Lessons Learnt from Design and Implementation of Ground Improvement in Geotechnically Complex Sites

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ABSTRACT: The design and implementation of ground improvement techniques in geotechnically complex sites require an integrated approach to the development. The design of the ground improvement works will have an impact on the type and nature of the development that can be built on the site; and conversely by stipulating the end use requirements this will have a significant impact on the ground improvement works required. This paper presents a case study to highlight some of the issues that can occur during the design phase of a geotechnically complex site. Also presented are 6 key lessons learnt from undertaking various ground improvement projects.

1 INTRODUCTION

The design and construction of ground improvement works has become more critical in the development of marginal lands. In geotechnically complex sites the integral nature of the development, ground improvement works, cost and program forms a critical element in the successful delivery of the development.

For a recent development in Port Hedland, in the north of Western Australia, an initial design was developed to suit the client's requirements. Unfortunately, as the project progressed, these requirements evolved and introduced new challenges to the delivery of the project.

This paper presents the challenges of designing a ground improvement strategy in a complex geotechnical environment; with a particular emphasis on the project management issues and decision making cycle.

The intent of the paper is to provide a case example and discuss lessons learnt from undertaking ground improvement in geotechnically complex sites.

2 SITE CONDITIONS

2.1 *Initial Development*

The project is located near the town of Port Hedland in Western Australia. The town is in an area that is subject to (annual) cyclonic winds and rainfall that also flood part of the township.

The project development involved the construction of 35 two-storey houses and a six-storey apartment block over an area of approximately 30,000m^2.

Due to relatively high flood levels in the vicinity of the site, the development involved raising the ground surface level approximately 3m; hence involved the construction of retaining walls around the perimeter of the site.

A central road was proposed for the development, which also included a service corridor connecting all of the houses to the main service corridor external to the development. The main service corridor traversed two sides of the development and was typically 4m from the site boundary. The service corridor included a ceramic sewerage pipe and mains water pipe, storm water drains and optic fiber cables.

The performance brief set by the client was initially to have a high end specification for the development. Movement of the walls was to be less than 20mm at the top of the wall and foundations were to have less than 40mm settlement over a 50 year design life. There was also to be no effects outside of the site boundary.

2.2 *Geotechnical Conditions*

The site is located on an alluvial / fluvial flood plain and had been unused prior to the development. Over time, there had been some fly tipping and fill placed over the site in a random and uncontrolled manner.

Underlying the fill were alluvial deposits that were between 4m and 8m thick over the site. The alluvial deposits were assessed as being very soft to soft, medium plasticity clays with interbedded sand deposits.

The alluvial deposits were underlain by calcarenite which, in turn, was underlain by very dense to hard silty sands.

The geotechnical conditions at the site were not overly complex, however did require some ground improvement in order to render the site suitable for the clients development requirements.

3 GEOTECHNICAL DESIGN

3.1 *Initial Design*

The initial geotechnical design involved undertaking a staged surcharge strategy where the side with the shallower thicknesses of alluvial deposits were initially preloaded and made suitable for the development while the deeper deposits were preloaded during the second stage for a subsequent release of the property.

The first stage for the release of the property would require a surcharge for approximately 6 months. Depending on the thickness of the alluvial deposits, some areas of the development did not require wick (vertical) drains whereas other areas were designed to have wick drains installed at a 1.5m horizontal spacing. The second stage of the development involved a longer surcharge regime of approximately 9 months; however the staged approach provided the client a solution that satisfied their development criterion.

The key to the surcharge and wick drain design was that it gave the client flexibility to alter the form of the final development. By treating the entire site, the subsequent contractors to view the site as a "greenfield" development and vary the services and buildings accordingly (provided it was a single or two storey development).

The foundation design for the apartment buildings involved a piled foundation system to manage the larger (concentrated) loads.

Differential settlement for services being connected to the houses and the apartment buildings was limited through the design of the surcharge strategy. By preloading the entire site, the issue of differential settlement between areas having and not having houses was mitigated through design.

One of the key elements was the design of the retaining wall around the perimeter of the site. The surcharge strategy was altered around the perimeter of the development to address the lack of confinement (and hence large rotational ground movements) and also increase the stiffness of the alluvial deposits. Upon completion of the surcharging regime, the alluvial deposits were designed to be sufficiently stiff to allow the construction of any type of retaining wall.

The service corridor that was external to the development was also considered during the design process. Designs were provided to limit the effect on services and included options such as: relocation of services, protection of services through a sacrificial bentonite filled trench and a monitoring and repair approach.

3.2 *Revised Design*

Approximately 9 months after the completion of the surcharge strategy design, the designer of the project was changed.

Shortly after a new designer was brought on to the project, the entire project management (or delivery) team was changed for the development.

The new delivery team revised the scope of the development to just doing 25 two-storey houses and did not entertain the staged approach to the development. Furthermore, the timeframe to implement the works was reduced such that the surcharge strategy was no longer viable (from a program point of view).

Controlled Stiffness Columns (CSCs) with a Load Transfer Platform (LTP) were identified as an alternative ground improvement technique that could satisfy the program requirements for the project however would cost considerably more. As program was the key driver, the design of the CSCs was undertaken.

The CSCs were designed to achieve the original specification of no more than 40mm of settlement across the site. The design of the CSCs was undertaken using Plaxis to assess the amount of movement at the ground surface level, rotations in the retaining walls, movement at the external services and forces within the LTP.

Various models were used in the analysis depending on how the load was transferred through the soils. The CSC and LTP model provided a load transfer path that provided a limited increase in stress to the alluvial deposits. By varying the stiffness of the LTP the spacing of the CSC could be optimized.

Based on the results of the design a detailed cost estimate was provided. The client then wanted to reduce costs and a series of different designs and performance expectations were provided to the client such that they could assess the preferred design for the estimated budget.

The integration of the ground improvement design with the assessed movement of the walls and the effects external to the site was a complicated issue and an integrated problem. Compounding the problem were constructability issues – for example, the preferred retaining wall type (from a design point of view) was an articulated wall that could withstand differential settlements. However from a construction and cost point of view, a masonry limestone block wall was easier and cheaper to build.

A lot of these issues are not insurmountable but the selection of a preference has significant effects on other elements of an integrated design. Furthermore, changing the engineers and the project management team resulted in redesigning items that had previously been addressed.

This compounded the delay that already been incurred, which also meant the program to deliver the project was further reduced and further compromises were made regarding the type of building going on the site.

In this case study, the integral nature of the design, program and cost were not appreciated in a complex geotechnical environment. However, it does provide an opportunity to review the lessons learnt as to why this has occurred.

4 LESSONS OF GEOTECHNICALLY COMPLEX SITES

The changes that have occurred during the development discussed herein are not unique to this site and have also been encountered on other geotechnically complex projects requiring ground improvement works.

From the authors' experiences, there are 6 main lessons learnt from undertaking ground improvement works in geotechnically complex sites. These 6 lessons are discussed in the following sections.

4.1 *Consistent Team*

When delivering a complex project, often over an extended construction period, having a consistent team throughout the project is fundamental to the successful delivery.

Changes to the team resulted in significant delays to the project and a significant amount of re-education of different team members.

From a geotechnical view, changes to geotechnical teams often resulted in additional stages of geotechnical investigations being undertaken, to confirm the reliability of previous data.

It should also be noted that having the right team members is also key. Companies (and more importantly) the individuals on projects need to have worked in geotechnically complex sites before. All team members also need to have a similar drive and goal to deliver the project.

4.2 *Consistent Plan*

Having a consistent plan on the project is also fundamental to the successful delivery of a project. Changes to the development plan often result in a significant delay that far exceeds the initial costs.

Changes to plans often result in confusion among the project team and introduce a series of naming convention, quality assurance and control issues and contractual issues not realized at the time of changing the plan.

It is noted that some flexibility in a development plan is required to adapt to unexpected conditions and fluctuating markets (often beyond the control of all parties involved); however the fundamental plan should remain unchanged.

4.3 *The Value of Time*

In geotechnically challenging developments, the value of time is often no appreciated. As a general rule of thumb, the longer the program to develop the site the cheaper the development costs.

For example, a site can be surcharged with or without vertical drains over a long duration to provide a relatively cheap ground improvement option. As the amount of time allowed for ground improvement decreases then surcharging is not viable other options such as stone columns, soil mixing or other such solutions are required. These techniques deliver a solution quickly but do so at a significantly higher cost than a surcharge option (for example).

Often developers are reluctant to commit to incurring significant costs many months (or years) before a site can be developed. This is particularly the case for implementing a surcharge regime where large earthworks are required early in the development process. However; the authors have found that on four recent developments on geotechnically complex sites the cost of the initial outlay has been far less than the costs occurred for developing a site on a much shorter timeframe.

4.4 *Understanding Performance Expectations*

The performance expectations and the design intent of any development define the nature of the works. In the example presented herein, the initial brief was for a high class development with very small resultant ground movement (and wall movement). Once the cost of having such a tight performance specification was realized, the performance specification was changed to something more economic.

While this process is very much part of the project review cycle, it can take a significant amount of time and money to implement; particularly if two or three changes to the performance expectations occur.

4.5 *The Decision Cycle*

While a lot of geotechnical issues are discussed herein, on geotechnically complex sites often there are other input parameters that influence the decision as to what ground improvement process that needs to occur – i.e. there is no 'silver bullet'.

Other factors include: environmental impacts, heritage issues, local labor content, personal preferences (or what has been done before), reluctance for new technologies, program, costs, supply / availability of construction materials, impact on other parts of the development, weather impacts and staging of the works just to name a few.

Often changing the development plan (refer above) and/or the ground improvement methodology has an effect on the issues noted above.

These issues are not insurmountable however the development manager needs to appreciate the effect any change has on all the elements of the development. In the example discussed herein, the impact of such issues was not being understood by the development manager and resulted in multiple redesigns which also impacted on the cost and program.

4.6 *Communication of Issues*

The communication of issues and the effect of any change forms a critical part of any development. For projects where that extend over a longer period of time and involve changes in the team the communication of issues forms an even more critical process.

In the United Kingdom, the Construction (Design Management) regulation published in 2007 (referred to as CDM 2007) defines the legal duties of companies operating in the United Kingdom from a health and safety point of view. A key element of the CDM 2007 is that it recognizes the ability of Designers to identify and eliminate risks from the project. While CDM 2007 is primarily focused on health and safety management, the process provides a sound mechanism in identifying and managing projects risks across a number of disciplines.

Considering the sentiments of Section 4.5, the CDM 2007 process of documenting and communicating the issues for a development – and also the change in any designs – provides a means of managing these issues.

5 CONCLUSIONS

The implementation of ground improvement works is becoming more critical for the development of marginal lands. In order to do so successfully, the design and project management of the works become more critical.

This paper provides a case study and 6 main lessons learnt from the delivery of various ground improvement techniques. These are:

1) A consistent team
2) A consistent plan
3) The value of time
4) Understanding performance expectations
5) The decision cycle
6) Communication of issues

REFERENCES

Construction (Design and Management) Regulations 2007, United Kingdom