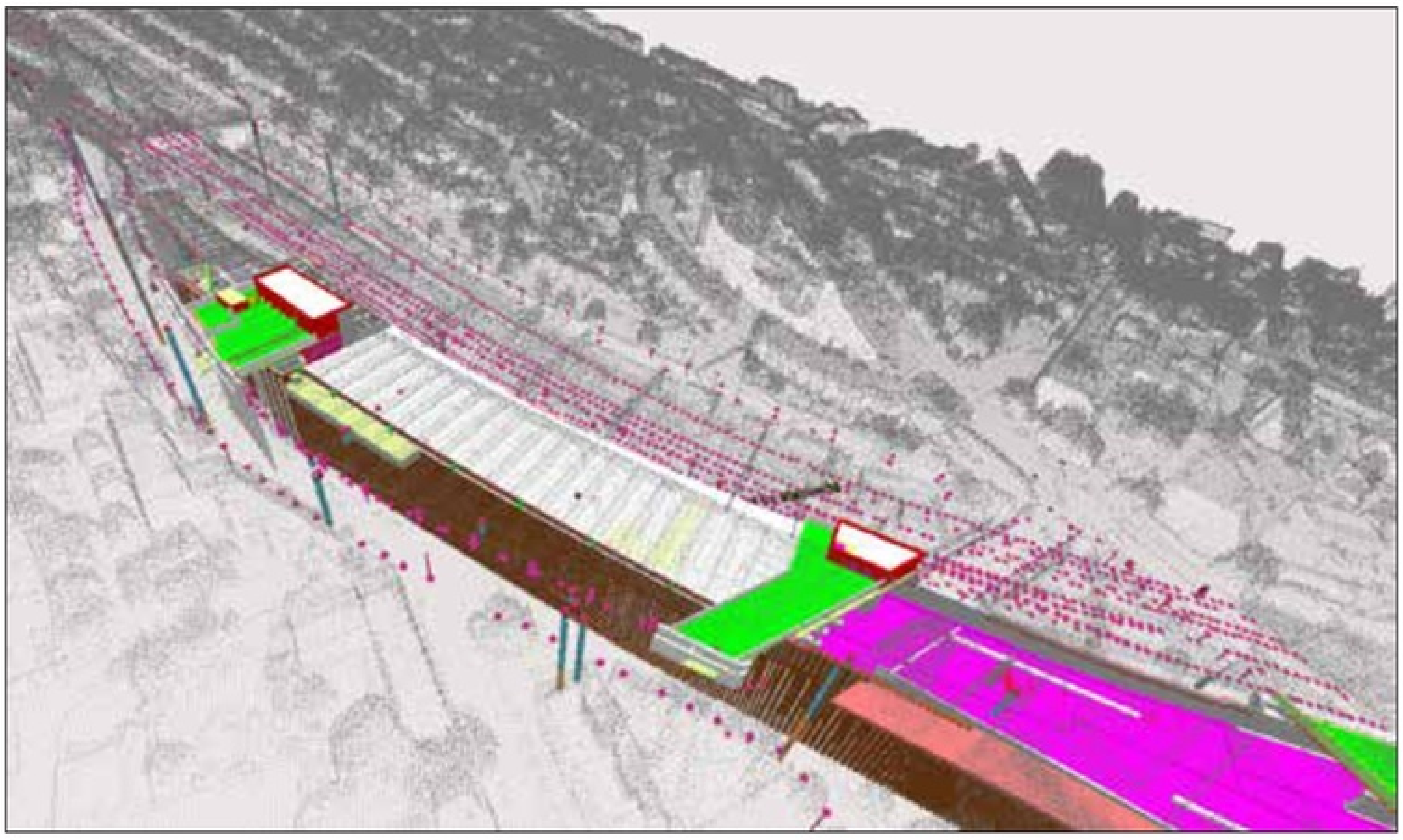
Installing 500ft horizontal real-time inclinometers above a TBM.

Photo: Maxwell Geosystems

How can monitoring be used to mitigate risks on tunnel projects?

Thurlow: Monitoring is key to mitigating risks on tunnel projects: It verifies the design, asset protection measures, TBM efficiency, and risk review. It is really encouraging to see more and more TBM performance zones being specified and included in tender documents. These zones at the beginning of the drive are highly instrumented on the surface, but recent requirements now have real-time inclinometers up to 500 ft drilled horizontally 4 to 5 feet above the intended TBM path to get valuable data in the ground.

Galisson: I think that we see a big difference in the culture between Europe and the U.S./Canada. Contractors in Europe are using monitoring data to adjust their methods in almost real time, to re-optimize their schedule and the cost of their construction adjustments could be for volume of material, factor of safety, cost efficiency, etc. I know of a project in the south of France, an SEM tunnel, where the contractor used monitoring data to change the design of the supports as they were tunneling, to give an example.



A plot from the UK's HS2 project showing a live combination of ground and monitoring data with the construction progress even while design is on-going. Photo: Maxwell Geosystems

North America is different in that the designs remain more conservative. We repeat what we've done in the past because we know it worked. When it comes to construction, contractors don't seem to pay too much attention to the monitoring data. Monitoring data is used when there is a big issue, something obvious. Instead of being seen as a burden and cost, I wish contractors would see they can use instrumentation as a helpful tool to optimize the overall construction process.

Maxwell: We are finding that more owner and insurance groups are recognizing the importance of accepting the existence of uncertainty on tunnel projects and implementing systems to manage this through observation and instrumentation. This generally improves safety and may provide opportunities for increased progress if monitoring shows that ground conditions are better than anticipated.

Currently the industry still uses manual methods for updating trigger values for allowable movement. It also focuses only on the basic measurements. More direct engagement with the engineering design teams during construction will allow more automated and dynamic feedback systems to be implemented. As a result, the systems will be able to use the basic measurements to calculate more relevant structural parameters such as distortion or torsion of a gas pipe.

Internal monitoring of tunnels during construction using LIDAR and thermal scanning is another way to improve the quality control. We see this of particular use for sprayed concrete lining thickness, to give greater assurance.

Let's talk a little more about digital twins and BIM. How can monitoring systems be integrated with digital twins or BIM to make these virtual models more usable?

Maxwell: On HS2 in the UK, the design is going on at the same time as the construction and there is a need to update the digital twin progressively. Maxwell Geosystems implement a semi-automatic tool to extract the ground engineering objects (piles, anchors, excavations) from the CAD models. Construction objects are then absorbed and updated into our software using SQL where progress and other metadata is added. Effectively our software uses fast online rendering to create on-demand, live digital twins of any selected area with progress of the works, up to the minute instrumentation and other ground and remotely sensed data combined. This type of modeling simplifies interrogation of data since users only build what they wish to see.

Galisson: A digital twin is the combination of an accurate BIM model, advanced calculation models and relevant monitoring data. By monitoring data, I mean information collected from geotechnical and structural sensors installed on the asset, but also from non-destructive and semi-destructive testing. This is the world of Structural Health Monitoring (SHM). Today, construction monitoring and SHM are two different worlds. Although there is a big overlap in the technologies used, the purpose, the time scale and the users are very different. It would be very interesting to integrate an SHM vision at the time of the construction. This would ensure the ability to collect the information we need during the life span of the asset, to adjust aging models, refine models, validate assumptions and hypotheses… and therefore make the digital twin evolutive and useful.

Thurlow: I have been a big fan of digital twin technology for years now. I like the fact that it is scalable, and the construction/monitoring data interface really gives an immersive touch to monitoring meetings. The ability to work in real-time with the designers and constructors is very rewarding too. I am excited at the progress being made in this field with monitoring data. It is regularly brought up in bid meetings now in the USA.

AI is a big topic right now. How can monitoring help to advance AI in tunneling?

Galisson: Monitoring contributes by feeding the databases that are used by AI algorithms to work. I'm personally a bit cautious with the term AI. Monitoring will help AI to get into our industry but I don't think we are here yet. If you scrape the surface of some claims in the industry, it's an algorithm, there's no real intelligence yet. We are building the backbone of info that in the future will enable some AI. However, many engineers would agree with me that you would rarely find two tunneling projects similar enough that you can reuse data on a second project. The ground or other parameter is always different, even on parallel tunnels. Each project is so individual, we should be cautious in how we see and use the data for AI algorithms.

Maxwell: The monitoring is one sensory input for the AI learning process. We are currently developing AI and ML (Machine Learning) methodologies for TBM control focused on better management of settlement, soil conditioning, cutter wear and production rates. Our MissionOS systems will be providing a big role in the near future giving recommendations for TBM driving parameters.

Thurlow: There are some really clever prediction models around for tunneling and they work really well in some soils. Automated data transfer to TBMs from the surface or in-ground instrumentation, linked to the TBM control software, has been around for a few years now.

Automated Total Station measuring rail during a TBM transit.
Photo: Geo-Instruments

Sustainable tunneling is a topic that is here to stay in our industry. How can monitoring help us to build more sustainable tunnel projects?

Thurlow: The more monitoring data that is collected, stored and used for future projects in similar ground conditions, the more it should reduce the amount of monitoring required. The footprint to install MPBXs (Multipoint Borehole Extensometers) and Inclinometers is big and wasteful in some cases. The use of wireless instruments and nodes is another example where improvement is needed, as the manufacture and disposal of typical instrument cables is a huge strain on the environment.

Maxwell: The main area here is in the monitoring of concrete performance with embedded sensors. This will allow concrete designers to push the envelope in terms of excluding carbon from concrete mixes by proving in situ capability.

Galisson: Monitoring itself is somewhat limited in its impact on the environmental footprint. Instrumentation however, if it is used properly, to avoid failures, etc. can make a project more efficient. One trend we do see in North America is that requirements for noise and vibration are becoming more stringent. That contributes to a reduction of environmental and social impact.

How big of a trend is lifecycle or legacy monitoring, where monitoring remains in place for the life of the structure, and how can this data help us to build more sustainable underground structures?

Maxwell: In most cases we have seen this only for parts of tunnels where stresses are expected to be complex, such as at cross passages or at geological boundaries. In some cases, such as the 30km of sewage tunnels in Singapore, the multilayer concrete and HDPE linings are being constructed with embedded optic fiber along their whole length to check for interlayer strains and deterioration during operation.

Thurlow: Big progress has been made on this, which is great. The way forward is for the owners of the structure to specify it from the start with clear intentions of the instrumentation, and own it once installed. The model of getting contractors to install instruments and then handing them over for the structural health monitoring long term does not work too well right now.

Galisson: We don't see it in tunnels so much in North America – in bridges we see it a lot, and somewhat in dams. There were a few initiatives to place sensors in concrete segments, and there is some interest but it's not a standard yet.

What resources are available for contractors, owners, and stakeholders to learn how to interpret monitoring data?

Galisson: More and more vendors offer economic solutions including hardware and software, directly to the final user. They also provide the training to their clients to deploy and operate those products. This works well for small and basic monitoring projects. I'm a bit more cautious with this model in case of large complex monitoring programs (typically urban excavations or tunneling). I think it may be misleading to pretend that through a quick and limited training, you can convey all the important information to anyone starting a new monitoring program.

Integrators remain a rich and unbiased source of information for the tunneling community, should it be for the design of a monitoring plan, for good practices on site, for the processing and visualization of the data and for the screening of the integrity of the monitoring data. They built their knowledge on experience and R&D for decades and are aware of the most recent cutting-edge technologies available. Involving those specialized companies as a partner at an early stage in a project is most likely beneficial for the success of the project team.

Maxwell: I think it is assumed that since engineers did a design prediction they will have an idea of what they are expecting to see. Unfortunately, it is rare for the designers to be supervising the job and results don't always give the expected for a variety of reasons. Whilst the industry has a lot of guidance on best practice for installation and ongoing monitoring methodology, there doesn't seem to be much out there for how to decipher what the data is telling you.

Thurlow: Apart from suppliers' information, there is not a lot out there for interpretation. The best resources are case studies. There are so many great conferences that now have added an instrumentation section for submissions. There are some excellent online sources such

Structural monitoring of the 6th Street Bridge in Los Angeles, CA.
Photo: Geo-Instruments

as the Canadian Geotechnical Society who have collected all the 246 papers on instrumentation that John Dunnicliff edited and published over 20 years. It's well worth a browse. Good, experienced practitioners are always the best resource.

There's been some talk in recent years of an open-source database where anyone can learn from monitoring data on real projects. How close do you think we are to something like that, and what are the barriers? Do any paid databases exist?

Galisson: We have been trying to collect a database from past projects for years so students can learn from it, understand the benefit of instrumentation. However we have never been successful at convincing clients to share monitoring data even after completion. They see it as too sensitive even for academic purposes. No, as far as I know, there is no open data source, either for research or academic purposes.

Thurlow: The mechanisms for storing and preserving monitoring data have been around for many years. There is always the question of who owns the data and how it will be used, which suffocates the industry. UCIMS for example was a project database I know of, formed by the owner on Crossrail. A lot of work was put in to pull in data from all Instrumentation & Monitoring (I&M) software used across the project, but it is not available for public or academic use after.

Maxwell: The owners need to agree to release the data. Over the past 10 years we have gained agreement from a handful of parties to provide data to universities but even though this was available it was seldom used. The only database I am aware that is completely open is the New Zealand Geotechnical Database. I am not aware if this contains instrumentation records. One frustration I hear frequently is the absence of a standard lexicon for the transmission of instrumentation data. AGS-M (a standard of data transfer produced by the Association of Geotechnical & Geoenvironmental Specialists) exists in the UK and some other countries but is suited for archival use and not real time.

What is something about monitoring systems that you wish more contractors and/or owners knew about?

Galisson: The level of peace of mind that they could get if the monitoring system is properly designed, installed, maintained and presented. It's rare to have all those components done well and properly thought out when the project starts. It's something we could all benefit from – whether it's the owner, contractor, or public living around the project. Having a good monitoring program provides a lot of transparency in what's happening, which reassures all the stakeholders around the project.

Thurlow: That you don't buy sensors off the shelf, and they immediately work. There is a lot of work behind the scenes to install, commission, maintain and deliver the digits you see on the screen. Take advice from the start of a project. The location and compatibility of instruments are important to consider while planning. Get the instrumentation in – ahead of time—to understand the environment you are going to monitor.

Maxwell: The importance of identifying and understanding natural ambient movements of things being monitored. These are always present and mostly driven by temperature and saturation. Failure to recognize these movements lead to impossible criteria being set.

A long time ago I tunneled under an existing immersed tube tunnel (IMT). It was experiencing some cracking at one 120m long box. We were told as a result that the allowable settlement was zero. A liquid level system with manual levelling was undertaken and the box connections were monitored in XYZ directions. Due to tunnel delays we had a year of data before the tunnel approached. As our tunnel passed the IMT appeared to drop by -5mm which caused some alarm. Since in the previous year it had also been observed to have dropped with no influence of the tunnel, calm heads prevailed and the excavation was allowed to continue. By the time the tunneling was complete the tunnel had rebounded to +1mm. The monitoring of the box junctions showed that these were also opening and closing by almost 10mm every year. The structure was really in constant motion and it was this that contributed to the ongoing cracking.

The common pre-supposition that objects are stationary is just not correct and the identification of ambient movements is a key part of a successful monitoring exercise.