Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-863

Geotechnical risk management of embankment construction over soft soils

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ABSTRACT: Geotechnical risk management is critical in the design and construction of embankments over soft soils. Geotechnical risk is not a term used in these projects until recently although it is well known that it must be addressed in any project. When geotechnical risk is mentioned, it is assumed that the risk is related to stability failure and could be mitigated by adopting conservative values for design strength parameters and the use of a factor of safety on stability analysis results. While a higher factor of safety reduces the risk of unexpected performance in relation to stability, engineers usually underestimate the reality that settlement related issues could lead to major risks, in the short term and/or long term, when the performance of earthworks does not satisfy project criteria specified by the client. Rectification of such issues could be a costly exercise.

Management of geotechnical risks commences long before design and/or construction. While the reference design is a document useful to obtain knowledge of the intent of the design, the designer must commence his work starting from appreciation of regional and local geology, carry out additional investigations if necessary and determine appropriate parameters based on results. The completed design should also include appropriate instrumentation and monitoring requirements. The construction behaviour needs to be matched against design expectations and changes made at appropriate times.

This paper explains the management of geotechnical risks in providing advice on useful actions to be taken during design as well as in construction of embankments over soft soils.

KEYWORDS: soft soil, earthworks, construction

1 INTRODUCTION

Geotechnical risks resulting from soft soils can be significant compared to other geotechnical challenges in that there are aways residual risks to programme and long-term asset performance. Over the years geotechnical engineers have come to manage these risks through the adoption of an observational approach (Wakita & Matsuo, 1994), where designs are undertaken and monitoring during construction is used to confirm the design outcomes, or if not, enable decisions to be made to undertaken design amendments or remediations.

This paper presents a discussion on the risks and challenges in the design of embankments on soft soils and presents some approaches that have been used on recent projects.

2 GEOTECHNICAL RISK MANAGEMENT PROCESS

The geotechnical risk management process follows several steps which cover the project lifecycle (Figure 1). For a project involving construction on soft ground, geotechnical investigation needs to be targeted, and the functional requirements need to be known early on as these will ultimately determine the final engineering solution.

As the project develops the risk management process develops with it. With more information and the firming up of solutions the risks can be identified and evaluation of which risks can be eliminated, managed, mitigated or treated. The detailed design will address these risks and should ensure that ongoing risks are going to be adequately considered during construction.

For embankments on soft soil, two design criteria govern:

- instability during construction – short-term considerations govern when placing embankments on soft soil foundations but as pore pressures dissipate the stability improves
- long-term settlement requirements to ensure ongoing performance of the asset

These aspects are further discussed in detail in the paper.

3 GEOTECHNICAL INVESTIGATION

The value of adequate ground investigations for earthworks has been discussed at length in many books and papers. In Tyrrell et al. (1983) a review of 10 UK highway contracts indicated that poor site investigation planning and interpretation led to an average increase in costs of 17% and 32%, respectively. Later work, also on 58 highway projects in the UK (Mott MacDonald and Soil Mechanics Ltd, 1994), showed that there was a correlation between site investigation cost and cost overruns. It also identified that extra geotechnical costs represented an approximate 16% increase in the tendered price. The main causes of geotechnical related cost increase could be related back to desk study and inadequate site investigation planning and implementation. In the US, a survey of a small number of highway agencies indicated that claims, change orders and cost overruns due to subsurface conditions occurred annually and that these could be reduced by changes to site investigation practices (National Academies of Sciences, 2016).

The scope of any investigation will be dependent on the approach adopted for design. Where possible, the data obtained from relevant and local previous projects which traverse the same geological units can be incorporated into the data collection and may allow for a reduced scope of investigations and testing.

For soft soils, CPTs are often the preferred investigation choice, combined with boreholes and associated laboratory testing. It may also be possible to install instrumentation to monitor groundwater and soil movement at this stage.

The value of a desk study for any project should not be ignored. This can include geological and historical maps, client supplied data, aerial photographs and also published technical case studies, historical photographs and even newspaper articles. For example, on a recent soft soil project, one of the authors was able to obtain a technical paper providing details of a case study where surcharging was undertaken on an adjacent site. Newspaper articles also noted that the site had been used as a plague pit.

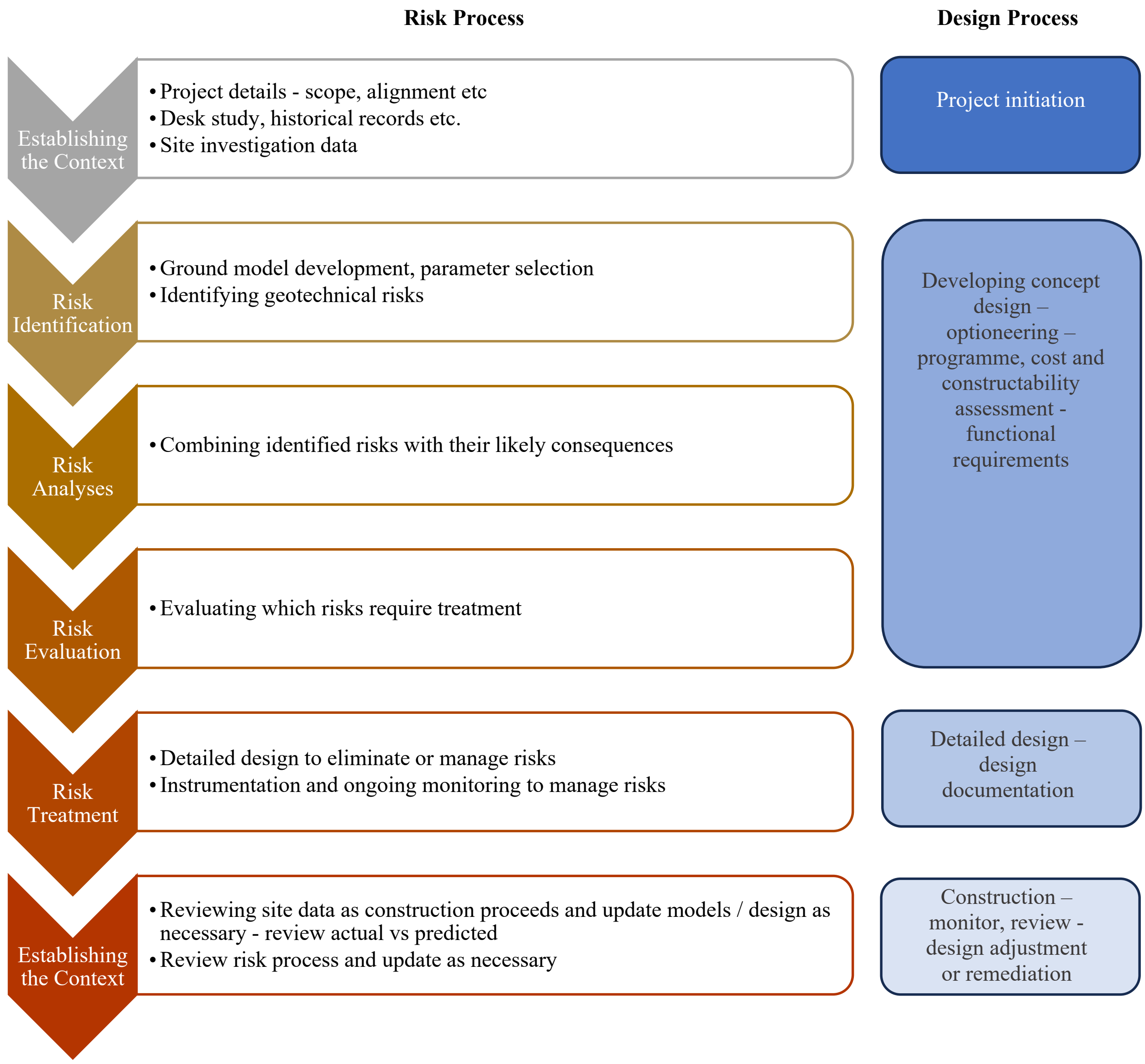

Figure 1. The project risk management process.

4 GEOTECHNICAL MODEL

The geotechnical model is developed as the geotechnical investigation results are assessed alongside existing data. As more information is gathered, either with additional investigation or from other sources, then the model is updated. This can even stretch into construction, where areas previously inaccessible can finally be reached.

The criticality of the geotechnical model to the project cannot be underestimated. Incorrect choice of parameters, for example, can lead to predictions of settlement to be significantly less or greater than actual. It is important that these parameters are discussed and reviewed with experienced professionals before being adopted in design.

Where possible, access to data from previous and adjacent projects can enable back-analyses of parameters for existing structures which can lead to more rigorous parameter estimation.

As with any project, there are numerous uncertainties associated with any dataset and these are a function of:

- the size of the dataset upon which the parameters are based
- the accuracy and quality of the testing and consequent scatter of results
- selection of dataset – inclusion and exclusion of outliers
- location of data in relation to the site
- extrapolation of test results to the soil mass
- laboratory and in situ test error
- understanding of the geological model

5 CONCEPT DESIGN

The concept design process is typically an iterative process which can involve the client and contractor as well as the designer. For some projects, a client may issue a “reference design” – a pre-concept level design, which may identify vertical and horizontal alignment as well as any major structures. Data from a preliminary geotechnical investigation may also be available before or during any tendering process, when engaging either a designer (design only package) or contractor / designer (design-build package).

A major aspect of developing a concept design is understanding and, if necessary, challenging the functional requirements. These set the performance requirements of the earthworks. The risk with setting these requirements is that if set too tight, the earthworks may be overdesigned and expensive to build, such as relying on extensive ground treatments. If too loose, then the earthworks may not perform adequately resulting in poor ride quality or damage to pavement or structures.

Design development during this stage involves the consideration of time, cost, constructability as well as performance. Options are typically considered and a series of iterations of design can occur. It is critical that the geotechnical risks for each option are identified and explained (Figure 2). With embankments on soft soil, it is important to identify design options that may change embankment heights or add additional loading to the embankment. An engagement with senior geotechnical professionals is important through all stages of design development.

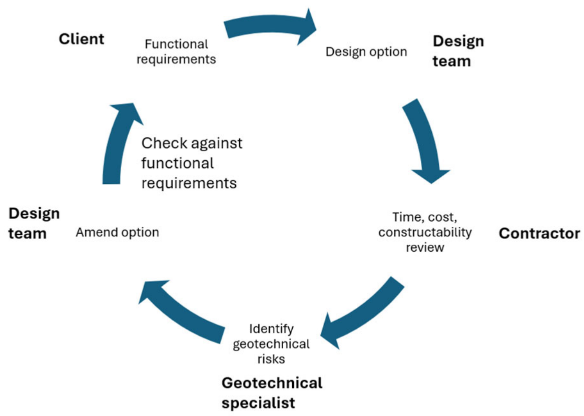

Figure 2. The optioneering process.

6 DETAILED DESIGN

It is not unusual for all the results of the geotechnical investigation to be unavailable during concept design. Similarly, other aspects of the design may not have been finalized at concept. So, the likelihood that some elements of the design will change between concept and detailed design should be expected. This uncertainty brings an element of risk that needs to be managed.

Despite the amount of data collected during the initial stages and into the detailed design stage, there are still uncertainties around the likely performance of an embankment on soft ground both during construction and in the long-term. To manage these uncertainties instrumentation is installed prior to and during construction and the design refined as construction proceeds (Sections 7 and 8). It is important that a range of possible remediations or design amendments are planned for should the data indicate that the embankment is not performing as predicted. These should be communicated well in advance to both the client and construction team.

Although detailed design can be completed without contractor involvement, having discussions with a contractor with respect to construction sequence and programming can result in more cost-effective solutions. Similarly, programing constraints such as traffic management can drive solutions - such as rigid intrusions over surcharging when speed of construction is important. Additionally, risks should be managed or designed out such as adopting ground improvement which may offer more certainty of outcomes compared to surcharging or preloading.

7 INSTRUMENTATION AND MONITORING PLAN

The risks associated with embankment construction on soft soil are typically managed using extensive instrumentation and monitoring. However, just installing instrumentation without a plan offers no benefits.

The plan should include:

- the purpose of the plan – the plan should be directed at confirming the performance of the proposed works as well as ensuring that no damage occurs to existing assets
- location plans including details and instructions for the instrumentation
- details of baseline and ongoing monitoring requirements including monitoring frequency and duration
- instrumentation trigger levels that would lead to action – these ramp up to more onerous conditions as the trigger levels are exceeded
- action plan including who should be contacted in the event of a trigger exceedance
- frequent reporting – weekly, monthly – of the monitoring data

Instrumentation and monitoring are critically important and enable design assumptions to be tested. Should the monitoring indicate that the actual readings are different from those predicted, a redesign may be warranted or, in the worst case, remedial action taken.

8 CONSTRUCTION

The construction phase is not only when the works are constructed, but when the embankments are monitored for performance. Throughout the construction process, the monitoring results will be compared against design predictions. As more data is received predictions can be refined enabling back analysis of parameters and more precise predictions to enable forecasting of preload and surcharge removal as well as future performance.

Where predicted settlement is outside of performance requirements then the design can be adjusted during construction, through additional surcharging, change of surcharge duration, or in the worst case the adding of ground treatment.

As well as considering the rate of settlement, monitoring can also indicate the potential for instability. If the possibility of instability is identified, several actions can be taken:

- additional temporary instrumentation and increased monitoring frequency
- placement of temporary berms
- removal of material from embankment or cease adding more material
- adjusting the design

Finally, the opportunities for additional investigation data during construction cannot be ignored and can lead to a revision to the design. For example, Campbell and Bridges (2019) detail how investigations undertaken during construction, combined with detailed programme conversations with the construction team led to considerable savings in ground treatment.

9 GEOTECHNICAL TEAM

Having the right team is important for any job. This is especially important in geotechnical engineering where each project is unique with respect to scope and ground conditions. One aspect which is often not discussed is geotechnical team credibility with the client and/or contractor. If the team is not seen as credible, then any advice and recommendations around geotechnical risk management can be ignored or downplayed (Bridges, 2019; Bridges, 2024). An example can be seen in the Heathrow Airport tunnel collapse in the UK in 1994. In this case the role of the geotechnical/tunnel specialists was downplayed and relegated in the team. This led to inadequate engagement and poor management decisions which ultimately led to failure (Health and Safety Executive, 2000).

Although the magnitude of this failure is likely to be greater than when constructing on soft ground, the inability of the geotechnical team to get the risks communicated and acted upon can lead to poor long-term performance, short-term instability and expensive remedial action when things go wrong.

10 CONCLUSIONS

Soft ground engineering has inherent risks that must be managed through adequate processes, technical knowledge and experience, and clear communication. As detailed above, it is common to undertake embankment design on soft soils with monitoring during construction. This enables changes to design to be undertaken as data is received.

11 HOWEVER, FOR THIS TO WORK WELL AND TO REDUCE PROJECT RISKS, ALL PARTIES - CLIENTS, CONTRACTORS AND CONSULTANTS - NEED TO TAKE OWNERSHIP OF THE PROCESS. REFERENCES

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