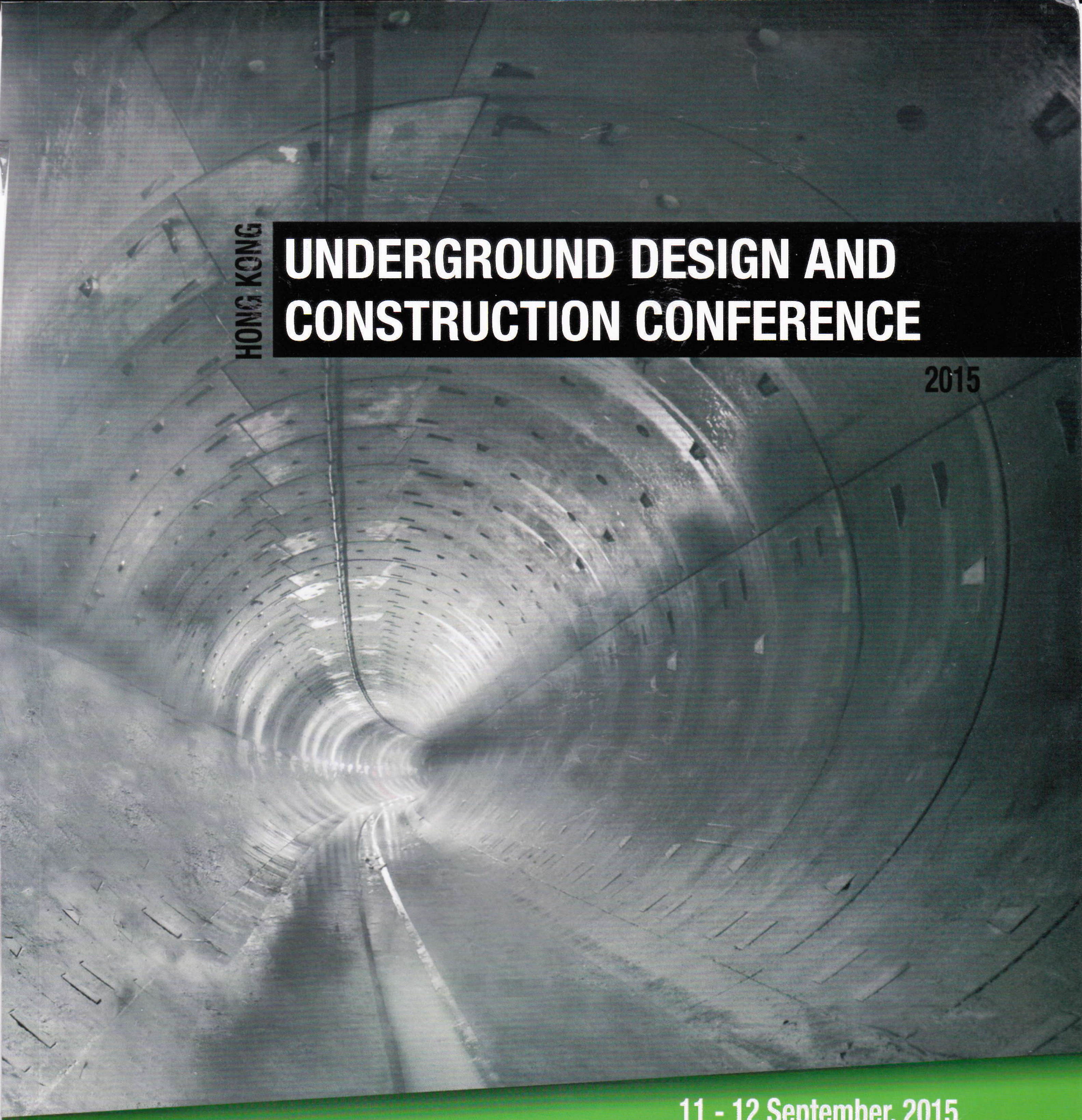

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Guidelines for the Implementation of Data Management Systems on Tunnelling Projects

S. Maxwell, A.M. Pearson & J. McCallum
Maxwell Geosystems Ltd., Hong Kong

ABSTRACT

As the amount of data increases on tunnelling projects the need for effective management systems becomes more apparent. With the increased use of mechanised tunnelling it is no longer possible to manually process and combine information quickly enough to manage tunnel excavation and ring build control effectively. Systems have evolved over the last 20 years to assist in this process. Initially systems focused on particular areas such as TBM control, guidance and segment construction as well as drill logging, geotechnical mapping and production management. Recently systems have evolved to bring all data streams together into one single management system for a project; a one stop shop for data delivered from the cloud. With all data easily accessible to engineers of client, contractor and design consultant the systems have started to form the foundation of tunnelling reviews and by keeping the systems 'open' and allowing the users to develop the systems in new directions there has been a growth in the development of expert systems to manage both technical and commercial tunnelling risk. The paper will review historical developments and describe delivery modes in several Asian countries.

1 INTRODUCTION

Since the dawn of the computer age there have been continued promises that computers would lead to a leaner more focused construction industry. According to McKinsey (2013) the last 30 years have not delivered the promise of increased efficiency and effectiveness for construction companies in line with the level of computer usage. In short computers have become a hindrance to achieving success of a construction project.

As with many things the best laid plans have fallen foul of human nature. Rather than being a tool to share work and speed up its completion computers have become a conduit for increasing the amount of work to be done. Computers have raised our expectations of quantity, quality and flexibility and because of the ease with which actions are passed around the number of un-actioned tasks in circulation has ballooned. This has led to a serious diversion of engineer's focus away from producing safely constructed works to producing libraries of paper which ultimately very few people read. As stated in the Tang report (Tang 2001) produced by the Hong Kong Construction Industry Review Committee in response to the Hong Kong piling scandals of 1998-2001 too much time is spent on paper administration of contracts and not enough on the direct supervision of construction. The industry needs to focus on its use of IT systems in order to achieve the benefits long promised but rarely delivered.

2 DATA AS A CONSTRUCTION RISK

2.1 Quantities of information

Aside from the general growth of data traffic the quantity of raw information collected on construction projects has more than doubled in the last 10 years.

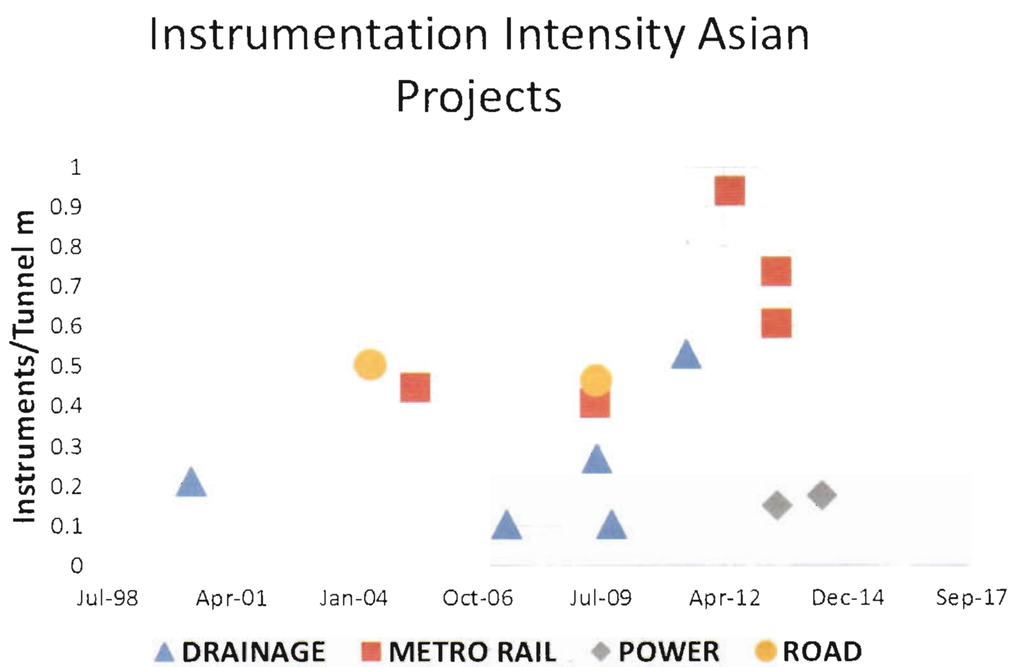


Figure 1: Instrumentation Intensities on Asian Tunnel projects

It is clear from Figure 1 and Table 1 that the data quantities have grown to a size which challenges our ability to manage it in a timely manner particularly on a project which is changing by the minute.

Table 1: Data Statistics for Asian Projects

	KVMRT*	XRL*	Powergrid*
Tunnel Length km	14km	52Km	39Km
Completed %	100%	90%	25%
Type	Metro Shallow	High Speed Various	Utility Deep
Number of Instruments	11259	32000+	14600
Instrumentation readings	20 million		10 million
Instrumentation Database Size	22.7GB		4.6GB
Number of Rings	9763	Not Monitored	5579
Max. Ring file size	100MB+	Not Monitored	250MB
Ring Database Size	>100GB	Not Monitored	>55GB

* At end 2014

Historically such data has been manipulated by individual data owners using spreadsheets. The data within the spreadsheets cannot be queried, is not easily shared and is not formulated within any standard convention either on a contract, project or enterprise level. The data is effectively unusable except by the individual who created the spreadsheet or to people he explains it to. As a result only very few people are aware of the actual situation or can use the data in a meaningful way. Furthermore since the data is only updated by the owner the data distribution to other parties may be delayed and this represents significant risk to projects.

2.1 Speed of collection

The amount of data which is now being collected in real time is increasing. For most tunnel projects "real time" is taken to mean data recorded at 10 minute intervals and sent remotely to servers for display within half an hour. This is distinguished from continuous data which will be recorded at potentially higher frequencies but is often only sent infrequently. Tunnel boring machines and other equipment with measure while drilling (MWD) capabilities may record at frequencies of 0.1 to 10 Hz and this need to be transferred quickly to the user for immediate analysis and decision making. The speed and volume of data requires heavy duty data management in order for it to be turned into useful information.

2.2 Demands on data turnaround

A summary of the data turnaround requirements is shown in Table 2. Many of these are same day and require post collection processing which leads to staff overtime.

Table 2: Data Turnaround Requirements

Data	KVMRT	XRL	Powergrid
Real Time Instrumentation	Within 30 mins	Within 30 mins	Within 30 mins
Manual Instrumentation	24 hrs	48 hrs	Before 8am
Alarm Notification and Response	24 hrs	Within 24hrs for alert and immediately for other	Within 24 hrs
Blasting	NA	Date and report within 4 hours	Data immediately Report within 24 hrs
Safety events	Immediately	Immediately	Immediately

The need for overtime working can be mitigated by increasing the amount of automated processing of the data which requires smart systems to recognize and deal with the errors which may creep into data measurements. It can further be improved by moving data management and data measurement to the point of collection. This enables the technician to incorporate more effective checks on the data before forwarding for release to the public.

2.3 Data ownership and the human effects

Data hoarding and data leakage are recognized employee traits which result in the storage of enterprise data in the wrong places. According to InformationWeek (2013) every source of enterprise content should be completely under management's control, and hoarding must be disallowed. Increasingly, companies are losing control of their information, and employees are starting to save all of their enterprise information elsewhere.

2.4 Understand structured data

In many cases computer systems are put in place to accomplish a task only for managers to implement human systems which do not dovetail with the computer systems. This may be the format of the reports or the way in which the reports are delivered. Systems are powerful but must have a fairly rigid structure and syntax. Failure to recognize this introduces double and triple handling which deflects attention from important engineering tasks at hand.

Sometimes this is used as a reason to promote paper records or spreadsheets which can easily be altered at the final stages to user's desires. By moving towards this informal system the data contained becomes inaccessible to wider systems and is often lost to posterity.

2.5 Understand the processing

With such a large amount of data we would become quickly swamped and risk not seeing the important relationships between data sets. Systems give us the opportunity to perform extended processing on data to calculate new parameters which may have more direct construction relevance. With every layer of processing there comes a layer of assumptions, methods, corrections and extrapolation and users have to be aware of what has been done otherwise we are again reliant on a small number of people to truly understand the data.

Processing like any calculation should be checked and signed off by the relevant parties and this means that it must be transparent.

2.6 Communication

How can we communicate and use these large volumes of information effectively? If systems are inefficient they are ignored. A highly efficient way to have effective data communication is through the web. However, connection speeds are variable and information must therefore be condensed so that it can be delivered in time to be useful.

3 AN ABUNDANCE OF SYSTEMS IN ISOLATION

Systems arise as an answer to a focused need and these needs tend to be relevant to a small number of people who develop a high level of expertise in them. Examples might be CAD, BIM and GI databases, finite element modelling software and risk systems, and programme and commercial packages (Table 3). Only a few individuals have the expertise in each area, promoting bottlenecks and increasing the risk of a wider knowledge or understanding gap. Groups exist in separate silos and data is only given if asked for. What brings the systems together and where are the fail safes?

Table 3: Silo systems in infrastructure projects

Silo	Owned by	Needs data from	Interacts with
Commercial control	Commercial	Production, Programmer	Director
Document control	Owned by QA	All	All
Environmental control	Environmental (Sub)	Production	Production
Risk Management	Risk manager	Planning, Production, Geotech, Programmer, Environmental	All
Safety	Safety Department	Risk, Production, Geotech, Planning, Design	All
Instrumentation and monitoring control	Geotechnical, Survey	Production	Design
Ground investigation	Geotechnical	Geotechnical	Design, Production
Technical production	Production,	Geotechnical, Survey	Design, Planning, Production
Survey control	Survey	Design, production	Planning
Design and construction sequencing	Planning	Programme, Design	Programmer, Production
To be built and as built BIM	Planning, CAD	Design, Production	Director, Production, Client
Production Progress	Production	Planning	Director, Programme

4 DATA MANAGEMENT SYSTEMS: GLUE AND LUBRICATION

With each area having its own system to perform its specific function there is a case for another system to enable the communication of data between silos. This system acts as the repository for basic data used by all and a platform for each silo to publish its results from time to time, thereby communicating their information to the wider community. The system does not replicate the specialist software each silo uses but provides just enough capability across all the areas to enable non specialists to become informed in all areas. The systems are web enabled and are both the glue to bind the project's data together and the lubrication to smooth its flow.

4.1 The history of system development on tunnel projects

Computer systems have been implemented on tunnel projects since the late 1980s and these have been progressively widened, first over local and wide area networks and more recently on the web. A summary of the implementation of some of these systems is given in Table 4. Systems have been implemented by the designer's staff, by the client, by the contractor for the client and by the contractor themselves. If the contractor implements the system themselves they are unlikely to share the results with the client or client's representative. The largest natural uptake is when the system is implemented by the designer's supervisory staff. This is not surprising since the supervisor's job is to compile data, analyse and then present to the client. However in this case they are unlikely to share their data with the contractor and the contractor will also be collecting his own data. In this case we have two data sets and time will be spent arguing which data is complete or correct. Whoever implements the system uptake is always enhanced when the company empowers a driver to force its use across the whole project. For this to happen the drive must come from the Director or Executive level.

Outside of alliance, PPP or BOT/BOOT schemes where parties are already contractually united, a single system can only work in classically adversarial contracts if implement as part of a partnering approach. This is best driven by the Client who ensures that all parties are audited on their approach, commitment and effectiveness. This puts data management on a par with environmental, safety and quality control as a project level metric shared by all.

Table 4: Systems in infrastructure projects

Year	System	Coverage †	Owned by	When Implemented	Implemented by	Used by	Driver and Outcome
1988	Channel Tunnel (Black Ball)	P, Pr, SR	Resident Site Staff (RSS, QPS)	Construction	Design Supervision	RSS	Production Director -High Uptake
1993	CTRL (GDMS)	GI, Ec, Ev, R	Designer	Design/Tender	Designers geotechnical engineers	All	Geotechnical Director - High Uptake
1997	TDMS 1	Dc Sf, IM, GI, T, Pg, P, SR	RSS		Design Supervision	RSS, Client, Designer	Project Director High Uptake – used for future designs
2007	TDMS 2	Sf, IM, GI, T, TBM, Pg, P, SR	Contractor (specified)	Construction	Contractor	Client	None - Low Uptake
2011	UWD (IMC)	IM, GI, P, Ab‡	Client	Construction	Client	All	None - Moderate uptake
2012	JLE	IM, P	Client	Post construction	Client	Designer	Design director - low uptake
2013	UCIMS	IM, P, TBM	Client	Construction	Client	All	Client Director - low uptake – performance issues
2013	CDMS / IDMS	R, IM, GI, T, TBM, S, D, Pg, P, SR, Ab, B	Client	Construction	Client	All	Client Director - High Uptake
2015	TDMS 3	R, IM, GI, T, TBM, S, D, Pg, P, SR, Ab, B	Contractor (specified)	Construction	Contractor	Client	Contractor Technical Manager - High Uptake◊

† Cm Commercial, Dc Document, Ec Ecology, Ev Environmental, R Risk, Sf Safety, IM Instrumentation, GI Ground investigation, T Technical production data, TBM TBM data, S Survey control, D Design, Pg Programme, P Production Progress, SR Shift Reports, Ab As built, B BIM
‡ Only partially successful
◊ Misalignment with contract requirement means double handling

4.2 Integrated Project Wide System using Partnering – Powergrid Cable Tunnels Singapore

The Powergrid IDMS brings together information from investigation, design, production and monitoring. The system enabled all users to see the current status of their part of the project and some part of adjacent contracts where there was an interface. Each element of data can be queried and plotted both singly and in groups and can be combined with other elements for plotting either of common axes or against each other.

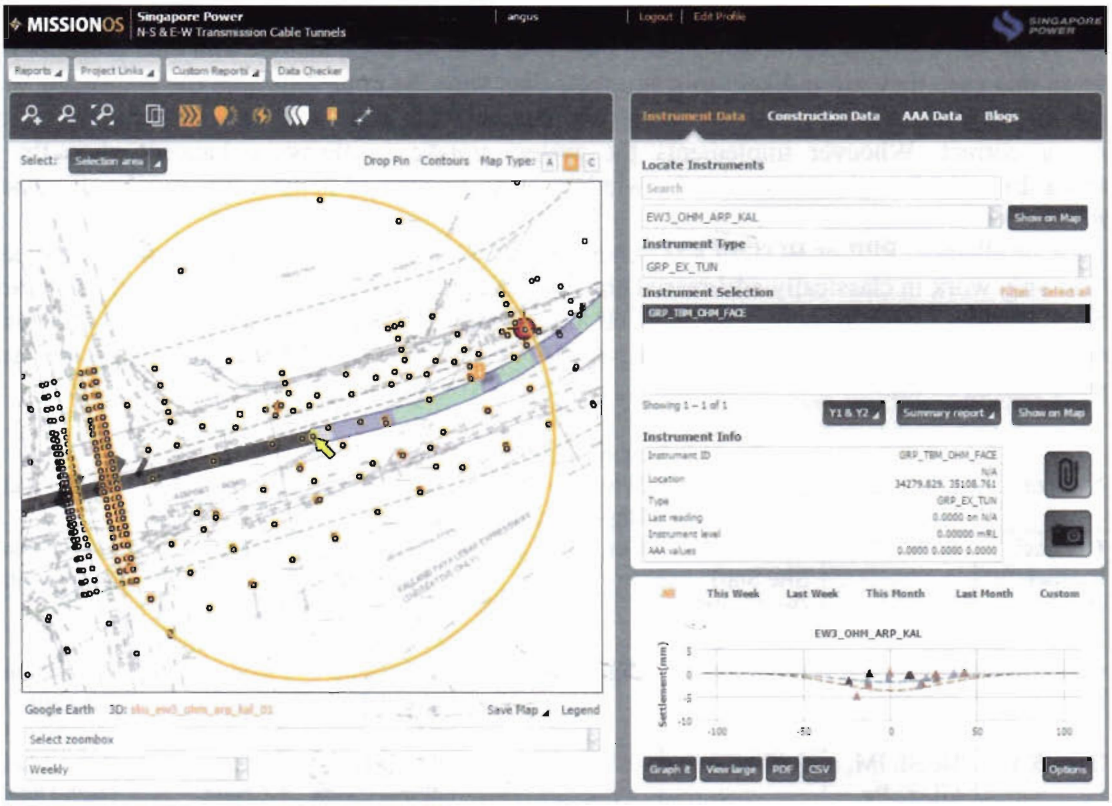


Figure 2: Detailed view of progressing tunnels with auto-calculation of predicted Gaussian settlement troughs. Ring colours show weekly progress. Excavation is beneath the KPE Expressway which is monitored real time by total station

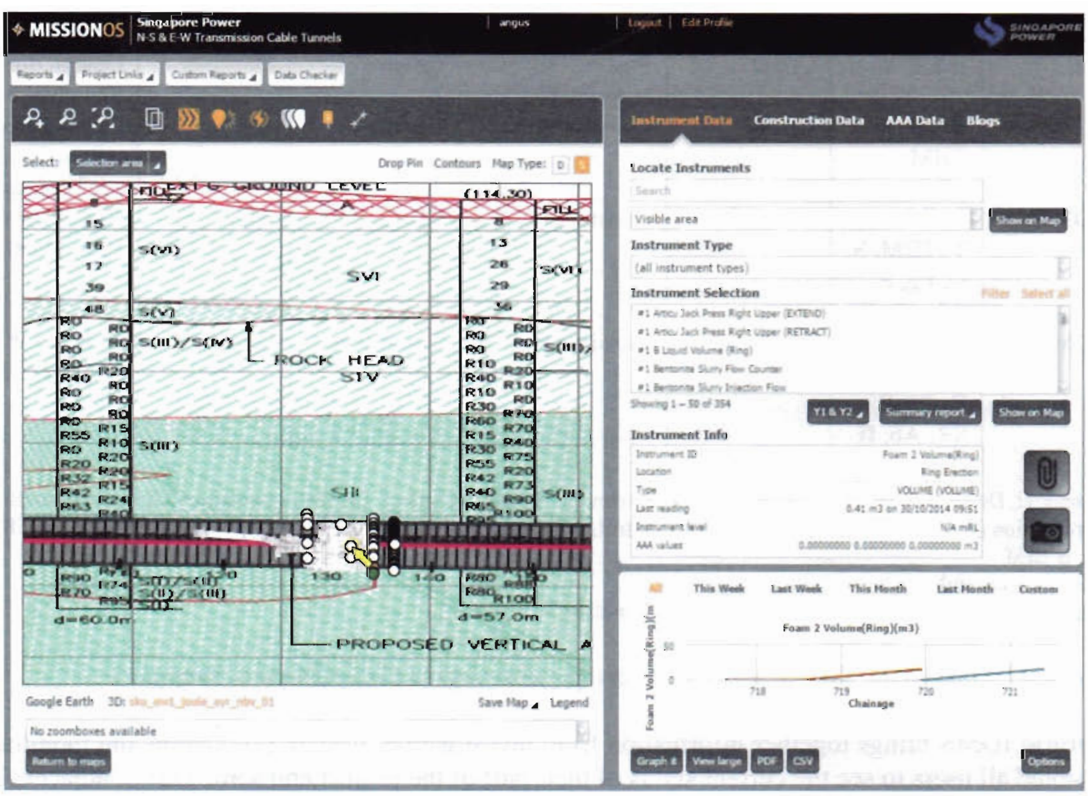


Figure 3: Interactive sectional views of tunnelling enable review of tunnelling parameters against geology

Information can be plotted as plan and sectional map views with overlain contours, as schematic user defined sections, as graphs against time or as X vs Y. All graphs are highly customisable.

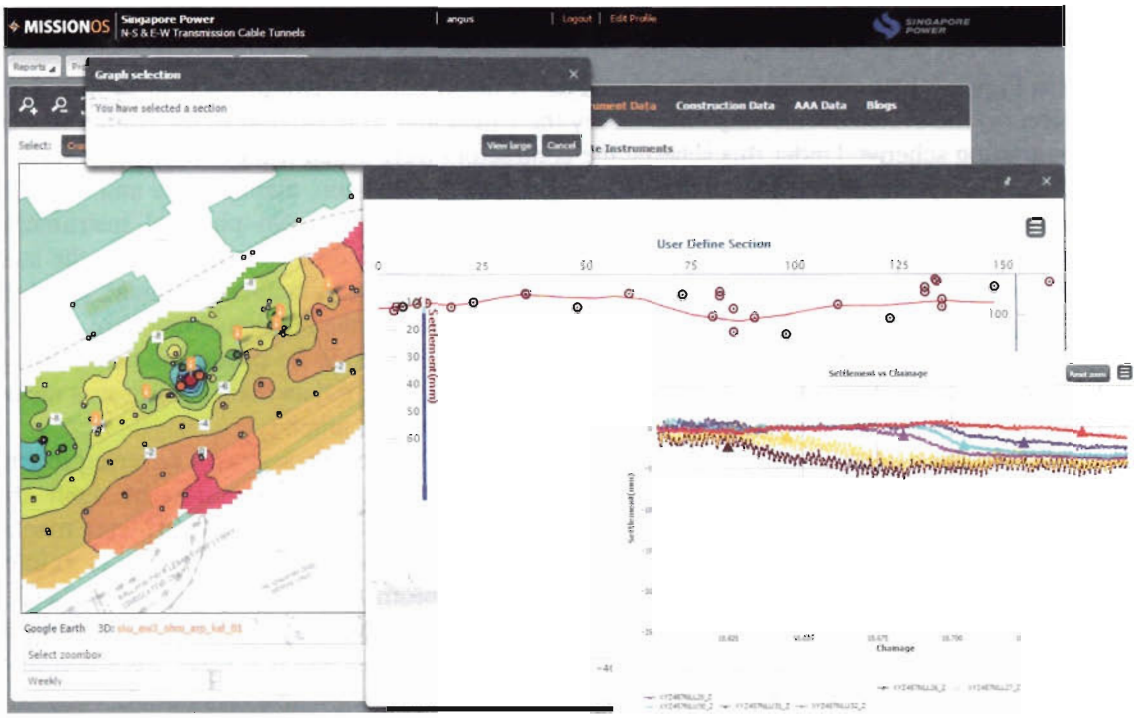


Figure 4: User defined sections can be drawn in any orientation and in any location and combine with contoured layers for best estimate settlement on the section line. Settlement time/chainage plots show pre and post excavation settlement

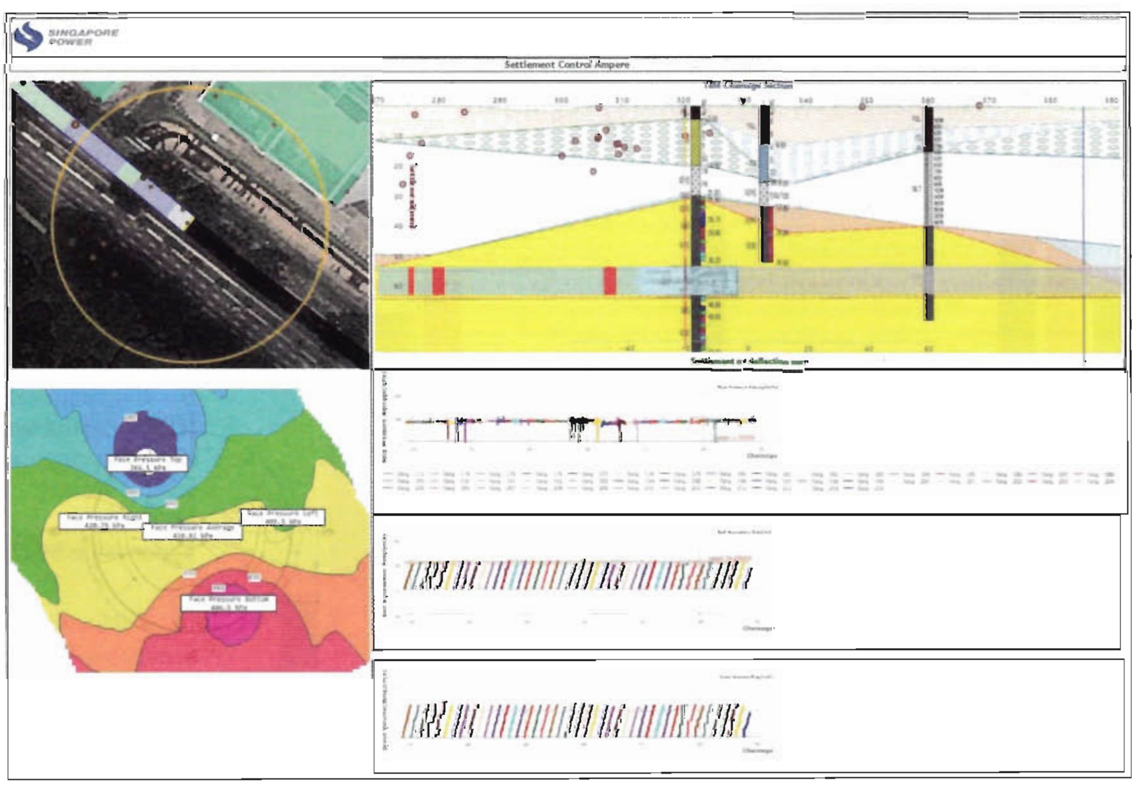


Figure 5: Combined TBM data and instrumentation data management canvas produced automatically

With all data spatially related analyses can be undertaken in terms of proximity to construction faces as shown in Figures 2 to 5 show. These spatial relations are calculated on the fly and are useful tools for analysing settlement development around the tunnels in varying ground conditions.

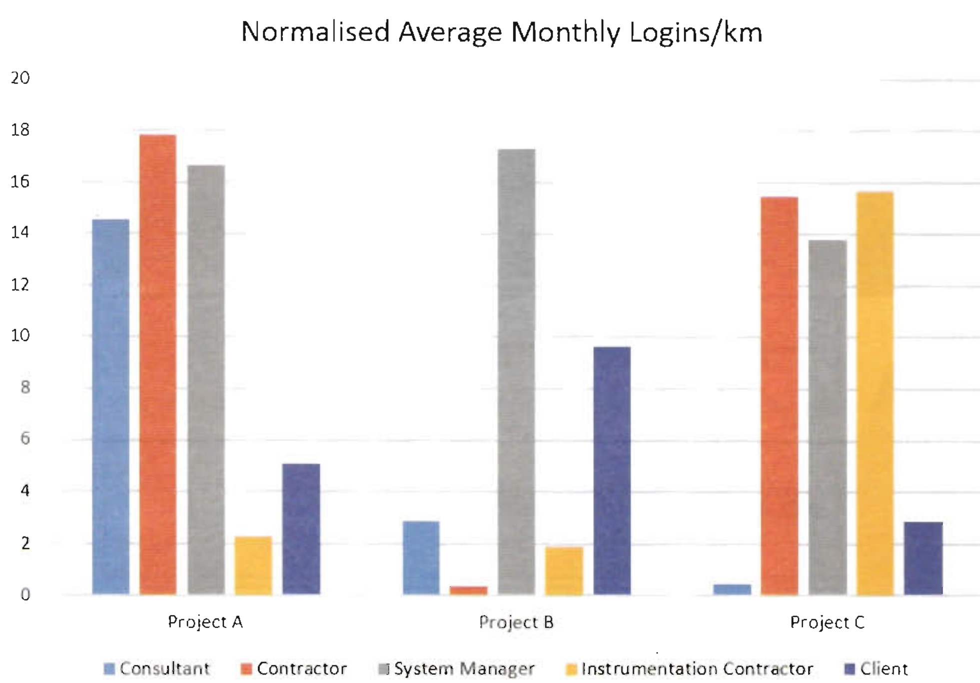
4.3 A comparison of usage on three projects

The graph in Figure 6 below shows the take up and use if the systems on two projects of similar size.

On project (a) the systems were implemented by the Client and were offered to the contractors at tender as part of a partnering scheme. Under this scheme the contractors were asked if they would contribute to the cost of the system. The system was tendered out as a single system provision, maintenance and data management contract to specialist system providers within the tunnelling industry. No physical instrumentation was required to be performed. Management of the contract was undertaken by the client under the auspices of a steering group populated by representatives from all the contributing contractors and client. Most importantly the client Project Director and Designers were all key drivers in the implementation of the system. All meetings to review instrumentation and production data were required to be conducted using the system as a platform. In this case the time saving and productivity improvement for data management was measured to be in excess of 25% which was recognized by the award of a government grant.

On project (b) the systems were implemented by the Client to provide a system covering instrumentation only but with a high reporting and a high physical instrumentation requirement such that system implementation represented only a small proportion of the contract value. The contracts were managed by the Clients geotechnical team. All construction contracts contained clauses requiring contractors to interface with the system provider but use of the system was not mandated or promoted to the contractors at the beginning of the project. During meetings the Contractors were not required or encouraged to use the systems to perform any of their duties under the contract. The Client's drivers in the geotechnical team were non director level and did not have authority to influence other teams of the project.

On Project (c) the systems were required by the client and delivered by the contactor. The systems covered instrumentation and TBM monitoring. The job was delivered as a design and build and the system was used extensively by the contractor to satisfy the contract requirements for control and to deliver the results to the Clients engineer. Supervision of the works was largely undertaken by the contractor and client themselves.



A. Conventional Contract, IDMS contracted by client, partnering with Contractors on system provision Director level driver. I&M no independent. Supervision by consultant.

B. Conventional Contract, IDMS contracted by client, no partnering, no Director level driver, I&M by contractor with IMC. Supervision by client.

C. D&C contract IDMS contracted by contractor for client. No Director level driver. I&M by contractor, supervision by contractor and client.

Figure 6 A & B, C: Monthly System logons on three projects normalized by size of job (tunnel length km)

These differences are clearly reflected within the usage statistics especially when the size of the project is removed. The system manager logons are similar around 15-20 per km/month. In project A the key members of the team, contractor and consultant are fully engaged enabling the client to take a smaller role. On project B where the client has implemented the system but only required the contractor to provide data to the system and not to use it, only the client has utilized the resource. The design and construct project C shows the contractor to be fully embracing the systems to deliver his contractual obligations but in this case the client and clients engineer have not.

4 GUIDE LINES FOR SUCCESSFUL IMPLEMENTATION OF INFRASTRUCTURE DATA MANAGEMENT SYSTEMS (DMS)

How to ensure proper take up of such systems in the future. Since data management and communication is key to successful delivery of construction projects by modern standards implementation strategy must be considered carefully. The implementation method must consider the following issues:

4.1 Role of the system

Systems should be considered as long term investments in the management structure of organisations and not purely on a single project basis. Such long sighted views sow the seeds for the development of information resources over the long term which have potentially huge commercial and technical value.

Once decided, then this raises the importance of decisions on nomenclature and coding. Standard shift activities, plant and labour types must be set at the head office level and promulgated to projects so that cross project analytics can be performed at any time. Such standards apply to all technical records and must be considered early.

In addition to decisions on the codification of data organisations should consider what they want the system to do. As discussed earlier in the paper, systems will already exist within organizations and these will be sponsored by focused groups of specialists each of whom will question why another system is required? What these systems lack is the ability to communicate and collate information outside of their immediate focus groups. They are often not based on the internet are not designed for use over modest bandwidths and expose the user to a level of detail and complexity that most are unable or indeed unwilling to learn. They address data manipulation and analysis not day to day project processes. This is the Silo effect and represents considerable risks to project management.

The key role of the DMS is first and foremost to act as a repository for all raw project data. From here it can be fetched into other systems for analysis. It also acts as a repository for all results from where end users can fetch for use in their own analyses. This is the glue that binds a project and an enterprise together. The system's functionality aims to address project processes performed by all staff on a day to day basis and to make these more efficient and effective. This is the lubrication which makes projects run more effectively.

There will undoubtedly be areas where the systems performs roles which are duplicated by other focused systems however it is unlikely that any system can cover all the requirements of an engineering project. Data management systems must be open to communication and collaboration with other software systems suppliers.

4.2 *When to implement*

Projects start to accumulate data from inception through to maintenance but often formal systems are only implemented across all partners to a project at construction stage. Prior to this systems are in place but are often run by the individual planning, investigation or design contract owners, specifically for them to produce their deliverables, in most cases PDF reports. Structured open data does not seem to cross these contract boundaries and is seldom offered by the consultant or contractor unless required to.

Clearly this is counter to the general benefit of the project or of the enterprise owner. This data is owned by the project since it has been collected on the projects time and account. It is for the project owner to demand structured databases as a deliverable for contracts and for these to be made available to future project operatives. This is already happening in BIM but in this case the focus is directed at CAD as the first point of entry rather than at the collection and sharing of structured data in more openly accessible forms.

It is clear that enterprise and project owners should implement systems as early as possible within the project, a view upheld by insurers (*pers comm* Bailey & Townsend 2015). With systems implemented early hazards and risks and assumptions collated prior to detailed design are readily available as structured data at design, tender and construction stage. At tender data extraction from online systems rather than re-typing from tables in PDFs saves time and makes tenderers more able to quantify risk and identify and test alternatives which ultimately may be beneficial to the client.

In 1994 a geotechnical data management system was initiated by client organization responsible for delivering the Channel Tunnel Rail Link in the UK and made available to the tenderers for the construction contracts at time of tender. Some twenty years later this appears still to be the only example of such openness.

The need for data collaboration is being recognized in a variety of standards. The recently published BS8574 (2014) promotes wider sharing of data for the management of ground risk and uncertainty using the Association of Geotechnical and Geotechnical Specialists (2005, 2010) and other formats as standards.

4.3 Alignment of system ownership with results ownership

Who brings the system to the project? Generally this should be the person who most needs the data or most needs the people working for them to use the data. It depends very much on the form of contract but the Client is always involved in some form. In Engineer's design and in Design and Build contracts the adversarial nature of contracting is a natural barrier to the use of shared systems. Each party tends towards doing their own thing and provides only the information they are contractually obliged to provide the other. Collaboration to streamline processes requires that systems be taken out of the contract and implemented as a partnering exercise. In which case the systems must be brought by the Client but committed to by the Contractor and by the Client themselves. The commitment must be to use the systems to target key project processes to reduce project overhead and improve and speed up communications and decision making.

Where Client and contractor collaborate directly as in the case of Alliance, Target Cost or BOT/BOOT/PPP schemes then such collaboration is guaranteed and the system are implemented on a best for project basis. Agreement on formats and coding must still be made and in order from individual parties to benefit from the data in the long term a system may need to be flexible enough to translate project formats into formats used by enterprise systems belonging to each member of the team.

Table 5: Recommended System Delivery and Contract Type

Contract Type	System/Data Owner	Contracted by	Administered by
Engineers Design	Client/Contractor in Partnering Arrangement *	Client Direct or Client Designer SubContract	RSS/Designer
Design and Build	Contractor/Client in Partnering Arrangement *	Contractor Direct	Contractor and contractors designer
Alliance or Target Cost	Alliance	Alliance	Alliance
PPP/BOT/BOOT	Consortium	Contractor	Contractor and Contractors Designer

* Data coding must satisfy both client and contractor systems

4,4 Coupling with other services: The IMC role

In Hong Kong and China clients have required projects to appoint an IMC or Independent Monitoring Consultant. This involves provision of a system for the project to display information on instrumentation results and progress of the works, undertaking between 10 and 20% of the contractors instrumentation independently of the main contractor and consultancy services to check, review and report on this data and any discrepancies.

By far the largest part of these contracts as procured currently are the physical instrumentation and the party winning the project is the party offering the lowest cost of instrumentation. This is a counter incentive to the role of the independent reviewer. In fact a comparison with ground investigation shows that investigation consultancies do not wrap physical works up in their contracts. The consultant is the agent who invites tender on behalf of the client, recommends appointment of a contractor to the client and then administers and supervises the contract.

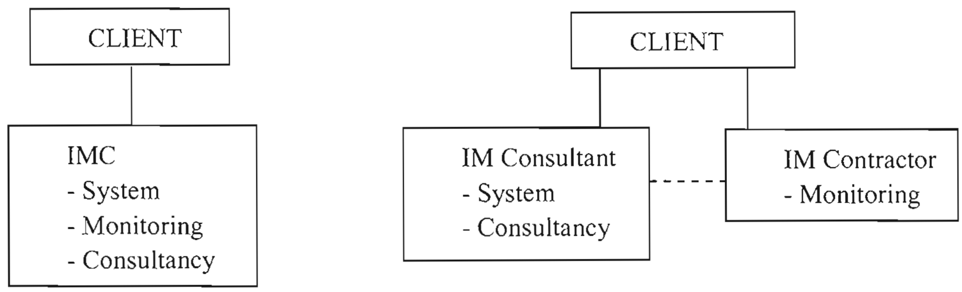


Figure 7: Current (left) and preferred (right) contracting methods for systems provision involving other services

4.5 Specification and contracting

Specifications for systems take a variety of forms varying from the detailed method specification to performance and capability specifications. Method specifications are not encouraged since this leads to long development times. Engineers and owners are also not best able to dictate how systems should be implemented. This is best left to the specialist to decide. Performance and capability specifications are better suited to delivery of systems within project timescales.

Tender evaluations should always review the system proposed to be supplied to ascertain that it is in fact developed to a standard commensurate with the requirements of the tender/contract and will not require a lot of further development to meet the requirements thus entailing long delays in actual deployment. In some tenders the tender is required to declare if a particular function satisfies the spec, partially satisfies or would need development.

There will always be additional enhancements and an allowance for additional development time should be included in the specifications as provisional quantities to be instructed as required. The client should also consider appointing a data manager from the supplier to act as the focus for the system, act as an agent for change and to provide data quality control services throughout the contract period.

4.6 Delivery and contract supervision

The systems should be delivered through a working group with senior representatives from each discipline (Table 3). This should meet on a regular basis to discuss the interaction of all groups using the systems and to update on development and implementation items. The chair of the meeting should be a Director level from the system owner be it contractor, client or alliance. The system should not be owned by a single discipline. The supervision of the systems contract should be undertaken by representatives of the working group chairman.

Training is key to the uptake of any system and regular formalized training sessions with small groups should be a requirement of the contract. However repeated use of the system and an on-site expert to promulgate and develop local capability is most effective. The formal training schedule should be owned and driven by the client. Contract deliverables should be required to utilise the system and this should be driven by the client.

4.7 Key drivers

The absolute key to success in implementation of systems on major infrastructure projects is the presence of a driver of sufficient authority to overcome inertia to change. This staff member should be at Director level and must be engaged in the system use such that staff within the organization know that he or she is relying on the information on a daily basis.

4.8 Intellectual property ownership

Most systems of the size needed for major projects involve many tens of man years of development and it is not sensible to suggest that the Intellectual Property contained in this development can be signed over as part of a system contract. In most cases contracts are let as "System as a Service" contracts (SaaS) in which the background intellectual property (IP) is licensed to the contracting party for a period of time. Foreground IP may be developed exclusively for a client on top of this IP but the IP ownership cannot curtail the background IP owner from developing the systems in any way he or she likes including ways similar to those developed for the client. The exclusivity in that case relates to the specific code created not the idea. New code can be prepared by the background IP owner at any time.

4.9 Data ownership and long term management

All data is owned by the client contracting the software as a service. After the contract terminates this would normally be downloaded and provided to the contracting party as a set of databases with no interface. As with other worldwide systems for long term use the client should either pay for the ongoing system on an enterprise basis or to pay a custodial fee to keep the data readable in the long term.

4.10 Middleware licensing

Clients should be aware of long term licensing implications of systems built on third party middleware since they do not have any contract directly with such middleware supplier and this can cause significant difficulties in long term maintenance.

5 THE MOVE TO EXPERT SYSTEMS

5.1 Real time analytics in construction

The key overarching benefit of data management systems on infrastructure projects is the ability to bring diverse but related data streams together in a structured manner and start to explore the relationships between them. This is often referred to as analytics.

Table 6: Examples of Expert Systems for Tunnel Operations

System	Expert System
Cutter Wear Management	Link records of TBM parameters (torque, thrust etc) to rock types revealed (Rock type, UCS, fracture frequency) to predict cutter head performance and optimum intervention strategy
TBM Face pressure	Back analyse actual settlements observed and modify assumed ground stiffness parameters in a variety of ground conditions
Soil Structure Interaction	Analyse structural response to ground movements and forecast forwards to completion modify work methods and sequence accordingly
Optimise instrumentation layouts	Analyse ground movement characteristics and modify monitoring requirements to suit based on observed ground conditions

Once relationships are established, data can be queried and correlated in real time to give informed forecasts on the state of key project metrics. This data may be data recorded on the current job but extended by data on previous jobs with similar characteristics. The ability to cross correlate historically is a key tool for improving project performance over time, something which the industry has traditionally been not so good at. Expert systems arise where the system modifies its behavior in the light of information gathered. Tunnelling by definition is an observational method and is constantly reviewing methods of working in light of the observed behavior. Systems can automate this process. Examples of expert systems are shown in Table 6.

5.2 BIM driven by data not by CAD

There is a significant move towards the use of BIM within construction. This starts during design and enables object characteristics to be added to 3D drawings, sequences to be worked out and schedules and BOQ items to be derived directly. Whilst this works at design time, during construction CAD staff are often hard pressed to keep up with the as built. The DMS contains all this data and is designed to track the project progress in real time. Once the data progress is digitised in the DMS the 3D shapes can be automatically generated and updated. As Figure 8 shows this can also include information about instrumentation results which may highlight pinch points or areas where stresses may be highest in the completed construction. These simple BIM components are created in real time for easy communication and for inclusion in larger models. Without the need for human intervention staff can be appraised on the latest status of the construction and understand all the interactions with the surrounding infrastructure.

6 CONCLUSIONS

The quantity of data now being collected is requiring ever increasing amount of time to manage manually and it has become accepted that computer systems are needed to reduce the impact on site teams. Project teams conventionally split into silos with each having their own specialist software. This silo effect is a risk to project performance and there needs to be a means to share data and collaborate in addition to managing the long term value of data to an enterprise. Web based systems are available to do this but their implementation has been dogged by uncertainties over when and how to implement and even why they are being implemented in the first place. Keys to success include decoupling systems and data management from data collection, avoiding over-specification, including data management and communication within project partnering charters and ensuring that systems are owned and driven at a very senior level by the groups who need them and want them and not contracted out down the chain.

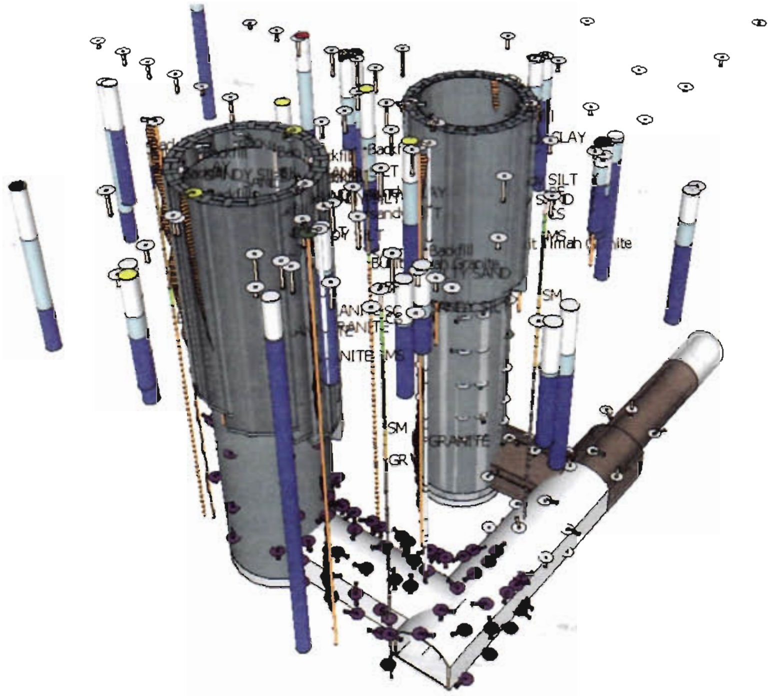


Figure 8: BIM implemented in code and showing movement data ground conditions and as built information

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