Keynote address

Using geotechnical innovation to reduce project risk

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ABSTRACT

Project risk is commonly defined as an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives. As the construction industry continues to deliver larger and more complex projects, improving how we manage project risk is a key priority for clients, contractors and designers. Within this digital age, innovation and change in our industry will play a key part in how we manage risks and deliver projects. This paper considers how we can define 'innovation' and how innovation can be promoted within organisations and on projects. The classification of something as innovative can vary widely depending on its novelty and context. The journey from creativity (an idea) to a productive solution (innovation) is difficult and frequently does not materialise. Three examples of innovation are presented to highlight the range of productive solutions that can be considered as innovation within their context.

1. The development and benefits of public Geotechnical Databases; novel within the context of Victoria
2. Incremental innovation in the use of InSAR satellite monitoring.
3. Radical/modular innovation using automated processed to import piling construction records back into project models to validate QA and geotechnical ground models.

Keywords: Innovation, InSAR, Geo-database, piles, risk

1 DEFINING INNOVATION

There are many definitions and concepts around innovation. The definition of innovation varies according to the context and field of application such as organisational structure, customer service or technical fields. Across the many definitions and fields, two main dimensions of innovation can be considered (Edison, et al., 2013):

1. the degree of novelty (new to a firm, new to a market, new to the industry or new to the world), and
2. the kind of innovation (whether it is a process, product, or service system innovation)

Within this framework, innovation can take many forms and in particular, the degree of novelty means the technology systems which are well developed elsewhere, can still be considered as innovation providing there is a productive outcome.

1.1 Technical innovation

Within technical fields, a commonly adopted framework divides innovation into four types (Henderson & Kim, 1990):

- **Radical innovation:** Establishes a new dominant design and, hence, a new set of core design concepts embodied in components that are linked together in a new architecture (e.g., the establishment of Finite Element Modelling (FEM)).
- **Incremental innovation:** refines and extends an established design. Improvement occurs in individual components, but the underlying core design concepts, and the links between them, remain the same (e.g. improvement in viewing FEM results)
- **Architectural innovation:** innovation that changes only the relationships between them core design concepts (e.g. ability to import ground profiles into a FEM)
- **Modular Innovation:** innovation that changes only the core design concepts of a technology (e.g. improved algorithms for resolving FEM)

Each of these fields could have different kinds of innovation (process, product or service) noted above.

1.2 Creativity Vs Innovation

While creativity and innovation are related, they should not be confused as the same thing. Creativity is the ability to generate new ideas or plans, whereas innovation is the ability to apply the ideas in a productive manner. Early models of innovation (Utterback, 1971) considered three phases of innovation: 1) creative idea generation 2) turning the idea into reality (i.e., an invention) and 3) having an economic impact through implementation.

1.3 Delivering innovation

Successfully taking creativity and delivering it into innovation depends greatly on the environment within an organisation. A culture which both embraces innovation and has a process for delivering innovation is required. To successfully develop an innovation, first a specific need must be identified, macro and meso trends must be understood, competency must be developed (people and technology) and financial support provided. Goals and aligned actions must be defined, supported and tracked using metrics during development.

Once an innovation is developed, the lifecycle and impact on the market changes over time as the product is first established, then widely adopted, incrementally developed as it matures and eventually declines is usage (Figure 1). Businesses and industry which rely on innovation require a succession plan of innovation projects moving through the product lifecycle.

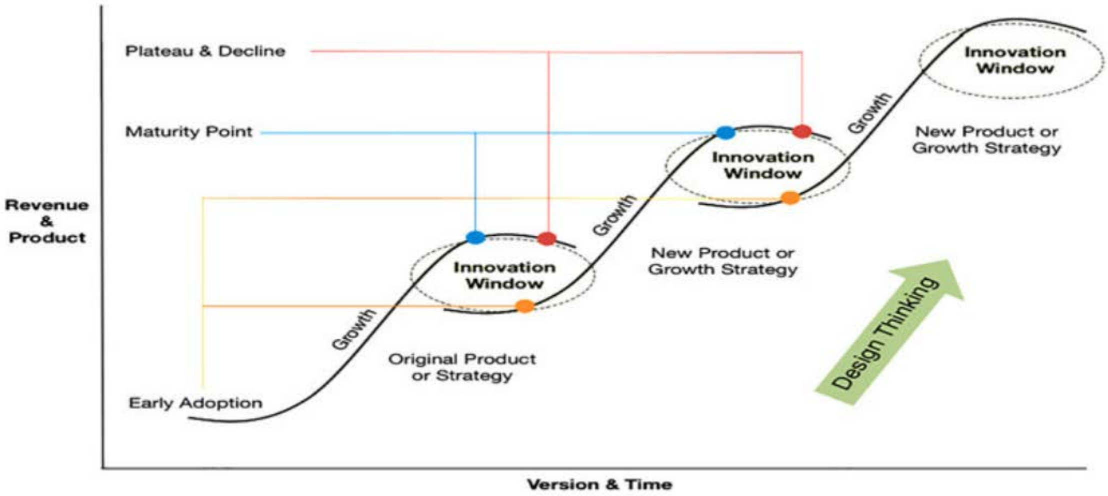

Figure 1. Innovation life cycle showing with succession planning within a market for continued high performance (Mazouz, et al., 2019).

1.4 Opportunities for Innovation

Within this digital age, the opportunities for innovation to revolutionise how we operate are emerging into all facets of our industry. Opportunities include;

- Automated processes ranging from simply eliminating repetitive activities, to scripting complex models to parametric design process.
- The evolution of Digital Twins connected to the Internet of Things (and conversely their Evil Twin, bloated with excess data) (Hannel, 2019).
- Machine Learning and Artificial Intelligence are changing our use of data and design processes.
- Robotics and drone automation as our construction sites become smarter, with autonomous trains, vehicles, and drone 'swarms'
- Virtual reality and augmented reality
- 3D printing
- Big Data, Blockchain and Cloud technologies supported by 5G and Wi-Fi 6 networks

For this paper, three examples of innovation have been selected to show different ranges of activities which could be defined as innovative. A key feature of all three are the degree of novelty, the kind of innovation (process, product, service) and the generation of productive outcomes.

1. The development and benefits of public Geotechnical Databases.

2. Incremental innovation approaches for the use of InSAR satellite monitoring.

3. Radical innovation in adopting construction monitoring data into digital models, akin to integrating the Internet of Things into construction. The Smart Piles platform presented is modular application of the broader concept, which is globally novel from a design and QA perspective

2 SHARED GEOTECHNICAL DATABASES

Innovation can be classified as the adoption of existing technology or system and applying them within a local market. Within the Melbourne market, there is a gap in the collation, management and delivery of geotechnical data that supports industry and maximises the return on public investment. Public geotechnical borehole databases, and associated geoscience datasets acquired as part of geotechnical investigations, are a relatively common structure in other States within Australia and globally, although the structure and sophistication of the databases vary. The Geological Survey of Victoria (GSV) is working with government partners to scope the development of a Victorian geotechnical database. The aim of the database is to augment existing free public resources delivered by the GSV such as GeoVic, the online mapping application that enables users to build their own maps, using an array of datasets, perform searches and access data, the GSV catalogue, and the Victorian Drill Core Library located in Werribee.

2.1 Benefits of public geotechnical databases

The following are the key benefits generally identified with public geotechnical data bases, many of which directly assit reducing project risk:

- The greater the availability of geotechnical information to inform design and construction, the more efficient and less wasteful design and construction can be. This logic would be shared by most geotechnical practitioners.
- Increased information and knowledge of wider geotechnical conditions mitigates the risk of project delays, cost over runs and environmental impacts.
- Databases present geotechnical logs and other information in a single accessible location and thereby reducing data management inefficiency, optimise site investigation planning and support scoping, early-stage design and feasibility stage geotechnical risk assessments.

- Reduce the cost of projects both by reduced investigations and less conservative designs with more informed geological (3D) modelling.
- Provide a cost-effective way of compiling and sharing information, opening opportunities for cumulative crowd sourcing from smaller, private projects, which reduces inefficiencies in retrieving achieved files and relying on historic knowledge of projects when planning investigations.
- The data lives on in the public domain following the end of the project and/or agency.
- Facilitate the research into geotechnical properties of materials, geological profiling, and education.
- The re-purposing of geotechnical investigation data from projects for other areas of public good geoscience, examples in greater Melbourne include improved understanding of sea level rise and fall and volcanic eruption frequency.

It is estimated the total site investigation saving for residential property from the Christchurch Geotechnical Database is in the order of $50-$100 million NZD (Scott, et al., 2015). This excludes savings in infrastructure and commercial development project and qualitative benefits such as the improved confidence in project risk and more efficient delivery.

2.2 Geotechnical database examples

A of review of relevant geotechnical data bases is summarised, demonstrating the recognised benefit to the construction industry:

- In the 1970's the Urban Geotechnical Automated Information System (UGAIS) was developed in Canada, funding the creation of geotechnical databases for 27 cities involving records from over 110,000 boreholes. While several of the data bases are no longer in use, many still are. The Ontario databases includes data from over 90,000 boreholes and in 2015 was accessed on average almost twelve times every workday (Thompson, 2016).
- The British National Geotechnical Properties Database was launched by the British Geological Survey (BGS) in 1992. The database includes over 100,000 boreholes and the web viewer portal is accessed over 60,000 times a month (Thompson, 2016).
- The Perth, Australia Central Business District (CBD) database was created in 2004 with 649 boreholes from the 1970's.
- The Canterbury Geotechnical Database (CGD) was created to generate efficiencies in sharing geotechnical information following the earthquakes of 2010 and 2011 around Christchurch. In addition to hosting over 26,000 borehole and CPT records, it also includes regional assessments and maps of liquefaction susceptibility. The CDG assisted with the design and construction of residential, commercial and infrastructure rebuilds, as well as city planning and enabling the insurance industry to understand and manage development risks. In 2016 the New Zealand Ministry of Business and Innovation launched the New Zealand Geotechnical Database (NZGD), which combined the CGD with other regional databases. The NZGD has over 130,000 data points and is used by over 6,000 users.
- The Queensland Geotechnical Database (QGD) was launched in 2017 with a view to consolidate primarily tax and toll payer subsidised exploratory investigations. The database holds over 1,600 geotechnical investigation records.
- The NSW government is currently working on the Government Geotechnical Repot Database Project (GGRD) to collate geotechnical investigation records.
- Progressive European nations have recognised the value and importance of geoscience (geotechnical investigation) data and knowledge (urban geology models) in infrastructure planning and development for sustainable cities. Sub-Urban group compiles data and models from multiple European Geological Surveys, Cities and Researchers (including international partners) http://sub-urban.squarespace.com/

2.3 Development of a Victorian geotechnical database

There have been recent changes to Victoria's public construction guidance. When procuring services for geotechnical investigations, or Works or Services that may require geotechnical investigations, Agencies must ensure that their contracts provide for the ownership and custody of geoscience data collected for the project to be transferred to the State of Victoria, where:

- 'geoscience data' includes geological, geotechnical and environmental information, reports, maps, images, recordings, survey results and drill core, drill cutting and associated materials embodied in any form; and
- 'geoscience data collected for the project' includes geoscience data generated, placed, stored, processed, retrieved, printed, accessed, or produced using data supplied by the Principal, for the purpose of the contract.

Within Victoria, the GSV is in the process of scoping the compilation and public delivery of all geotechnical investigation physical (i.e. drill core) and digital geoscience data acquired as part of geotechnical investigations undertaken as part of State of Victoria infrastructure projects.

The GSV are working through agreements with current major projects and stakeholders on the transfer and release of geotechnical data. The Suburban Rail Authority Loop Authority (SRLA) is coordinating with GSV to provide data from 560+ geotechnical investigations already completed for Stage One of the project. Discussions are ongoing for the provision of construction stage face mapping and geological records to supplement the project investigation data.

3 DEVELOPMENT OF INSAR MONITORING

Interferometric Synthetic Aperture Radar (InSAR) is a radical, innovative satellite-based ground movement monitoring system that is increasing become commonly place on major infrastructure projects and forensic studies. It significantly enhances and complements traditional survey monitoring approaches.

Satellite based InSAR has been applied across a range of major infrastructure, mining, forensic and geohazard assessment projects. Within the sphere of metro rail tunnel projects, InSAR came to prominence in Europe slightly over 10 years ago on multiple projects (Crossrail in London, Paris Metro Line 4, Barcelona Metro, Warsaw Metro). Within the Victorian context it was adopted on the Metro Tunnel Project in Melbourne and has been procured by the Suburban Rail Loop project to baseline and understand existing historic ground movements.

InSAR measures ground movements by comparing two or more Synthetic Aperture Radar (SAR) images of an area to identify surface movements over time (refer Figure 1). InSAR enables ground movements to be monitored over spatially extensive areas to a high level of accuracy (typically 1-3mm). Radically innovative technology considering the data comes from satellite hundreds of kilometres above the earth. Benefits of InSAR include:

- Extensive spatial coverage which is suitable for assessing regional ground movement trends.
- Can assess seasonal shrink/swell effects, thermal effects (e.g., bridges) existing consolidation and/or groundwater related settlement.
- Satellites have been collecting and storing data over most urban centres in Australia for more than seven years, enabling historic data to be processed from time periods prior to project commencement and assist with establishing baseline ground movements; and
- Monitoring can cover sensitive urban areas and structures, mitigating the need for access (e.g., rail corridors) and approval (e.g., heritage structures).

Limitations with InSAR include:

- Satellites typically collect data every 7-14 days and, therefore, more conventional automated systems are required to assess movements during construction. Additionally, data requires processing, which is typically undertaken in batches of 3-to-6-month intervals.
- The location of monitoring points cannot generally be controlled. The processing requires consistent backscattering to develop a reliable data point for processing (such as kerbs, outcrops, or structures) and may not be reliable over vegetated areas. On Crossrail the X-band data generated one monitoring point approximately every 40m2 (Garcia, et al., 2016); and
- "Unwrapping" errors if rapid ground movements occur between satellite passes. Where large settlement (i.e. <10mm) occurs between satellite passes the comparison of SAR images can assess the data as heave instead of settlement. Unwrapping errors in data can be easily re-calibrated with manual settlement monitoring if required.

While InSAR can't replace automated systems, it can successfully complement them, providing historical ground movements, assessing regional settlement/heave, reduce the extent of conventional monitoring and provide cost effective long-term monitoring. On the Crossrail project the procurement and data management of InSAR was in the order of a magnitude cheaper than maintenance and data management of automated data monitoring (Gonzalez, et al., 2017).

InSAR's massive spatial coverage, high accuracy, regular readings, and ability to model historical movements make it a radically innovative approach to surveying.

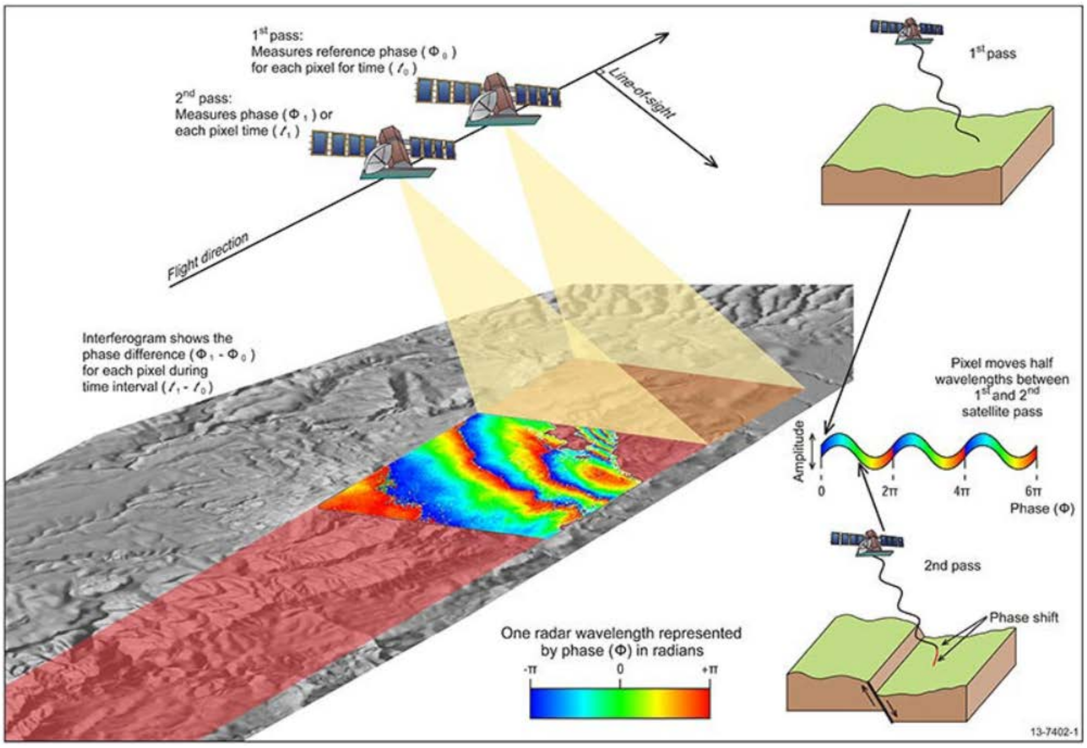

Figure 2. Two SAR images of the same area are acquired at separate time intervals and the phase shift in the reflected wavelength is used to assess the differential movement (Geoscience Australia, 2021)

3.1 InSAR incremental innovation

Incremental innovative improvement of InSAR is ongoing to expand its use and application. Two examples are provided.

3.1.1 Artificial Reflectors to monitor areas of low coverage

The Suburban Rail Loop Project is collating historic InSAR data to baseline existing ground movements and identify areas of existing ground movement risk. Part of the project includes the construction of stabling yards over areas which have a history as former mixed landfill sites (Suburban Rail Loop, 2021). It could be reasonably expected that historic landfills have an ongoing settlement risk. These areas would be a perfect application for InSAR monitoring, however there is very poor spatial coverage due to the vegetated nature of the area and ongoing site activities.

Suburban Rail Loop Authority, working with our technical advisors and Sixense Oceania have established a series of InSAR artificial reflectors over the site (Figures 3 and Figure 4). The reflectors generate a strong and reliable image which can be readily recognised in SAR data. The adoption of artificial reflectors grassed areas overcoming one of the traditional limitations of InSAR and facilitates accurate, frequent and access free monitoring at a significantly cheaper cost compared with traditional survey approaches.

Figure 3. InSAR reflector installed at the SRL stabling yards (courtesy of Sixence Oceania).

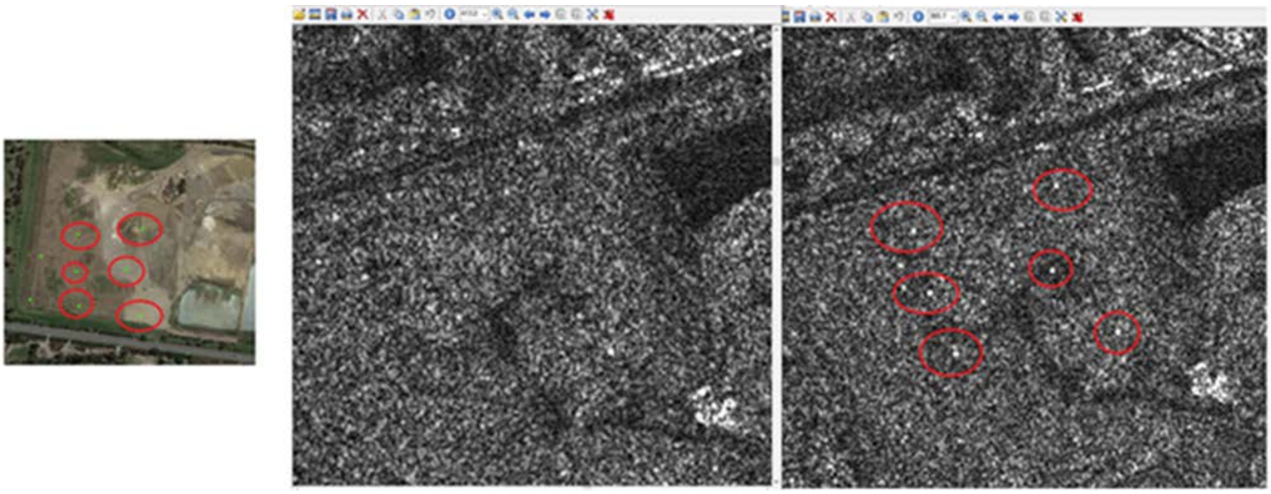

Figure 4. InSAR reflectors installations being picked up clearly within a grassed area (before and after images courtesy of Sixense Oceania).

3.1.2 Commercialisation of space

The miniaturisation of satellites combined with the increasing availability and affordability of commercial space payloads has significantly reduced the cost of launching satellites. Subsequently the number of commercial satellites orbiting the earth is quickly increasing, enabling incremental innovation in the use of InSAR monitoring.

Within the context of InSAR, the increased number of satellites relates to an increased frequency of readings. Currently InSAR reading using a single satellite are typically recorded on a two-week frequency (8-14 days), which is one of limitations compared with traditional survey approaches. However, commercial organisation such as Capella Space are rapidly launching additional satellites and within three years, by using readings from multiple satellites the monitoring frequency may reduce to daily, or even multiple times per day. Subject to the InSAR image overlay and batching process becoming more automated, this increased frequency has the potential to significantly alter how InSAR monitoring integrates with traditional monitoring approaches. This higher frequency of monitoring has the potential to move InSAR through a subsequent cycle of innovative growth.

Within a broader industry context, the commercialisation of space with increased frequency and higher resolution of satellite imagery may have large impacts in fields such as coastal engineering, hydrology and tracking construction progress, particularly when combined with advanced in artificial intelligence and data-driven models.

4 CONSTRUCTION DATA TO DIGIAL DATA

While advances are being made in developing existing asset data and designs into digital models and digital twins, to complete the data cycle we need to look at integrating construction data directly back into our models. Currently construction data collection and automation are typically targeted around increased productive to reduce construction costs and programme. One of our next steps as an industry must be integrating these digital systems directly into our digital design models to validate geotechnical models, improve quality control systems, manage geotechnical risks and provide efficiencies in automated development of as-built records.

Collection and use of data from sensors, aka the Internet of Things (IoT), is already rapidly occurring within other industries such as healthcare, manufacturing, agriculture and energy. The construction industry is not as advanced, but the use of automation and machine learning processes are advancing rapidly. The industry already has many established systems ranging from data collation on automated monitoring platforms, robotics in construction (e.g. drilling for tunnel ferrules), autonomous mining trucks, UAV surveys, tracking materials/supplies and GPS positioning of plant.

Adopting IoT construction solutions has the potential to improve workplace safety (e.g. wearable IoT devices, fall detection apps), resources management, reporting and maintenance, reduce insurance premiums, mitigate wastage and theft. However, the industry also faces challenges including employee privacy, data security, cost vs benefit and collection of all data vs useful data. For the time being it is likely that advances in IoT construction solutions will come from large building and infrastructure projects where the benefit will outweigh the effort to implement new systems.

4.1 Smart piles

Smart Piles is an innovative product which has been developed by Arup as a tool for collating and using data from piling rigs. The tool collects site data from piling rigs to visualise progress, undertake quality checks and integrate construction record data back into project geotechnical models. Research within Arup has played a fundamental role in identifying and leveraging business opportunities, with a structured, global approach to research engaging over 1,900 staff across 500 research projects annually (Arup, 2021).

Most modern piling rigs have sensors which record data with depth for piling, soil mixing and ground improvement activities. Examples of data types include penetration depth, inclination, drilling torque, rate of progress and concrete pressure (see example in Figure 1). Traditionally these records are provided as hard copy PDFs for a review of quality (embedment depth, grout pressure etc) or as a record of construction. However, this digital information can also be uploaded to a cloud-based server relatively easily akin to an Internet of Things (IoT) approach, opening various avenues of digital manipulation.

Within the construction industry, many operators have already similar approaches to extract digital piling rig data to provide insights into construction productivity and quantities. Smart Piles takes the same data and uses automated processes to provide:

1. Automated quality control reviews.
2. Verification and development of project geological models,
3. Interrogation of data during construction and visualisation of piling data into BIM as-built models.

4.2 Quality control reviews

Quality reviews of piling records by designers are typically complete at the end of the project or when zones of the work are completed. Designers normally check grout pressure and embedment depths to confirm that the as-built records meet the design requirements. Smart Piles uses automated processes to review piling construction records to verify the quality of each pile as it is constructed to provide early warning of construction issues (Figure 5). The system effectively completes all necessary QA checks, reducing input from engineers reviewing logs and providing confidence in the works.

4.3 Verification of project design models

Manual reviews of piling records will often look at changes in drilling penetration/torque to help validate ground models and design assumptions. This is particularly important in lateral loading designs including lateral spreading associated with liquefaction, where the depth to a firm layer is a key design assumption. On sites with variable geological profiles, pile layouts may change across the site according to changes in subsurface profiles.

Smart Piles uses automated process to review logs during construction, enabling changes in construction conditions to be assessed immediately once pile records are completed and integrated back into the geological models. This is a more proactive approach to identifying ground changes and managing ground risks, particularly on complex sites.

4.4 Interrogation of digital pile data

Once pile data is available in a digital format, it opens new opportunities for construction reviews. Within the piling industry some organisations are using digital piling records to review construction programmes and assess the rate of piling productivities.

Smart Piles can take the automated quality control and design verification process and integrate them spatially into digital models. This enables the automated quality and design verification processes and checks to visually communicated across the site, enabling both issues to be address early in the construction process and opportunities for refinement to be identified early enough so that they can have a material impact on the works.

Smart Piles also enables digital as-built models of the piling works to be produced in an automated manner, providing cost savings and improved quality to produce LoD 500 BIM models.

Smart Piles is a step towards closing the gap from 'design' to 'as-built', using modern digital technologies in an automated and innovative way.

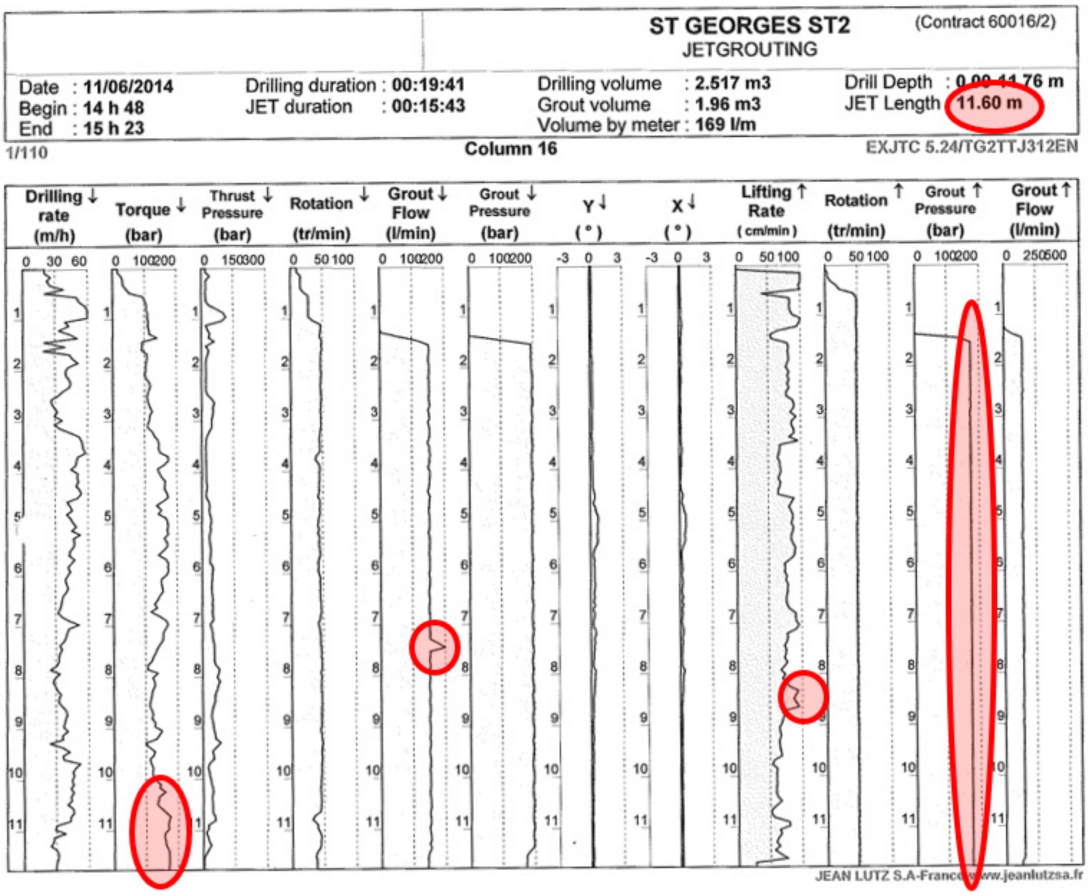

Figure 5. Example of a piling rig installation records where checks can be completed on consistency or variations in the data.

5 MANAGING PROJECT RISK THROUGH INNOVATION

Project risk is commonly defined as an uncertain event of condition that, if it occurs, has a positive or negative effect on a projects objectives. As the construction industry continues to deliver larger and more complex projects, improving how we manage project risk is a key priority for clients, contractors, and designers. Introducing ideas, practices or object that are new (aka innovation) are a central component to improving how we manage project risk.

The three examples presented show different ways in which innovation will continue to shape our industry within Victoria ranging from adopting established systems, implementing emerging technology and looking forward to the development of future tools and processes. The innovations described all improve our knowledge on project and reduce the potential for errors and uncertainty, effectively assisting us in reducing project risk. Added benefits of innovation also generally include program and cost savings.

However, experience shows that the process of taking creative ideas, developing them into reality and then successfully implementing within the industry is difficult, requiring focus and effort. The journey from creativity (an idea) to a productive solution (innovation) is difficult and frequently does not materialise. Typically of the small number of innovations which do emerge, very few make a significant impact on our industry. To continue to support innovation we need to establish a culture of embracing innovation and processes to support innovation though its lifecycle.

6 CONCLUSIONS

There is a range of ways in which innovation can be implemented to reduce project risk. In defining innovation, the degree of novelty is an important concept, ie adopting an established system which is new to its local context can still be considered innovative. Similarly, we can differential between radical and progressive innovation as we progress through a products lifecycle.

Three examples of innovation have been presented to highlight the range of ways innovation can be applied on projects. 1) The development of public geotechnical databases within Victoria is an adoption of an established structure as a novel tool into an existing market. 2) InSAR satellite monitoring is an established radical innovation for ground movement monitoring which becoming increasing adopted on projects. Innovation with InSAR technology is being incrementally developed with the potential for a subsequent significant growth cycle. 3) Emerging innovation using data-driven automated systems to integrate construction data into digital models using tools such as Smart Piles. These innovations improve our understand of project hazards, reduce uncertainty, and subsequently enable us to manage and reduce project risks through planning, design and delivery stages.

Within this digital age, innovation will continue to play a key part in how we manage risks and deliver projects. The journey from creativity (an idea) to a productive solution (innovation) is difficult and frequently does not materialise. Successful continued delivery of innovation within organisation and the industry requires a culture of embracing innovation and a commitment to processes to deliver innovation.

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