Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Communication of risk and opportunity in geotechnical engineering

Communication des risques et opportunités en ingénierie géotechnique

Thomas St John

Mott MacDonald, UK, thomas.stjohn@mottmac.com

ABSTRACT: The geotechnical industry is faced with communicating information with inherent uncertainty. The objective of this study was to develop a strategy for effective communication of risk and opportunity in geotechnical engineering. Through review of existing practice, it was found that communication difficulties arise principally from the complexity of our discipline and the diverse nature of our audiences. It is concluded that in order to meet future challenges, the industry needs to engage with schools, incentivise communication in contracts, integrate geotechnical risk and opportunity into project risk management, capitalise on technological developments and continue to share knowledge within and outside the discipline. Each recommendation is considered within the paper as part of a collective strategy for effective communication of risk and opportunity in geotechnical engineering.

RÉSUMÉ: L'industrie géotechnique est confrontée à la communication d'informations avec une incertitude inhérente. L'objectif de cette étude était de développer une stratégie pour une communication efficace des risques et opportunités en géotechnique. En examinant la pratique existante, il a été constaté que les difficultés de communication découlent principalement de la complexité de notre discipline et de la nature diversifiée de nos publics. Il est conclu que pour relever les défis futurs, l'industrie doit s'engager avec les écoles, encourager la communication dans les contrats, intégrer les risques et opportunités géotechniques dans la gestion des risques des projets, capitaliser sur les développements technologiques et continuer à partager les connaissances à l'intérieur et à l'extérieur de la discipline. Chaque recommandation est considérée dans le document comme faisant partie d'une stratégie collective pour une communication efficace des risques et opportunités en génie géotechnique.

KEYWORDS: Hazard; risk assessment; communication; opportunity.

1 INTRODUCTION

Civil engineering schemes involve construction on, within or using ground, which has been cited as the greatest contributor to scheme risk (Egan 2008) and the greatest cause of programme delays and cost increases (Trenter 2003). On a major project, the likelihood of experiencing a significant geotechnical risk that results in cost increases or time delays is between 20-50% (Baynes 2010). Inadequacies in communication of investigation information and ground models, lack of understanding of geological language and not asking the right questions (and/or not listening to the answers) have all been cited as factors that can contribute to geotechnical failures and/or project cost and programme overruns (Stapledon 1983; Baynes 2010; Woodward 2019). Godfrey (1996) suggested that lack of communication might be the greatest hazard in construction risk management.

Major civil engineering schemes continue to suffer delays and budget increases due to ground conditions, whilst site complexity is ever growing due to existing constraints in urban areas. There is a need to understand and improve communication of geotechnical risk and opportunity as part of the geotechnical risk management strategy. This paper considers the challenges of communicating, best practice and presents a strategy for the effective communication of geotechnical risk and opportunity.

2 RISK AND OPPORTUNITY MANAGEMENT

2.1 *Defining hazard, risk and opportunity*

In establishing a strategy for communication of geotechnical risk and opportunity, it is essential that all project parties understand terminology and definitions. A geohazard is as an attribute of the ground with the potential to cause harm and/or loss. Risk is defined by ISO 31000:2018 as the effect of uncertainties on objectives, i.e., it may have positive and/or negative outcomes. In geotechnical engineering, risk is often thought of as having undesirable outcomes, with Clayton (2001) defining risk as the chance or possibility of danger, loss, injury or other adverse consequence. Geotechnical risk sources include geohazards, the geotechnical and project risk management process and people, as well as technical, construction and contractual project aspects (Fookes 1997; Clayton 2001; Trenter 2003; van Staveren 2006; Baynes 2010; Woodward 2019). A geotechnical opportunity is a set of circumstances that make it possible to do something, resulting in a positive outcome. Risk and opportunity stem from uncertainty and are linked in that every risk is an opportunity for mitigation, whilst every opportunity has risks, including the risk that the opportunity may not being realised.

2.2 *Risk and opportunity management frameworks*

National regulations and/or standards define the requirements, roles and responsibilities for management of project risks to health, safety and welfare and ISO 31000:2018 has been adopted by many countries for the management of risk in general. For civil engineering in general, several best practice guidance documents, frameworks and 'tool-kits' for risk management have been published, such as Godfrey (1996), Molenaar et al. (2006), ICE-IFA (2014) and Smith et al. (2014). For the identification and management of opportunity and value in civil engineering, best practice guidance, including the role of communication, is presented in Connaughton and Green (1996) and Hilson (2004).

Within the practice of geotechnical engineering, risk management is based upon the philosophy of continuous management i.e., the identification and mitigation of geotechnical risk throughout the project lifecycle (see examples in Table 1). Guidance on the management of geotechnical opportunities is presented in Simons et al. (2002), however the identification and management of opportunities tends to receive less attention than geotechnical risk management. This may be a result of a) attention is usually directed toward mitigation of negative consequences (risks) and b) realisation of opportunities is the expected outcome of risk management and engineering professionalism. Since the principles of risk management and communication can readily be applied to opportunities, it is possible to consider geotechnical risk and opportunity either as an integrated assessment or as two separate approaches.

Table 1. Geotechnical risk management frameworks/approaches

Approach	*Ref.*	*Key principles*
Subsurface conditions risk management, inc. 'STEPS' approach	Hatem (1998)	Risk management guidance from contract set-up to construction and dispute resolution
Managing geotechnical risk	Clayton (2001)	Continuous risk management approach
GeoQ framework	van Staveren (2006)	Project lifecycle-based strategy for management of risks and opportunities
SGF R1:2014E: Risk management in geotechnical engineering projects	SGS (2017)	Tailoring of continuous risk management to project.
CD622: Managing geotechnical risk	DMRB (2020)	Geotechnical certification process for UK highways schemes.
Geotechnical Baseline Reporting	Essex (2007)	Commercial risk management via definition of 'baseline' conditions.

Risk management is meaningless without communication. Within the above frameworks and relevant to any project stage, the principal means of non-verbal risk and opportunity communication include geotechnical reports, registers, contract drawings, sketches and models. The strategies agree that communication should start early, be timely and unambiguous, involve all parties and be continuous and reviewed throughout a project, including feedback after the communication. The challenges posed to the practical application of the above concepts are considered below.

3 ADDRESSING COMMUNICATION CHALLENGES

3.1 *Discipline complexity and uncertainty*

A key challenge to understanding and discussing geotechnical engineering is the complexity of the discipline. Since the composition, properties and behaviour of ground materials can vary in a non-linear manner with distance, time and in response to external influences, ground is unlike any engineering material. Other complexities include extensive, varied terminology, variation in the interpretation of material properties/behaviour and uncertainty in approaches for analysis.

The variation in the meaning and interpretation of terminology is a barrier to effective communication between geotechnical engineers and engineers from other disciplines as well as the potential cause of confusion in the classification of ground materials (Fookes 1997, Braithwaite and Heath 2015). It is unlikely that laypersons will be familiar with geotechnical terminology. As an illustration, 'clay' might be a material with grain size below 0.002mm or with certain Atterberg limits, a particular geological formation or weathering product, a single or group of alumino phyllosilicates minerals, a material that is used to make ceramics or bricks, a material used in the construction of dams, or a slow-draining soil. Terms such as clay demonstrate that geological meanings might represent material types, processes or uses. As engineers we can use specifications to define meanings and applications. Where possible, and recognising the approach of medical professionals, we should avoid jargon in communications (Donnelly 2008, Sartain et al. 2015).

Since ground is variable and knowledge of it is limited to the very small volume sampled and tested during ground investigation, there will always be uncertainty in models and material properties. Limitations in geotechnical testing and assumptions in analytical methods add uncertainty, with judgment and interpretation remaining an essential skill of geotechnical engineers. A well-established approach to managing ground variability is to consider lower and upper bounds as part of sensitivity analyses and to err on the side of conservatism. However, such an approach may limit the potential for economic or low-carbon solutions.

To realise opportunities and reduce conservatism, clear communication of assumptions, sensitivities and confidence intervals is desirable. Contingency measures and implementation of independent quality verification teams for the supervision of construction works are means to mitigate uncertainty. The role of the site engineer as part of such a team is discussed later.

3.2 *Audiences and communication approaches*

For any project, with respect to risk and opportunity, we should ask ourselves who needs to know and how can we communicate what they need to know in the most effective and accessible way. Stakeholders in receipt of a geotechnical risk or opportunity communication might include geotechnical engineers, engineers and non-engineers of other sciences, managers, constructors, policymakers, authorities, members of the public and the media. The 'public' is a complex group and it is inappropriate to consider the group as representing laypersons. Any individual can move between audience groups and so a one-size-fits-all approach to communication is unlikely to be effective.

The audiences listed above represent all demographic groups and whilst all are motivated to remain safe, geotechnical risk perception and understanding (and therefore response to risk and opportunity communications) will vary. Examples of high-level communication approaches for different groups are summarised in Table 2. The importance of communication format, trust and perception are discussed later. For all audiences, a modern shift in communicating risk and raising awareness of geosciences is toward the use of social science, citizen science and sharing of stories within which the narrative explores the risk scenario and experiences of it (Gibson and Roberts 2018).

Table 2. Communication approaches for varied audiences

Audience	*Communication approach*
General public	Facts, consensus, transparency
Young children	Storytelling, demonstration
Students	Inspiring, site visits, leverage technology
Geotech. specialists	Enquiring questions in interpretation
Project parties	Question assumptions and interactions

To the public, geotechnical engineering is unlikely to be a familiar subject and as such, discipline complexities and uncertainty in communication can lead to intimidation and disengagement. Detailed analyses are unlikely to be helpful in conveying risk to the majority, with headline facts and consensus statements generally more suitable, backed up source information that is available separately for scrutiny.

In communicating the role of a geotechnical engineering and the safety of construction to young children with negligible geotechnical knowledge, the author found that engaging through storytelling and a scale bridge-building activity as part of the Institution of Civil Engineers (UK) 'Bridge to Schools Scheme' was an effective means of risk communication. For communication with students, the author found that demonstration of risk effects through case studies and site visits can give first-hand understanding whilst consideration of technology-enabled opportunities may aid engagement.

Complexity and uncertainty are less likely to present a barrier for communication with geotechnical engineers, but to ensure understanding it is beneficial to ask enquiring questions about information and interpretation. The same is true when communicating with the parties involved in delivery of a scheme with geotechnical elements. Project parties are motivated to mitigate risk and realise opportunity. Summarising our message without overcomplication and asking questions at coordination and/or risk reduction meetings such as: what are the acceptable ground movements? are the loads already factored? what will be built next to the site, what might be the impact of a changing climate? what plant will be used? can be very powerful for early mitigation of risk and opportunity identification. Effective communication at the construction stage is considered later.

For all audiences it is essential that we listen, engage and seek feedback to establish if our message has been understood. To ensure that risk and opportunity communications achieve engagement, we should consult our audiences in the early stages of a project with respect to the approach that is most accessible to them. For example, on investigating the use of verbal uncertainty descriptions in the Intergovernmental Panel on Climate Change reports, Budescu et al. (2012) found that the public often misinterpret the statements and that a favourable alternative would be the use of a combined verbal and numeric scale to improve understanding. From audience consultations, we can learn how to improve our communication effectiveness and gauge our audience's perception of risk and opportunity.

3.3 *Perceptions and acceptance of risk and opportunity*

Engineers communicate risk and opportunity to allow end-users to make informed decisions about whether to act. Everyone has their own view of what is 'safe' and often it is the perceived risk that influences audience response (Northey 1980), with content and context playing important roles in effective communication (van Staveren 2006). Perceptions might be influenced by who and/or what is at risk (and for what duration), consequence and probability of occurrence, personal circumstances and values, attitudes towards the hazard, uncertainty in communication and ability to influence or control the effects of the risk. Perceptions and any linked expectations should be considered as part of a communication strategy.

Familiarity of risk and opportunity is a key factor in the forming of perception. Some geotechnical risks have catastrophic, repeated and visible consequences which might be perceived as familiar and even acceptable to a population due to the hazards' low likelihood and the overall considered net benefits of living in a hazard prone area. Risks with low probabilities but severe consequences can be both hard to identify (UK GOS 2011) and to communicate effectively (when the intention is for end-user action) because of the infrequency of the consequences. Some areas of geotechnical engineering, such as dams and infrastructure earthworks have well documented 'failure' incidence rates which can aid the assessment and communication of risk likelihood and impact, however, many fields suffer from a lack of published failure records. The growing research base in geotechnical asset whole life performance will assist in opportunity identification and risk communication. Development of research will also play a key role in communicating risks and opportunities of ventures such as deep geological repository and sequestration, where perceptions are polarised, as well as for geotechnics on contentious infrastructure projects and for new technology such as 'self-healing' materials.

3.4 *Establishing trust*

Barriers to building trust include the inherent uncertainty and time-based behaviour of the ground, perceptions of the industry and the rise of visible misinformation. Analytical approaches are often used to assess the timing of geotechnical processes, however whilst the time-factor is generally well understood for some processes (e.g., consolidation), the timing of others (e.g., landsliding and weathering) is relatively poorly understood.

Lee (2016) indicated that landslide experts might be reluctant to share their degree of confidence in landslide risk assessments for reasons such as anticipated criticism and fear of lack of understanding of the uncertainties in their assessments. Making comparison to the medical profession, Lee (2016) described the Grading of Recommendations Assessments, Development and Evaluation (GRADE) scale for communicating the quality of medical evidence. Whilst uncertainty grading is rarely undertaken in geotechnics, Lee (2016) showed that it could be applied to landslide risk assessment and that such an approach could improve the ability of geoscientists to communicate risk.

In establishing trust, we should consider the three audience 'rights': the right to know, the right to be heard and the right to participate (Cerase 2020). To address the right to know, in addition to what and how to communicate, we are challenged with when to communicate. Communicating early without reassurance and transparency may cause anxiety whilst delaying may lead to uninformed and angry audiences. Since the properties of ground can change with time, the likelihood and impact of certain risks and opportunities also change, making it difficult to quantify and communicate their timing. Further research on trigger events and asset performance will aid the assessment of time in geotechnical risk.

Construction accidents, delays and cost increases can lead to public scepticism, suspicion and disengagement with risk and opportunity communications (van Staveren 2013). Case study reports of successful risk mitigation (e.g., those compiled by the ISSMGE) and other scheme benefits achieved through geotechnical engineering can help demonstrate the return on investment of geotechnical risk and opportunity management since it can be challenging to quantify the impact and longevity of some interventions. We can demonstrate competence to our audiences via Professional Memberships, which recognise communication ability as a core attribute.

Since many audiences use social media, organisations are moving toward such platforms to communicate risk and mitigation as well as gather feedback. Fact verification, scrutiny and moderation of messages and their responses (and authors) is likely to increase, helping to establish trust. The media profile of geotechnical engineering is limited compared to other industries and is an area for development to help build trust, dispel any misconceptions and attract the next generation of engineers.

3.5 *Format and medium of communication*

Common forms of risk and opportunity communication between teams on geotechnical projects include contract documents, registers, reports, specifications, drawings and models. External forms of communication might include social media campaigns and the use of visitor information centres. In regions prone to geohazards, communication might include accessible public information packs and warnings issued by SMS (for example alerting the message receiver to the risk of tsunami in a coastal area following an earthquake).

For infrastructure authorities, as owners of geotechnical assets, risk documentation and communication may be via ground-related hazard maps, utilising open and unambiguous presentation for understanding by non-specialists (e.g., Neville et al. 2020). Guidance on communicating effectively, using various formats, including consideration of appropriate language and communicating with the media, is presented in Donnelly (2008) and Woodward (2019). Engineers should remain mindful of whether a certain format is accessible to their audience. Irrespective of the format or medium, the appointment of a coordinator to ensure timely delivery, receipt and feedback of high-quality communication as part of a risk management team, is recommended by CIRIA (2002).

3.5.1 *Risk and opportunity registers*

A geotechnical risk register is typically a tabulated approach to hazard and risk identification alongside the mitigation (Godfrey 1996; Clayton 2001). Opportunity registers can be prepared using the same principles with action for realisation documented. Risk or opportunity is given a rating defined by consideration of the likelihood and impact. Registers should be updated at each project stage as mitigation or realisation takes place. In the author's experience, geotechnical engineers routinely prepare and review risk registers as part of design reporting. However, where opportunity registers are used, we often input to a project-wide document during the early stages of a scheme. We can help ensure opportunities are captured and realised as ground conditions are encountered by contributing to project-lifecycle geotechnical opportunity registers. Since there are no standards for registers, the format can vary considerably. Variations might include qualitative or quantitative assessments, consideration (or not) of time, types of impact (e.g., on cost, programme, quality, reputation, environment, human health, or another factor) and inconsistencies with other project registers. A lack of, or variation in the frame of reference for description of probability is a further challenge which can make risk likelihood difficult to define and compare between registers, unless absolute terms are used (Sartain et al. 2015).

To address the above challenges, it is recommended that a consistent approach to register preparation and definition is used across and throughout a project, to help ensure understanding and engagement. Registers should also be reviewed for relevance. Registers present a means for documenting mitigation; however, effectiveness is only achieved if the mitigation is communicated to those best placed to manage the risk. Other formats and approaches may be needed to share the risk and opportunity information and actions outside of the immediate project team.

3.5.2 *Site geotechnical engineer*

The role and value of site geotechnical engineers are shown in Eddleston et al. (1995). On large or complex schemes, it is likely that some residual geotechnical risk will require management during construction. On such schemes, communications made by site geotechnical engineers can contribute significantly to risk mitigation or implementation of optimised solutions. For the site geotechnical engineer to be effective they must be integrated into the project team or part of an independent quality verification team at an early stage to ensure they understand the design intent and construction methodology and can take a proactive approach. Risk mitigation and opportunity realisation aided by site engineers includes implementing inspection and test plans, application of the observational method, optimisation of designs through verification of surface and ground conditions, mapping to aid preservation of geological exposures of conservation significance and engaging and educating the community.

The above examples were achieved via a common approach of communication comprising building rapport with all parties, presenting updated ground models to the design team and contributing to risk reduction meetings. Building rapport with site operatives is especially important – those persons are at the forefront of the work and often best placed to identify and feedback features of importance. By involving the team through describing the design intent and the ideal outcome, the chances of collaboration and feedback are increased.

3.5.3 *Technology in risk and opportunity communication*

Visual geotechnical risk and opportunity communication, such as though maps, plans and models, have long been promoted as accessible formats for a wide range of audiences due to their ability to convey the complexity and uncertainty of the ground (e.g., Fookes 1997). Technological developments have enabled advancement from hand-drawn 2D plans to 3D digital ground models. Models are now integrated tools for simulation, clash detection, geotechnical analysis, material quantification, decision making and risk and opportunity communication.

3D digital models can add value even on small schemes with simple ground conditions. For example, for a site where a new river channel, culvert, retaining walls, earthworks and drainage network was required for redevelopment of a brownfield site, software (in this example Leapfrog Works, by Seequent) can be used to build a 3D geological model of the site and scheme (Figure 1). LiDAR and traditional topographic survey files were used to construct the ground surface, onto which satellite imagery was draped. Strata interpretations were then added to exploratory hole locations to allow interpolation of the geology. Finally, the scheme design model mesh was imported. The model enables the design team to quickly identify risks such as soft organic clays at the formation level of the retaining walls and subsequently to determine the clay thickness along the length of those walls. The model allows for the visual discussion of risk mitigation among the project parties (for example excavation and replacement of the soft clays) and assessment of earthwork interfaces through cutting of cross sections. Estimations of material excavation volumes could be made if required.

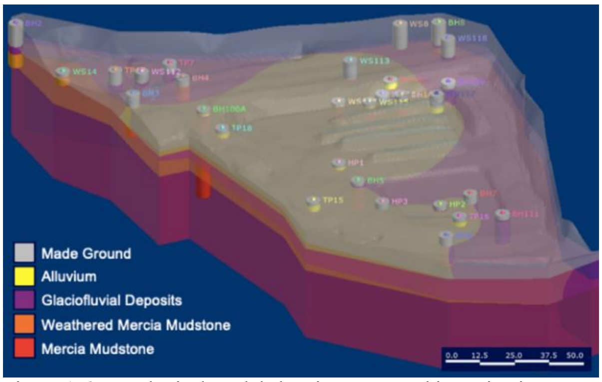

Figure 1. 3D geological model showing strata and investigation locations (scheme and satellite imagery not shown for clarity).

At the site of a proposed 171m long and 67m wide, 34ML capacity pre-cast concrete reservoir, digital technology was used to assess and communicate geotechnical risk between project teams (Kajastie 2021). Some 45,000m^3 of excavation was required to accommodate the reservoir due the topography of the site. Ground investigation at the site identified silt channels at the structure formation (surrounded by sand and gravel deposits). Since the structure comprised compartments which could be filled independently (and to different levels) and since ground conditions at formation varied across the site, total and differential settlement were key geotechnical risks to be assessed. A 3D geological model of the site was created which enabled quick visual demonstration to the project teams of the ground conditions from surface level down to formation level (further enabling construction phase organisation such as material re-use planning). In addition to providing visual communication, the model was quickly updated during excavation when an additional silt channel was identified and the outputs from the model could be incorporated into settlement analysis software. Rapid revision of models and calculations allowed timely communication of changes to both geotechnical risks and opportunities between project parties.

Further improvements to the visualisation of geotechnical designs, construction sequences and their consequences will be enabled using augmented and virtual reality systems – which should aid the engagement of stakeholders and impacted audiences. For all communications made using models, the assumptions, interpretation (e.g., interpolation and extrapolation) and model sensitives should also be communicated. Advancements in remote sensing, artificial intelligence and machine learning will improve our ability to identify hazards and risk trigger events, allowing faster mitigation communication and development of existing early warning systems.

In the UK, the major owner and manager of the nation's rail infrastructure, Network Rail, is implementing automated scanning of the network using a train-mounted plain line pattern recognition system to identify infrastructure defects (Kennedy 2020). Such technology is likely to be extended to a wide range of geotechnical assets and structures, connected with real-time monitoring of the environment (e.g., rainfall, soil moisture deficit, ground movement monitoring) to establish risk likelihood and permit instantaneous risk communications. The switching-on of landslide risk warning signs in response to exceedance of rainfall thresholds is already in place on parts of the Scottish trunk road network (Winter and Shearer 2017).

Globally, many authorities and government-owned bodies are communicating through growing visual databases of geotechnical information presented on freely available, easily accessible web-applications. Online geohazard maps are made freely available by some partly public (e.g., British Geological Survey) and public bodies (e.g., Coal Authority) in the UK, allowing potentially quick and easy access to geotechnical risk information to those outside of the geotechnical industry.

Advancements in mobile device technology now permits recording and communication at remote sites. Advanced data capture and visualisation techniques are becoming more accessible, with scanning methods utilising LiDAR now available for smartphones, allowing rapid recording of detailed information. Video calls from a ground investigation or construction site (where safe to do so) can aid timely decision making, whilst digital updating of risk and opportunity registers from site allows the project team to act on new information or confirm that action has been taken.

Since the early 1990s, the Association of Geotechnical and Geoenvironmental Specialists have been leading quality and consistency in the transfer of electronic geotechnical data. Now in the fourth edition, the AGS Data Format allows information communication in a common form between a wide range of systems and software. Increased adoption of the data format between software developers and organisations will continue to improve the quality of geotechnical data communication.

With any use of advanced technology, geotechnical engineers will play a key role in training artificial intelligence systems, validating their output and, critically, communicating the opportunities, limitations, assumptions and therefore, risks.

4 CONTRACTS

Contracts are effective tools for managing geotechnical risk and opportunity when collaborative terms are selected, roles are clearly defined, and risk ownership is appropriately allocated to those best placed to mitigate the undesirable consequences. A unique approach to the allocation and management of the commercial aspects of geotechnical risk can be achieved through the use of a Geotechnical Baseline Report (GBR) (Essex 2007). Within a GBR, the ground conditions at a site are defined as a 'baseline' in order to allocate ground risk between the Employer and the Contractor. A GBR enables the clear communication of contractual definitions of certain ground conditions but does not necessarily convey uncertainty in the definition. Whilst established in the USA, the use of GBRs in countries such as the UK has historically been limited generally to tunnelling schemes. Further training and guidance (such as that proposed by CIRIA) is likely to aid engineers with risk communication in GBRs and application of GBRs more widely across geotechnical schemes.

Geotechnical engineers can add value when engaged as part of contract procurement and tender assessments for civil engineering schemes by communicating significant geotechnical risks at the project outset. It is in these early stages that it is most beneficial that all parties are open about potential risks. Such an approach can allow identification of opportunities and reduction of conservatism, such as through early consideration of departures from standards or investment in new technology.

Brandsen and Cools (2015) have recommended that contract incentives be used to encourage geological risk management and collaboration. Incentives could also be used to address commercial reluctance to draw attention to risks and share risk management strategies at tender stage. Use of shared pain/gain contract options, especially on design and build schemes can incentivise all parties to collaborate to manage risk.

Early communication with contractors can help realise opportunities in the build, whilst ahead of the construction of a geotechnical structure, geotechnical engineers can contribute as part of a risk management team at 'readiness reviews' to communicate risk and ensure design understanding (Godfrey 1996, Woodward 2019). Timely clear communication, allocation of risk and transparency from all parties throughout a project will help to reduce the likelihood and/or impact of disputes as well as aid in their resolution.

5 TRAINING

Geotechnical risk and opportunity communication are not typically a core module of a geotechnical engineer's education, such that they may rely on skill development by experience and learning from miscommunication. Measures taken to address this issue include the launch of a risk management-focussed MSc Geo-Engineering MSc at Delft University of Technology (van Tol et al. 2009). The course covers sources and classification of risk, management tools and approaches, as well as the observation approach – all of which are built on communication and could be implemented into other degree programmes.

Within teams, the sharing of geotechnical case studies of failure where communication was a contributory factor can aid the understanding of when and why miscommunications occur and how recurrence can be prevented. Collation and sharing of geotechnical 'near misses' as well as working through risk scenarios can be helpful to highlight the role of communication. Further recommendations for the training of geotechnical engineers in communicating to various audiences are discussed in Donnelly (2008) and van Staveren (2013).

6 COMMUNICATION STRATEGY

Considering the above challenges and best practice, the key principles of a communication strategy are presented in Figure 2 in the context of a project with geotechnical works.

Figure 2. Geotechnical risk and opportunity communication strategy.

7 CONCLUSIONS

This paper concludes that there will always be a driver for communication of geotechnical risk and opportunity, however there are multiple barriers to effective communication. Engineers are experienced in managing risk, however coupling risk assessments with further consideration of geotechnical opportunities is likely to contribute to successful project outcomes and audiences that are appropriately informed. Current frameworks provide an excellent basis for geotechnical engineers to surmount communication challenges by integrating some of the innovation and best practice explored in this paper, particularly with respect to learning from and educating others, leveraging technology, utilising site engineers and incentivising communication in contracts. The key recommendations are summarised as part of a communication strategy and can be readily adapted to the specific needs of a project.

8 ACKNOWLEDGEMENTS

This paper was developed from the author's Geological Society of London Glossop Award 2019 presentation. The author is grateful to colleagues at Mott MacDonald and Marc Woodward for discussion on the topic.

9 REFERENCES

Baynes, F. 2010. Sources of geotechnical risk. *Quarterly Journal of Engineering Geology and Hydrogeology* 43, 321-331.
Brandsen, C., and Cools, P. 2015. Geotechnical risk management in Dutch public infrastructure projects. In: Schweckendiek et al. (eds) *Geotechnical safety and risk V.* 16-22.
Budescu, D., Por, H-H., and Broomell, St. B. 2012. Effective communication of uncertainty in the IPCC reports. *Climatic Change* 113, 181-200.
Cerase, A. 2020. From 'good' intentions to principled practices and beyond: ethical issues in risk commnication. In: Di Capua, G., Bobrowsky, P. T., Kieffer, S. W. and Palinkas, C. (eds) *Geoethics: atatus and future perspectives*. GSL Special Publications, 508.
CIRIA. 2002. *A simple guide to controlling risk*. CIRIA, London.
Clayton, C. 2001. Managing Geotechnical Risk: Time for change? *Proceedings of the Institution of Civil Engineers. Geotechnical Engineering* 149(1), 3-11.
Connaughton, J., and Green, S. 1996. *Value management in construction: a client's guide*. CIRIA SP 129. CIRIA, London.
Design Manual for Roads and Bridges (DMRB). 2020. *CD622 Managing geotechnical risk*. Rev 1.
Donnelly, L. 2008. Communication in geology: a personal perspective and lessons from volcanic, mining, exploration, geotechnical, police and geoforensic investigations. In: Liverman, D., Pereira, C., & Marker, B. (eds) *Communicating environmental geoscience*. GSL Special Publications, 305, 107-121.
Eddleston, M., Murfin, R., and Walthall, S. 1995. The role of the engineering geologist in construction. In: Eddleston, M., Wlathall, S., Cripps, J.C., & Culshaw, M.G. (eds). *Engineering Geology of Construction*. Engineering Geological Publications, 10, 389-401.
Egan, D. 2008. The ground: clients remain exposed to unnecessary risk. *Proceedings of the Institution of Civil Engineers. Geotechnical Engineering* 161, 189-195.
Essex, R. 2007. *Geotechnical baseline reports for construction. Suggested guidelines*. ASCE, Virginia.
Fookes, P. 1997. The first Glossop Lecture. Geology for Engineers: the Geological Model, Prediction and Performance. *Quarterly Journal of Engineering Geology*. 30, 293-424.
Gibson, H., and Roberts, J. 2018. Communicating geoscience in uncertain times. Meeting Reports. *Geoscientist*, December 2018.
Hatem, D. 1998. *Subsurface conditions. Risk management for design and construction management professionals*. Wiley, New York.
Hilson, D. 2004. *Effective opportunity management for projects. Exploiting positive risk*. CRC Press, Florida.
Institution of Civil Engineers and Institute and Faculty of Actuaries (ICE-IFA) 2014. *RAMP: Risk analysis and management for projects*. ICE Publishing, London.
Kajastie, N. 2021. Storage solution. *Ground Engineering.* March 2021.
Kennedy, C. 2020. Future of rail: artificial intelligence helps Network Rail's maintenance regime. *New Civil Engineer*. February 2020.
Lee, E.M. 2016. Landslide risk assessment: the challenge of communicating uncertainty to decision-makers. *Quarterly Journal of Engineering Geology and Hydrogeology*. 49, 21-35.
Molenaar, K., Diekmann, J., and Ashley, D. 2006. *Guide to risk assessment and allocation for highway construction management*. US DTFHA, Washington.
Neville, J., Power, C., Spink, T., Grant, D., and Patterson, D. 2020. Ground related hazard maps to aid risk management of the Highways England Strategic Road Network. *Quarterly Journal of Engineering Geology and Hydrogeology* 53(3), 466-471.
Northey, R. 1980. The acceptability of geotechnical risk. *Proceedings of the 3rd Australia-New Zealand conference on Geomechanics*: Wellington, May 12-16, 1980.
Sartain, N., Mian, J., and Free, M. 2015. Presenting uncertainty clearly: challenges in communicating geotechnical risk. In: Schwecken-diek et al. (eds). *Geotechnical safety and risk V.* 739-744.
Simons, N., Menzies, B., and Matthews, M. 2002. *A short course in geotechnical site investigation*. Thomas Telford, London.
Smith, N., Merna, T., and Jobling, P. 2014. *Managing risk in construction projects*. 3rd Ed. John Wiley and Sons Ltd.
Swedish Geotechnical Society (SGS). 2017. SGF Report 1:2014E. *Risk management in geotechnical engineering projects – requirements. Methodology*. Linkoping.
Trenter, N. 2003. Understanding and containing geotechnical risk. *Proceedings of the Institution of Civil Engineers. Civil Engineering* 156, 42-48.
UK Government Office for Science (UK GOS). 2011. *Blackett review of high impact low probability risks*. URN 12/519.
van Staveren, M.Th. 2006. *Uncertainty and ground conditions: a risk management approach*. Oxford: Butterworth-Heinemann.
van Tol, A., Korff, M., and van Staveren, M.Th. 2009. The education of geotechnical engineers should incorporate risk management. In: Hamza, M. et al. (Eds). *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering*.
Winter, M., and Shearer, B. 2017. An extended and updated technical evalulation of wig-wag signs at the A83 Rest and be Thankful. *TRL Published Project Report PPR743*.
Woodward, M. 2019. Effective communication to manage geotechnical risk. *13th ANZ Conference on Geomechanics*.