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An observational model for managing risk

The observational method, which has its roots in geotechnical engineering, is shown to be a particular instance of a generic approach applicable to the management of a range of construction project risks. A methodology is described for ensuring robustness in the observational method process, by applying the same principles on which it is based in a holistic way to the management of all project risks, not only those associated with the ground. A model is presented of the broader application of this approach to risk management and a practical example is given of a successful application of the developed methodology to a project with a complex range of risks.

The observational method is used by innovative geotechnical engineers, as an alternative to the traditional predefined design approach, to manage risks from ground conditions. It is based on a flexible design that is tailored to suit the actual conditions found during construction, confirmed by feedback from observation and performance monitoring.

A research programme, performed by the authors in conjunction with several industrial partners, aimed to make the observational method robust by using process models. It was found that the practice of the observational method follows the philosophy of 'systems thinking'. This provided a new theoretical basis for the observational method and established a link between the principles of the observational method and a generic approach to managing uncertainty that could be applied far more broadly than solely in the traditional sphere of geotechnical engineering.[1] The term 'uncertainty' rather than 'risk' is generally used in this paper, to emphasise that uncertainty can also create 'opportunity'.

The methodology developed in the research is based on applying the principles of the observational method at various levels—at the traditional level to manage uncertainties in the ground and at the organisational level to manage human uncertainties.

When analysing risk, engineers have a responsibility to consider the whole system. The most sophisticated analysis of one part of a system is of little value if other areas of significant risk are left unattended and it should be recognised that, generally, the more complex the technical risks, the more complex are the concomitant human systems used to manage them.

In contrast to prescriptive risk management guidance and traditional design approaches based on prediction of future behaviour, the central thesis of this paper is that to manage uncertainty in a complex system effectively, requires a process which recognises and responds appropriately to indicators of proneness to failure. The importance of designing the process as well as the product is emphasised, with contingency plans for all project risks in place from the start.

Managing geotechnical uncertainty

The observational method (defined by Peck[2]) has been demonstrated to be a most effective method for managing the uncertainty associated with ground conditions. Innovative geotechnical engineers have practised it for many years as an alternative to the more common 'predefined design' approach[3] on some of the most challenging geotechnical projects, in many cases as a best way out after predefined design approaches have failed.[4,5]

While it is somewhat surprising that the observational method is not more commonly considered on projects, since it is 'an inherently natural approach to address uncertainty',[5] certain project management practices have been identified that can block the use of the observational method.[6] It is the authors' belief that the fundamental reason for the lack of more widespread use of the observational method is that its systemic nature is incompatible with the linear, reductionist approach often applied to project management, where projects are broken down and managed as separate parts. The problems of the reductionist approach to management, in comparison to the systems approach, have been thoroughly discussed by Muir Wood.[7]

Under construction procurement approaches where risks are managed collectively and design and construction processes are integrated, the observational method can become the method of choice.[8]

A model of the observational method process, based on Peck's description,[2] is shown in Fig. 1. Following the gathering of information on the ground, designs are developed for the full range of conditions likely to be encountered. The selection of appropriate performance indicators is an essential stage in the design process. The performance indicators relate to the areas of greatest risk, for example ground settlement or deflection of a retaining wall during construction. Predictions are made prior to construction of the likely range of values of the performance indicators that are expected during construction.

In Fig. 1 the values are represented by the traffic lights, with green representing the expected value, amber representing a trend towards an unfavourable condition and red representing a condition that requires the use of contingency measures. In this model, the course of action (next stage of construction) is decided upon during the design review process and depends on the values obtained from the observations (performance monitoring). As performance is monitored during construction, knowledge of the actual response to construction is increased and the uncertainty and risk reduce. This allows designs to be refined, either to take advantage of favourable conditions to maximise opportunities or to increase robustness, by the use of contingencies, to reduce the risk of failure.

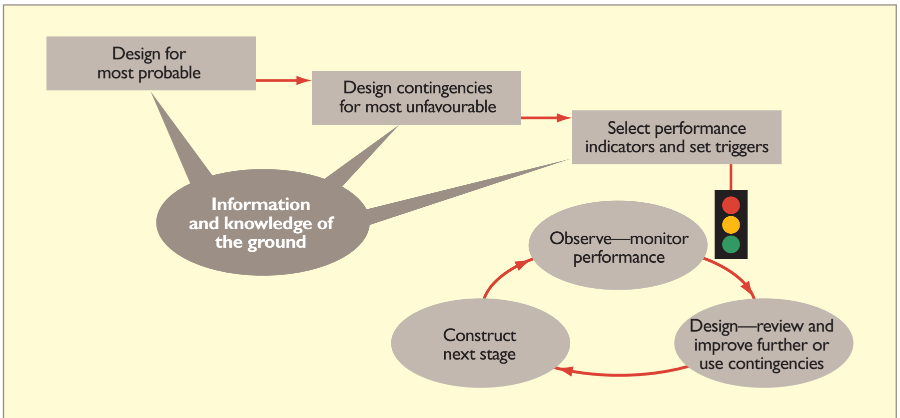

Fig. 1. A model of the observational method process

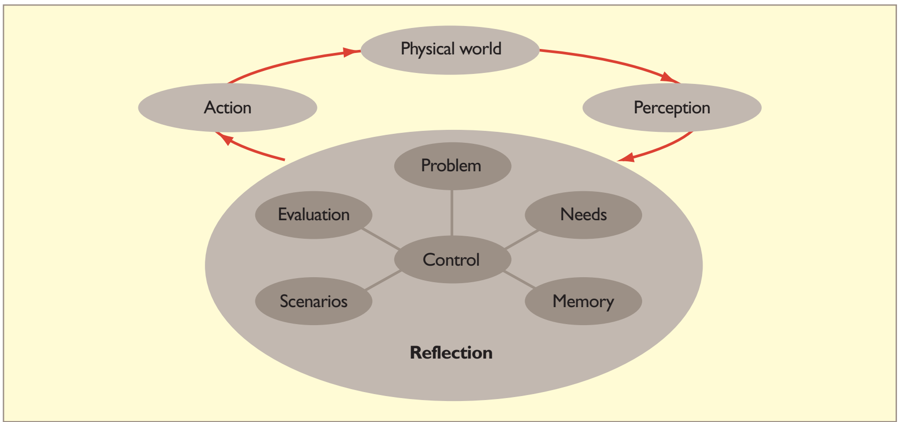

Fig. 2. The reflective practice loop[19]

A systems framework

'Systems thinking' is a term that is used in various fields to describe a view of the world that recognises the interconnected and holistic nature of systems. Systems can be viewed at different levels of detail and in this sense are hierarchical. Systems thinking has been applied in management generally for many years and, faced with increasingly complex challenges, the construction sector is recognising its value.[9–11]

In a dynamic system such as a construction project, a fundamental form of connection that exists between the parts of a system is the feedback loop, which allows processes in one part of the system to reinforce or counteract processes in another. For example there is a feedback process occurring during excavation of a tunnel as the surrounding ground responds to the changing loads. This feedback can be monitored to gain greater understanding of the system. A generic example of the feedback loop representing the fundamental processes by which people interact with the world is shown in Fig. 2.

Systems thinking can be shown to underpin the observational method approach. First, as in geotechnical engineering generally, it recognises the setting of geotechnical issues within the local and regional geology and hydrogeology and considers the properties and performance of the ground at both a macro- and micro-scale. Second, it considers the interaction between the parts of the systems, such as soil–structure interaction; and third, it actively uses feedback from performance to reflect on and learn more about the system, and then respond accordingly.

Systems thinking views the whole as interconnected parts in a hierarchy of levels of detail and this concept is also fundamental to the approach to risk management discussed here. The observational method approach recognises that design cannot be carried out solely by breaking down and individually analysing each part of a system, but rather that monitoring of performance indicators allows increasing understanding of the response of the system as a whole to changing conditions during construction. It is worth noting that the predefined design approach is not completely divorced from the observational method approach. The first stage in an observational method design is to do a predefined design, using a range of possible soil parameters. The difference is in how the design is implemented: the development of a robust management framework for the implementation of an observational method design is the theme of this paper.

Systemic nature of uncertainties

The Heathrow Express project provides a good example of the complexity of modern construction and how a holistic risk management framework is required to manage such complexity. The project suffered a tunnel collapse during construction which was one of the most significant construction disasters in recent times. The tunnel construction was attempting to use the New Austrian Tunnelling Method (NATM) which is a variant of the observational method. NATM involves excavating the ground, installing sufficient primary support (usually sprayed concrete linings), monitoring movements in the tunnel and then, where necessary, installing further permanent support to suit the actual conditions observed and arrest movements. This is a very efficient construction technique when applied successfully. NATM is, however, a complex process to manage and relies on complete integration of the design and construction processes.

A study of the Heathrow Express project serves to illustrate the systemic nature of engineering uncertainties. Extensive investigations were undertaken on this project prior to construction to understand the variability of the soil conditions and associated risks from tunnelling works, including a full-scale trial tunnel, together with the use of state-of-the-art analysis techniques. Despite the knowledge gained on the ground prior to construction and the ongoing monitoring and analysis during the main tunnelling works, a collapse of the tunnels occurred. This was not due to deficiency in the understanding of the ground variability or information on its response to the construction (subsequent analysis of the monitoring data indicated that a developing collapse could have been foreseen several weeks before it occurred[12]), but the problem lay instead in the 'cultural mind-set (that) focused attention on the apparent economies rather than the particular risks'.[12]

In a subsequent enquiry, the NATM design was vindicated; however, failure of the managerial process was highlighted.

> 'There were undoubtedly human errors; but these were merely a consequence of foreseeable cultural, organisational and management failures. The causes of the incident were rooted in failures in 'defensive' systems (i.e. preventative management systems) that did not adequately deal with hazard identification, risk avoidance and reduction and the control of the remaining residual risks. There was organisational blindness to the possibility of collapse. As a consequence, human failures were not readily identified and corrected; and mistakes in decision-making were more likely.'[12]

It is interesting to note that after the collapse, the culture on the project became one of the best examples of teamwork and cooperation seen in UK construction in recent times.[13] At this stage a 'best way out' observational method design was used very successfully and was probably the only solution for recovery of the collapsed tunnel.[14]

Observational engineering

If the observational method is applied under a management regime that does not take into account the full range of complexity associated with the system and provide the necessary integration of processes, then significant risks can be introduced into the system, as so starkly highlighted by the Heathrow tunnel collapse. Responding to uncertainty and variation is as much organisational as technical and the organisational structures and procedures themselves need to be as ductile as the mechanisms of ground response on which the observational method depends.

The connection made between the observational method and systems thinking earlier now allows extrapolation of its application to the management of the various interacting sources of uncertainty, not only those associated with the ground but also organisational uncertainties. A conceptual model of the way in which various levels of project risk can be managed through a hierarchy of feedback loops, using the generic observational method principles, is shown in Fig. 3. This generic approach is referred to here as 'observational engineering'; 'observational' to reinforce its grounding in the established principles of the observational method and 'engineering' to give it a broad context.

If a project is recognised in advance as being complex, with a number of interacting areas of uncertainty (which we would argue the majority of modern construction projects are) then, to dissect the quote from the Heathrow Express enquiry given above: 'defensive systems (i.e. preventative management systems)' should be put in place for 'foreseeable cultural, organisational and management failures'.

Observational engineering provides a framework for such a defensive management system. The steps below are based on the observational method 'ingredients' as originally defined by Peck.[2] The first three are as follows.

> '1. Use available means to gather information on the nature of the uncertainty
> 2. Assess the range of possible cultural, organisational and management conditions that could be encountered
> 3. Select performance indicators that relate to the major uncertainties and calculate their range of values'

The ground conditions are not the only area of uncertainty influencing success of a geotechnical design. Morale and behaviour of the project team members together form another. In the methodology proposed here, performance of the team would also be monitored and used to provide feedback to the management. Measuring these 'soft' key performance indicators (KPIs) is a greater challenge than the 'hard' physical measurements used in geotechnical engineering, but it is precisely these human factors that are crucial for success.

For example a 'team spirit' KPI could be measured using a questionnaire and provide evidence for success of a process; the measurement process can also lead to improved performance.[15] A discussion of research in this area is beyond the scope of this paper, however work is progressing in measuring

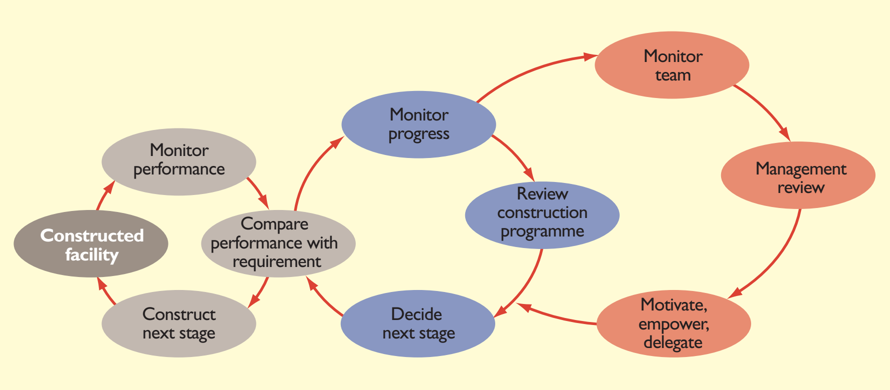

Fig. 3. A hierarchy of feedback loop processes for managing a range of project risks

'soft KPIs' in the construction industry, see for example *Teamworking—the Last Frontier for Measurement*[16] and Blockley and Godfrey.[9]

Steps 4 and 5 are concerned with designing the project processes, carried out in conjunction with designing the 'product', the traditional focus of design.

'4. Establish a plan of action based on the expected most probable condition
5. Select courses of action to cater for deviations from the predicted condition'

In particular the design should clearly define roles and responsibilities. The project team might collaborate in project workshops to define the project processes in process models. Process models are defined very broadly here as any representation of a process. They can include standard flowchart models as well as pictorial representations of processes and systems. The initial model building might use 'mind-maps'[17] or 'rich pictures'[18] to help the project team conceptualise their processes. Following this, the models could be developed in more detail, for example as a hierarchical model of project processes, each with a set of associated attributes including 'objective', 'process owner' and 'process roles'; for further details see Blockley.[19]

This approach concurs with *Management by Design* proposed by Muir Wood[7] as an antidote to the problems of modern project management, whereby design emphasises

'the essential interaction between product design (the design of the finished product and its operation) and process design (the design of construction and its means).'

Steps 6 and 7 are as follows.

'6. Put the plan into action, continuously monitoring and evaluating the actual conditions encountered
7. Modify the plan as necessary to suit the actual conditions'

The project team review and update the process model, in the same way that the model of the ground conditions and the design of the construction works are updated, based on feedback from performance indicators, as the project progresses. The process models are thus an integral part of the process; if there is a mismatch between the process enactment and the model, either the model needs to change or the process enactment needs to change; in either case the agreement of the team is required. So if for example the responsibility for responding to data on movements in a tunnel is not clear or not being carried out, the process (responsibility) needs to be redesigned.

By following this process it should be possible for 'human failures to be readily identified and corrected'.

Implementation

The implementation of 'observational engineering' is illustrated in Fig. 4. This is based on a combination of Figs 1 and 2. The framework is the generic perception–reflection–action loop as in Fig. 2, with the design of processes and selection of KPIs encompassed as 'reflection'. Starting at the bottom of this picture, observational engineering is founded on an integrated project team. The project team members collectively agree on and work towards a set of common project objectives. They then decide on the processes required to reach the objectives and make these explicit in process models. A range of performance indicators is associated with each of the project processes, shown in the table at the top of the picture. The KPIs are shown to include both 'hard' indicators related to time, cost and functionality and 'soft' indicators related to people. The actual values of these KPIs are monitored as the project progresses and reviewed against a set of 'traffic light' trigger value criteria. The data are fed back to the project team to inform their actions within the continuing project progression. The team carries out regular reviews that may result in modifications to the project objectives and/or the project processes.

Case study

An opportunity was identified to implement the observational engineering approach on a complex, deep basement construction in the City of London, shown in Fig. 5 and described in Chapman and Green.[20] A key driver for implementing the observational method on this project was to help catch up on programme delays that had occurred during secant wall installation and temporary propping of an existing basement during early stages of construction.

The use of the observational method allowed one floor level to be confidently omitted in the top-down construction sequence. The first named author was employed on secondment to Arup Geotechnics to implement the observational engineering process and help overcome 'some nervousness about innovative ground engineering techniques after the Heathrow Express tunnel failure'.[20]

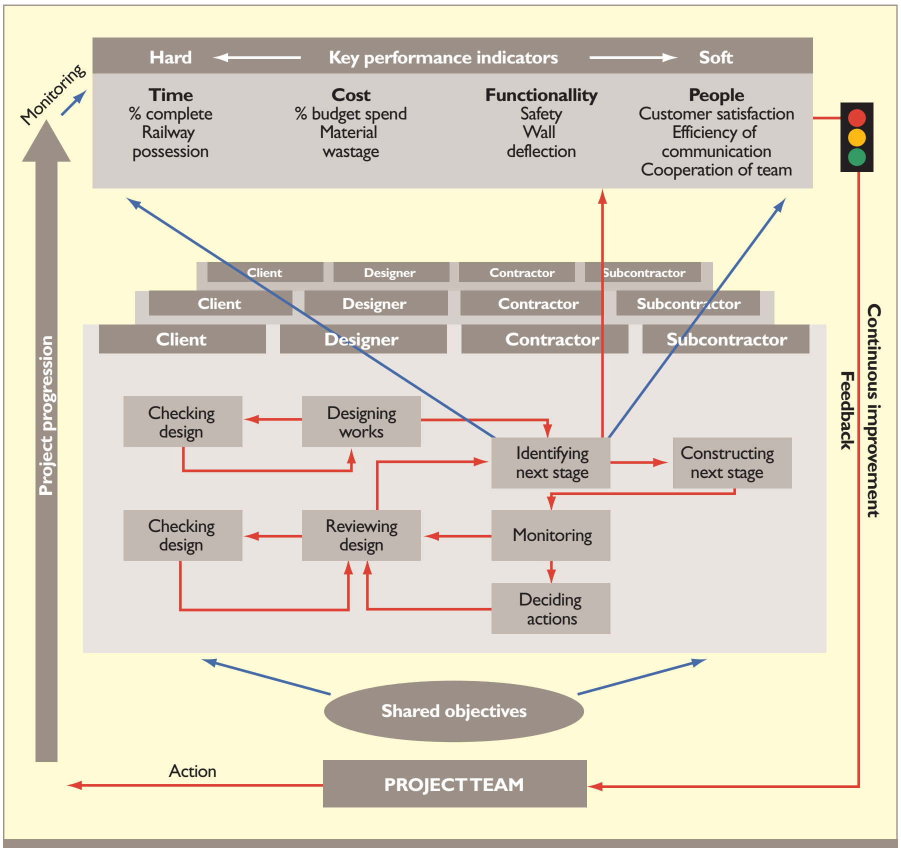

Fig. 4. A model of the observational engineering process

A number of process models for the project were developed by the project team. These included process interaction charts and a role interaction chart, details of which are given in Le Masurier *et al*.[21] and Chapman and Green.[20] The models proved useful in dialogue during management meetings within the construction team, to explain the principles of the observational method and to agree on the allocation of roles and responsibilities. Several iterations were made to identify and name processes, name and allocate the process owners and other roles and define responsibilities. The construction team members further refined the models at project review meetings.

Modelling the process brought clarity and the project team found that the models, including defined process roles, dispelled many assumptions and thus reduced the likelihood of failure of the process. A model of process owners and key responsibilities mapped onto the project processes, as developed by the team, is shown in Fig. 6. The three columns on the right of this model describe the processes required under the three trigger criteria. Each processes maps horizontally on to the process owner (shaded) and other roles within each of the participating organisations.

Fig. 5. Construction of a deep basement using the observational method

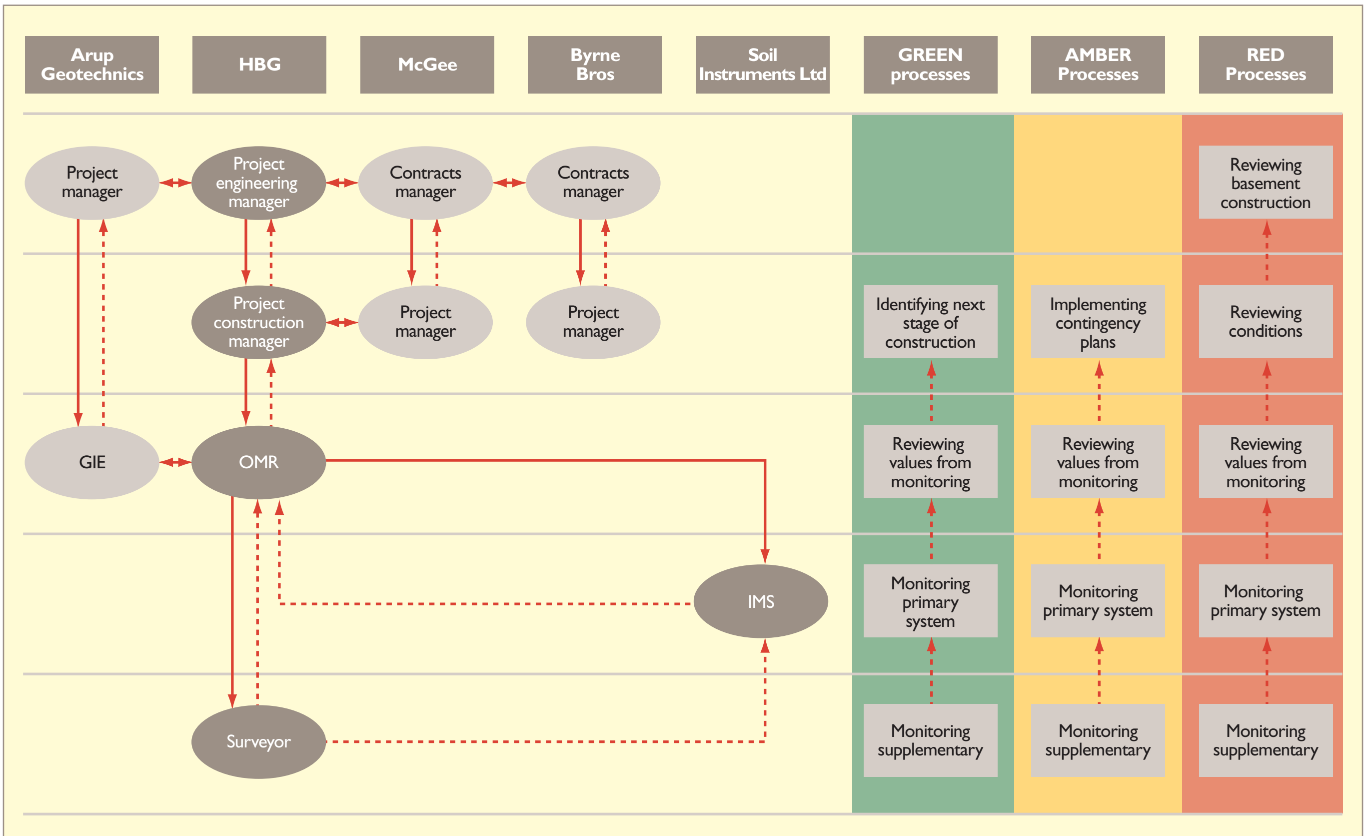

Fig. 6. Role interaction model of the observational method process (GIE, OMR and IMS are abbreviations for various roles responsible for monitoring and review)

The team was willing to adopt new ideas, such as the process models, and with the subcontractors integral to the design team they willingly participated in the process design and were able to develop innovations that improved efficiency and were taken forward as design modifications.

A range of KPIs covering time, cost and functionality metrics were monitored as part of the observational engineering implementation on the project. The behaviour of all project participants as described above was a proxy for measuring the level of cooperation and satisfaction within the team. The potential for significant cost and time savings for all participants led to close cooperation between contractors, subcontractors and designers, with no disputes which was unusual for a project of such complexity. The team were self-monitoring, so while there were no explicit KPIs placed on the people issues, the style of management, efficient communications and frequent review meetings provided a means of monitoring and a basis for contingencies should the relationship have deteriorated.

A questionnaire to measure team morale was developed as a contingency, but since morale remained high throughout, this was not implemented. In terms of 'hard KPIs', the additional cost of implementing the observational method was equivalent to about one week of project establishment costs; however, this was far outweighed by a saving of 20 weeks on the project programme.[20]

Conclusions

The observational method in geotechnical engineering has a proven track record in minimising risk and maximising opportunity when dealing with uncertainty in the ground. The observational method is a dynamic design process and as such requires rigorous management to support it. In the absence of such rigorous management another level of risk is introduced when processes are not clearly defined and roles and responsibilities are misunderstood.

The observational method has been shown to implicitly follow the philosophy of systems thinking. The basic principles of the observational method are generic and as such can be used to manage a range of project uncertainties. Applying the observational method model to the management of a range of risks at various levels in a project, not only those risks associated with the ground, is an effective, systemic approach to managing complex construction projects. Application of the methodology has been proven to increase the robustness of complex geotechnical engineering processes but the principles of observational engineering are naturally widely relevant to a range of applications in engineering and beyond. The key is to provide a formal structure to the management of the uncertainties, both hard and soft, that make up any project.

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