Construction Considerations in Geotechnical Design

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ABSTRACT: Although the term "geotechnical risk" was not a frequently used term until recent times, risks posed by ground conditions have been well known to Engineers over centuries which led to the adoption of a factor of safety for geotechnical design calculations. While a higher factor of safety reduces the risk of unexpected performance, this is not always relevant as geotechnical behaviour for each project needs to be studied and the risks identified before and during construction. Construction risks are partly related to design and therefore the designers should not provide a final design without a dialogue with the contractor. While the end product is important, how to get there is critical for construction projects. Two major Alliance projects in Queensland are used in the paper to highlight the benefits of paying early attention to the construction in the geotechnical design process.

1 INTRODUCTION

Designers play the initial and one of the major roles in civil construction projects. The contractor relies heavily on the designers to provide a feasible design which is economical and safe to build. The outcome of the efforts of the designers is generally a series of drawings and specifications to be used by the contractor to deliver the project. The contractor must then find a way of constructing the completed design in a timely and efficient manner to ensure project criteria are satisfied.

In a civil project, the geotechnical design is based on stability and settlement. Although the designers adopt relevant standards and guidelines to provide a design, it is well known that failures do occur in construction projects, due to instability or due to adverse movements. Such failures could be reduced if the project considers "geotechnical risk" in the design as well as during construction.

Although the term "geotechnical risk" was not a frequently used term until recent times, risks posed by ground conditions have been well known to Engineers over centuries which led to the adoption of a factor of safety for geotechnical design calculations. While a higher factor of safety reduces the risk of unexpected performance, this alone may not be sufficient unless you have considered the geotechnical behavior of the particular project and the factor of safety is applied to what is relevant by identifying the risks beforehand.

To complete a design, the designer has to make assumptions on construction and the steps/stages involved if he has to capture and assess the stress strain behaviour at every stage of the construction. For example, before a basement wall is designed to accommodate the insitu stresses that would be applied over the long term, the designer has to consider stresses, strains and forces during construction, i.e., loads and strains on the temporary supports, if the basement excavation is constructed bottom-up. Similarly, if the construction is top-down the induced stresses, strains and forces would be completely different which may, in most circumstances, have to be accommodated by the final structure.

It is not uncommon for the designer to set up the methodology of construction for his analysis to provide the final design without a dialogue with the Contractor. The Contractor informs the designer what they want to build and assumes the Designer will carry out the design taking into account all the external forces during and after construction. While a major decision such as a bottom-up or top-down is generally conveyed to the designer, there are many other steps that the designer has to assume to complete the design. For example, vertical spacing of excavation staging, spacing of anchors or braces, need to be assumed to carry out analysis. Similarly, in designing an embankment the contractor may prefera geotextile reinforcement rather than a berm to increase factor of safety because of space limitations.

Unfortunately the designer may not have the luxury of interacting with the contractor because of the way certain projects are set up. In D & C (Design & Construction), ECI (Early Contractor Involvement) and Alliance type projects the Contractor input is available right from the start of a project, who can advise the designer on the construction feasibility. While the end product is important, how to get there is critical for construction projects.

In the last decade or more, Alliance type contracting has become popular in Australia in the Government sector. Under an Alliance contract, generally a state agency contractually works collaboratively with private sector parties to deliver the project, taking collective ownership of opportunities and risks associated with project delivery with equitable sharing of pain and gain. Depending on the type of Alliance the advantages/disadvantages differ. While there are competitive Alliances where two or three parties work with different client teams to the concept design, other types of Alliances select the parties based on non-price criteria. Two major Alliance projects in Queensland of the latter type of Allianceare used in the paper to highlight the benefits of paying early attention to the construction in the geotechnical design process.

2 FUTURE PORT EXPANSION SEAWALL PROJECT IN BRISBANE

The Port of Brisbane is a fast growing capital city port on Australia's east coast and is the main port for the state of Queensland. It is located at the mouth of the Brisbane River at Fisherman Islands.

The Future Port Expansion (FPE) Project involved the design and construction of a seawall 4.6km long, extending up to 1.8km into Moreton Bay (Fig. 1), to accommodate maintenance dredging materials and fill the enclosed site which is earmarked for future land development (Ameratunga et al, 2005).

Fig. 1 Site layout – FPE Project

Significant geotechnical, environmental and construction constraints were associated with the project and some of the constraints were:

- Variable depth of soft clay, from ~10m to more than 30m depth.
- Very soft seabed materials; undrained shear strength as low as 3 to 5 kPa.
- Very shallow water (1m deep at Low tide) for 2/3 of the length, and deep water on the east bund (more than 6m at High tide)
- Sensitive Marine park abutting the site and therefore the design criterion imposed by client to any movement limited to <10cm
- Embankment height varying from 5m to about 8m
- Settlement during construction alone varying from 1m to 2m unless the ground is improved.
- Sea conditions and their effects on construction (e.g. movement of placed sand and geofabrics)

The design and construction of an embankment as high as 8m is no easy task on very weak subsoils. The designer quickly proposed a solution of using a high strength geotextile at the base. However, the initial reaction was that unless the construction is staged (which could take years) or ground improvement is adopted, it would not be possible to construct such a high structure in such weak soils. Also, how would you accommodate up to 2m or more of settlement without ground improvement because primary consolidation time was assessed to be over 50 years. The designer came up with several ground improvement (GI) solutions which obviously needed Contractor input:

1) Use of wick drains to accelerate settlement and increase subgrade strength. *Apart from the costs of mobilising a barge, risks included the inability to operate the barge in shallow waters, effect of barge movements on the wick drain installation and increasing disturbance of moderately sensitive soils. From a designer's point of view the latter was very significant because settlement rates could be adversely affected.*
2) Use of semi rigid or rigid solutions. *Risks include the significant costs for mobilization and construction, and environmental considerations near the Marine Park, the latter a serious risk.*

It was not a surprise that both the designer and contractor worked together to find the optimum, or rather, any solution to the problem they faced. It was in one of the open sessions that someone questioned the need for controlling and/or removal of future settlements considering the seawall is a containment wall only. Once the client was consulted and a maintenance strategy was proposed one of the issues related to design was removed because there was no necessity to resort to expensive ground improvement to control settlement..

Still the issue of construction to manage instability was a significant geotechnical risk. In the deeper sea, the high strength geotextile solution was adopted with a sand pancake about 4m in thickness and placed in layers by a barge. The high strength geotextile was also placed using the same barge with certain modifications carried out (see Strevens et al, 2005).

In the shallow waters, a simpler design was considered to construct using land based machinery because the draft for the barge was insufficient in shallow waters and/or limited to only a few hours when the tides were high. The designer and contractor worked together to propose a scheme, a two staged approach:

- a shallow embankment proceeding first which had a reasonable factor of safety (fos), and constructed when the tides are low during the day; and
- the construction of the upper part when the tides are high. The latter now had a higher fos because of the frontal berm done earlier in the day; generally a berm length of about 30m was required.

3 THE INNER NORTHERN BUSWAY PROJECT IN BRISBANE

The Inner Northern Busway (INB), Queen Street to Upper Roma Street Project involved the construction of a dedicated busway between the existing Queen Street Bus Station and the completed section of the INB at Countess Street. The project involved the completion of two bus stations (one within an existing underground car park and the other within an existing railway station complex) as well as 500m of cut-and-cover tunnel within the busy Central Business District (CBD) of Brisbane (Fig. 2).

The busway was constructed within the constraints of the Brisbane CBD. It begins beneath Albert Street where it connects into an existing underground bus station. The route follows Albert Street and cuts across Adelaide Street, both in Area 10 where it goes within the existing, below ground, King George Square (KGS) Car Park. In Area 20 a new underground bus station was constructed beneath Ann and Roma Streets with the busway continuing behind the abutment of Turbot Street Bridge before rising to ground level within the Roma Street Forum.

The tunnel varies in height and width throughout its length, being a minimum of approximately 9m wide between the piled walls and up to 14m deep.

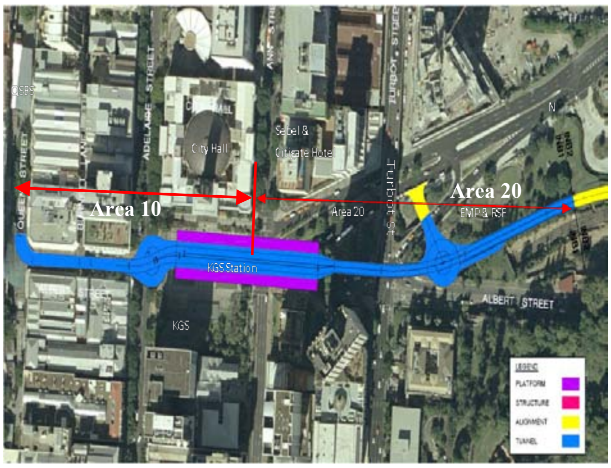

Fig. 2 Site layout – INB Project

The project team consisted of designers and construction specialists, as well as client representatives, from day one, working together to develop the alignment and construction form. The geotechnical members of the project team were, therefore, able to discuss and develop solutions with the construction specialist and other designers.

At the western end of the cut-and-cover tunnel (Area 20) bedrock was typically encountered at approximately 3m below ground level. The weathering of the bedrock encountered on the project ranged from highly weathered to fresh. Fresh and slightly weathered rock was typically high or very high strength crystalline material, more weathered rock was typically lower strength. The metamorphic foliation dominated the defect sets, with an additional two sets of joints and some randomly orientated joints also occurring.

This ubiquitous metamorphic foliation created the potential for varying shape and sizes of blocks along the busway. The orientation of the foliation and the busway were such that potential was identified for sliding along foliation partings to occur on the southeastern wall of the busway during excavation and construction and was considered a high geotechnical risk. In contrast, toppling was not considered a significant risk on the northern wall of the busway, though this assessment was made with the realisation that careful observation during excavation would be required to confirm this. An alternative was to carryout a more expensive pattern bolting. Therefore, an observational approach was agreed with the construction team and was adopted.

Supporting the observation was an extensive instrumentation layout and monitoring programme. The site was surrounded by critical infrastructure, and buildings of local significance as well as shops. Therefore, an advanced system was introduced which used a realtime database monitoring system called INCITE. Instrumentation consisted of:

- building prisms
- building vibration monitors
- surveyed building movement markers
- tiltmeters and tilt plates
- inclinometers, in-pile and in-ground
- standpipes & vibrating wire piezometers
- ground settlement markers
- rod extensiometers

The monitoring system combined the elements of the structural and ground monitoring to provide an early warning system during construction. Where possible the instruments transmitted data directly back to a receiving unit at the site office. For the other instruments monitoring data was downloaded directly once or twice a week. Building and ground settlement markers were surveyed and that data was downloaded into the database by the surveyors.

The ground support systems were developed in discussion between the geotechnical and construction teams. Although much of the ground support was designed prior to construction, the integrated site team enabled site observations to be combined with the comprehensive instrumentation and monitoring programme in order to offer flexibility during construction. Therefore, where ground conditions were seen to differ from predicted, changes were made to the ground support configuration. More often than not, this led to reductions in the original estimate of support requirements.

The choice of ground support was determined by a number of factors:

- ground conditions;
- location of services adjacent to the structure; and
- proximity of buildings and other structures.

The range of ground support options available included:

- piles – these provided permanent support, particularly on the south face of the excavation as significant adverse jointing was anticipated.
- dowels, bolts and anchors – these were provided as required. Temporary actively stressed bar and strand anchors were used for larger excavations to restrain piled wall. Dowels and bolts were permanent and used to retained potential blocks and wedges identified during excavation of mainly the northern wall of the excavation.
  - soil nails – these were proposed for the typically 3m thick upper soil layer above the bedrock. Construction methodology ultimately led to these not being installed.
  - shotcrete - was used between piles and areas of exposed rock faces.

This ability to have a range of solutions available enabled the project team to address some of the challenges and unique limitations imposed by such a project. These challenges were met in an innovative and dynamic way through the use of an observation approach. Through the endeavours of the whole construction team, the ground support works allowed the project to proceed unhindered with the project to finishing ahead of time and on budget.

4 CONCLUSIONS

Geotechnical design relies heavily on the construction steps and staging and therefore it is very important that the designer treats construction as part of the design and takes into account the procedures, staging and machinery used for construction. Having a dialogue with the contractor as part of the design process would reduce the associated geotechnical risks on any civil construction project.

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