GEOTECHNICAL INVESTIGATIONS FOR PILING PROJECTS – THE FALSE ECONOMY OF A CHEAP SITE INVESTIGATION

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1 INTRODUCTION

An adequate geotechnical site investigation is the corner-stone of any successful ground engineering project. However, in the current commercial environment, the scope of site investigations for piling projects is often minimised to the detriment of the project.

Inadequate geotechnical information precludes economical pile design and often leads to qualified piling tenders.

This paper summarises the current state of practice in Victoria in relation to site investigation for piling projects. Some hypothetical examples are presented which demonstrate the additional piling costs that can arise due to inadequate site investigation. These additional costs usually substantially outweigh the small up-front saving that may be achieved on site investigation works. While not actual case studies, the examples given are representative of real projects and realistic cost outcomes.

While a detailed discussion of site investigation requirements for piling projects is beyond the scope of this paper, some practical recommendations are given for those involved in engaging site investigation consultants.

2 STATE OF PRACTICE IN GEOTECHNICAL SITE INVESTIGATION

Australia is fortunate to be served by a highly skilled and experienced body of geotechnical professionals. Our consulting industry is lead by 'world class' practitioners, backed up by a body of skilled engineers and geologists for many of whom site investigation work is their 'bread and butter'.

Of these practitioners, Victoria has more than its fair share. We also have a number of very capable drilling contractors with the equipment and expertise to carry out high quality geotechnical investigations. However, a large proportion of the site investigations carried out for projects involving piling contain major deficiencies.

These deficiencies generally fall into the following categories:

- Inadequate number and/or depth of borehole or test (eg. Cone Penetromer Test [CPT]) locations to enable the piling engineer to properly interpret the geology of the site.
- Inadequate testing frequency and/or the use of inappropriate testing methods to properly charactise the materials present and determine efficient and safe design parameters and construction techniques.
- Inadequate investigation of groundwater conditions at the site.

These deficiencies are generally brought about because not enough money is spent on the site investigation to enable an appropriate scope of work to be completed. Often the geotechnical consultant is forced to reduce the scope of works to fit the client's budget. Alternatively, the site investigation contract may be awarded, on the basis of cost, to a consultant with insufficient piling experience who proposes an investigation with inadequate scope. In this case, the client often doesn't understand or acknowledge the deficiencies in the service he is purchasing.

It is common on larger projects for a 'preliminary' investigation to be carried out, implying that further investigation is necessary and will be completed at a later date. Often the project goes to tender on the basis of the preliminary investigation.

3 THE ECONOMICS OF INADEQUATE SITE INVESTIGATION

A certain degree of risk, due to changing or unexpected ground conditions, is inherent in all piling projects. Inadequate geotechnical investigation magnifies this risk considerably, which can be borne out in unpredictable construction costs and programming issues.

In the current contractual environment, in which risk is passed down from developer to builder to subcontractor, the piling contractor often bears the risk on ground conditions. When faced with insufficient geotechnical information, the piling engineer must either gamble on a favourable outcome, or price the risk into their tender. It will be demonstrated in subsequent sections that the cost of the latter is often well in excess of the savings made on the site investigation.

The following sections demonstrate the influence of site investigation data on piling costs. In the following hypothetical examples, comparison is made between a 'safe' piling design based on limited geotechnical information and an efficient (and safe) design based on a more comprehensive geotechnical investigation.

Examples are given for a bored pile scheme, a precast pile scheme and a retaining wall. Each case examined is considered to represent a realistic set of of outcomes based on some typical local geological profiles.

For each example, Case A is based on insufficient site investigation, while Case B is based on a more comprehensive site investigation.

3.1 BORED PILE EXAMPLE

Site Details:
The site measures 25 m wide x 45 m long. The piling scheme requires bored piles to be drilled through overburden soils to found on rock. Two boreholes have been drilled to Siltstone bedrock at opposite corners of the site. The bedrock characteristics are relatively consistent across the site.

Piling Requirements:
20 No. 1200 mm diameter bored piles, 14 MN SWL per pile.

Case A (Poor Site Investigation):
The two boreholes have been drilled to a penetration of around 21.5 m, approximately 3.5 m into the siltstone. Around 1.5 m of extremely weathered (EW) rock was encountered followed by highly weathered (HW) rock to the end of the boreholes, as shown in Figure 1.

The piling engineer assumes in their design model that the HW rock continues to a depth of 25 m, and then <u>speculates</u> that the rock will improve to become moderately weathered (MW). This would need to be verified during construction.

The required pile length based on this model is around 30 m.

Case B (More Comprehensive Site Investigation):
The two boreholes have been drilled to a penetration of around 28 m, approximately 8 m into the siltstone. From 21.5 m depth, the HW rock continues to 23 m, followed by MW rock to 25 m and slightly weathered (SW) rock to the toe of the borehole. This profile is also shown in Figure 1.

The piling engineer determines that the required pile length is 26 m.

Cost Comparison:
Based on a typical budget rate of $950/m for 1200 mm diameter bored piles the costs for each scenario are as follows:

- Case A cost = $570,000
- Case B cost = $494,000

The additional cost due to inadequate site investigation is $76,000.

The cost of drilling and testing the additional 6.5 m in each borehole is in the order of $2500.

3.2 PRECAST PILE EXAMPLE

Site Details:
The site measures 100 m wide x 120 m long. The piling scheme requires precast piles to be driven through soft overburden soils to found on rock.

Piling Requirements:
250 No. 350 mm square precast driven piles, 1800 kN SWL per pile.

Case A (Poor Site Investigation):
Two boreholes have been drilled in opposite corners of the site, which have encountered dense gravels and stiff clays from 26 m depth and siltstone bedrock at depths of 28 m and 32 m. Limited in-situ testing was undertaken in the

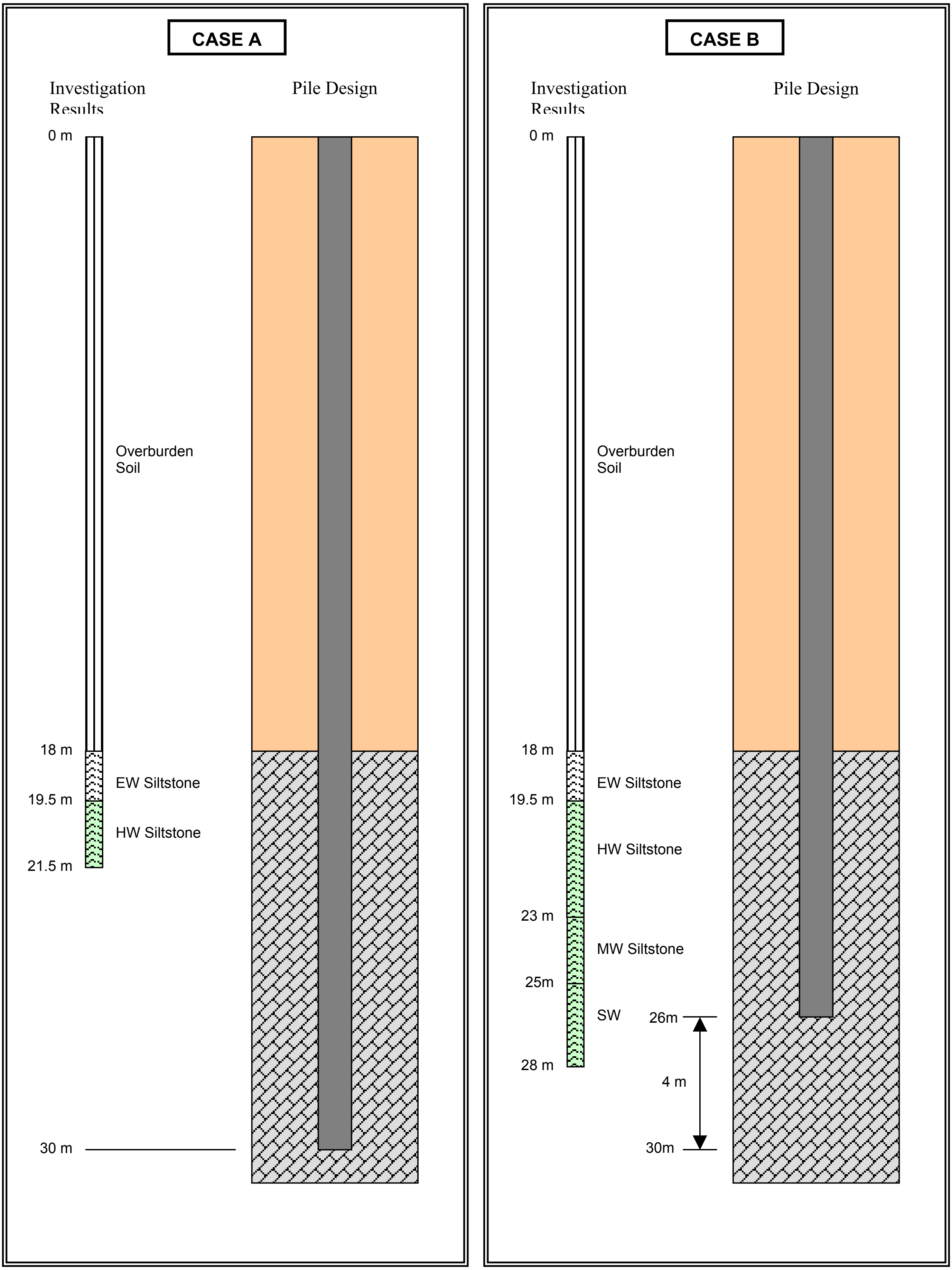


Figure 1: Bored Pile Example. (Not to Scale)

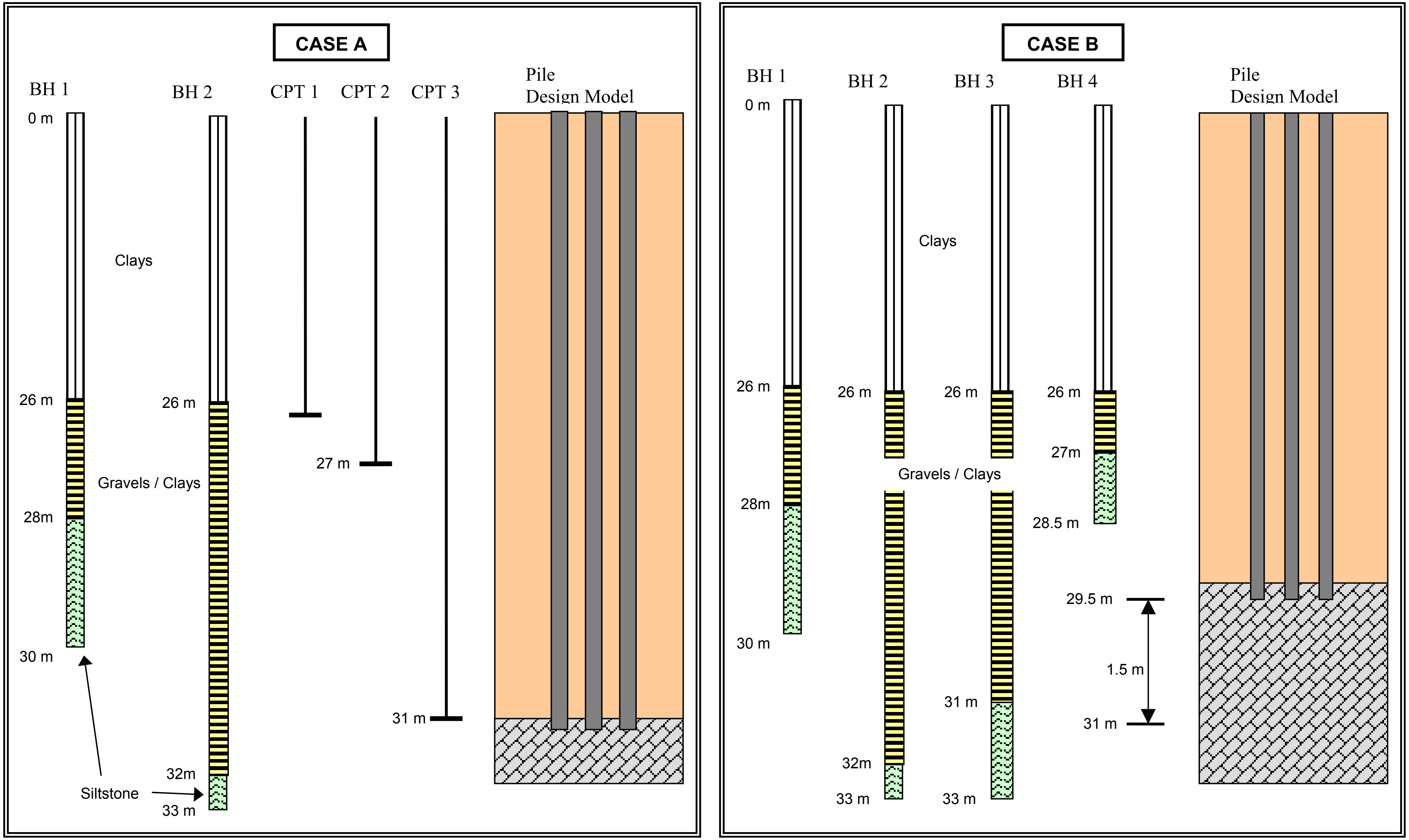
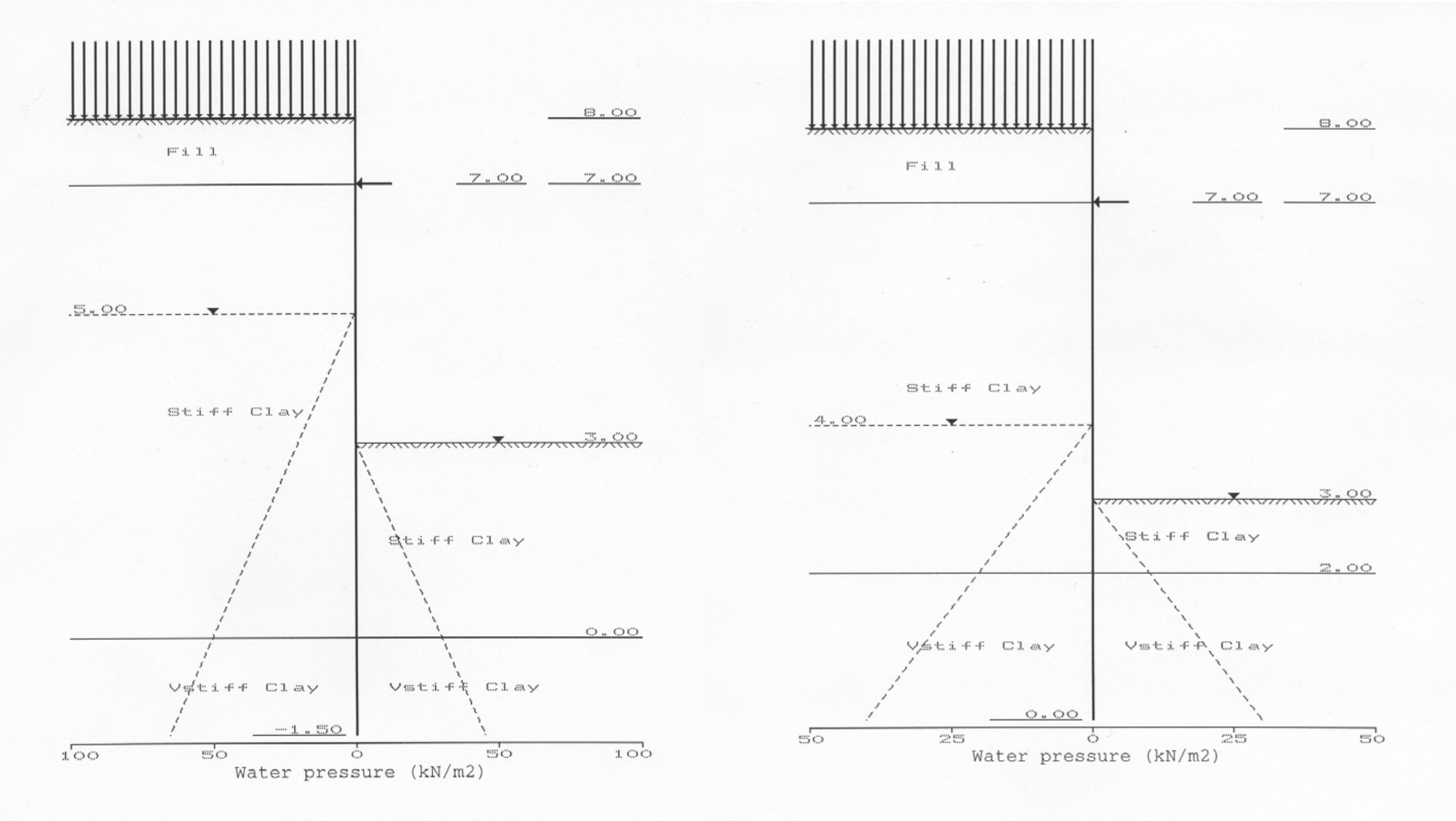


Figure 2: Precast pile example. (Not to Scale)



CASE A **CASE B**

Figure 3: Retaining Wall Example (Not to Scale)

gravel/clay layer. Three cone penetrometer tests (CPTs) have been conducted at the site, which encountered refusal at depths of 26 m, 27 m and 31 m respectively. The CPTs may have stopped on a thin layer of dense gravel, rather than bedrock. The results of the investigation are shown in Figure 2.

The piling engineer cannot draw any conclusion in relation to pile founding depth from the CPT data[1]. Based on the borehole data, an average founding depth of 31 m is assumed.

Case B (More Comprehensive Site Investigation):
Four boreholes have been drilled into the top of the siltstone. The depths to sound rock was found to be 28 m, 32 m, 31 m and 27 m. This profile is also shown in Figure 2.

Based on the borehole data, the piling engineer estimates and average founding depth of 29.5 m.

Cost Comparison:
Based on a typical budget rate of $110/m for 350 mm square precast piles the costs for each scenario are as follows:

- Case A cost = $852,500
- Case B cost = $811,250

The additional cost due to inadequate site investigation is $41,250.

The cost of drilling the additional two boreholes in lieu of CPTs is in the order of $6000.

3.3 RETAINING WALL EXAMPLE

Site Details:
The site measures 20 m wide x 30 m long and will be the site of a 5 m deep basement excavation. A hard-soft secant pile wall with a total length of 100 m is required around the basement. Two boreholes have been drilled at the site in predominantly clay material.

Piling Requirements:
100 No. 600 mm diameter hard secant wall piles and 100 No. 600 mm diameter soft secant wall piles to form a water-tight retention system.

Case A (Poor Site Investigation):
The two boreholes have been drilled to a depth of around 6.5 m, approximately 1.5 m below basement excavation level. The material encountered is described as fill to 1 m depth then a stiff silty clay to the depth of the borehole. Limited geotechnical testing has been carried out and the water table has not been properly observed. Groundwater seepage was recorded at a depth of around 3 m.

The piling engineer assumes in the design model that soil at the site is a stiff clay to 8 m depth, which then becomes very stiff. The water table is assumed to be at a depth of 3 m.

The required wall depth based on this geotechnical model is 9.5 m, with one row of ground anchors. This provides a factor of safety on wall stability of 1.8, and results in a maximum bending moment of 125 kNm/m.

Case B (More Comprehensive Site Investigation):
The two boreholes have been drilled to a depth of around 10 m, approximately 5 m below basement excavation level and a couple of metres below the expected toe of the wall. In-situ tests have been carried out for the depth of the borehole to establish the soil strength profile. The material encountered is found to be fill to 1 m depth then a stiff silty clay to 6 m depth overlying very stiff silty clay to 10 m depth. A standpipe was installed in one of the boreholes to determine water table depth. This was monitored for a period of time after installation and the groundwater table was found to be at a depth of 4 m.

The wall is designed on the basis of the above profile. The required wall depth based on this geotechnical model is 8.0 m, again with one row of ground anchors. This also provides a factor of safety on wall stability of 1.8, and results in a maximum bending moment of 90 kNm/m.

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[1] Cone pentrometer testing can be very useful in pile design, but it is generally of little value for determining the depth of precast pile refusal.

Cost Comparison:
Based on a typical budget rate of $160/m for 600 mm secant CFA piles the costs for each scenario are as follows:

- Case A cost = $304,000
- Case B cost = $256,000

The additional cost due to inadequate site investigation is $48,000. This does not include the cost of additional steel reinforcement to cater for the higher predicted bending moments.

The cost of drilling the additional 3.5 m in each borehole, completing in-situ testing, installing a standpipe and monitoring ground water levels is in the order of $2500.

For the case of a similar retention project with a contiguous pile wall or soldier pile wall the additional cost for a 1.5 m deeper wall would be as follows:

- Contiguous pile wall = $36,960
- Soldier pile wall = $13,440

This again excludes the cost of additional steel.

3.4 WELL TARGETED GEOTECHNICAL INVESTIGATION IS A GOOD INVESTMENT

The above examples demonstrate that, on larger projects, the cost of obtaining additional geotechnical investigation is generally insignificant in relation to the potential for additional piling costs.

On smaller projects, the difference between additional expenditure on site investigation and potential design savings will be less pronounced. However, it will be explained in the following section that inadequate geotechnical investigation can often weaken the contractual position of the builder or developer in relation to their piling works, and can lead to unforseen delays.

4 WHO BEARS THE COST?

In the current contractual environment, few piling contracts are let based on a schedule of rates with price adjustment for additional or lesser quantities. Most contracts are let as either fixed price lump sum contracts in which the piling contractor assumes all risk on ground conditions, or as a lump sum contract with upward variations where the risk of additional piling quantities is borne by the client.

Poor geotechnical investigation generally leads to the following outcomes:

- Piling contractors may submit qualified tenders with a requirement that additional geotechnical investigation be carried out by the developer or builder (the client). In this case, the project may be re-tendered once this work has been completed, with consequential delays.
- Tenders may be submitted with variation rates for additional pile length if required. Such tenders are difficult to evaluate as the correct pile length is not known to the client. The contract value may be subject to significant escalation if a contract is let on this basis.
- Fixed price lump sum piling prices are likely to include a contingency to cover the potential for additional piling costs due to the uncertainty of the site conditions. Due to the competitive nature of the piling industry, some contractors may speculate on favourable ground conditions. Additional costs to the client may be mitigated by such competition in some instances. However there is a strong likelihood that the piling will cost the client more than it should. In the event the successful piling contractor underestimates the risk, the contractor could suffer a significant financial loss on the project. In this instance, the client may have saved money on the piling. However, this scenario obviously constitutes unsustainable business practice for the contractor and such outcomes are in the minority.
- Fixed price lump sum piling prices may be qualified on additional geotechnical investigation to be carried out by the successful piling contractor. If the additional investigation finds favourable conditions, the piling contractor may get to retain a saving on his piling costs. If so, the client pays more than necessary. If unfavourable conditions are encountered, the successful contractor will seek to increase the contract price.

In the majority of cases, an inadequate geotechnical investigation will result in increased costs to the client. It is also likely to lead them into a contractual situation with reduced control over the final piling cost. Unforeseen ground conditions are the most common cause of delays on piling projects, presenting a significant risk to programs.

5 WHERE TO FROM HERE?

The detrimental impacts of inadequate geotechnical site investigations are well known to most geotechnical and piling practitioners. However, there is a need to educate and inform the wider engineering community and our clients in relation to this problem.

In the current commercial environment the value of sound site investigation is often given dangerously little recognition. Those ordering and/or specifying geotechnical investigations need to understand what they are getting for their money and when additional expenditure is a good investment.

A detailed discussion of the requirements for adequate geotechnical investigations is well beyond the scope of this paper. However, some general guidelines for those involved in engaging geotechnical consultants for site investigation are as follows:

- Investigations should comply with AS1726 – Geotechnical Site Investigation. Where appropriate, locally developed descriptions of materials should be incorporated.
- You usually get what you pay for – the cheapest site investigation proposals are generally based on a limited scope of works. Before accepting a cheap price, investigate the adequacy of the scope.
- Not all geotechnical consultants understand the requirements for efficient pile and retaining wall design. Preference should be given to consultants who have experience with design of the piling scheme/s under consideration.
- Piling contractors are usually willing to give preliminary advice in the early stages of a project. If you are unsure of the appropriate requirements for an investigation, talk to someone who designs piles for a living.

It is the author's hope that this paper goes some way to assisting practitioners who engage site investigation consultants to understand the economics of the investigation and design process.

6 CONCLUSIONS

On many projects involving piling, inadequate geotechnical site investigation is carried out at tender stage. In the majority of instances, this leads to inefficient pile design and/or qualified piling tenders.

The savings to be made by opting for a cheap site investigation are generally insignificant in comparison to the detrimental impacts to the project. These impacts may include the following:

- Increased piling costs due to inefficient design and contingencies for risk.
- A weakened contractual position on the part of the client and piling costs that can be subject to escalation as the project proceeds.
- Program delays due to unexpected ground conditions that are encountered during the works.

The aims and objectives of the site investigation must be properly considered by those awarding contracts for the investigation works. These should be developed in consultation with engineers who understand the pile design and construction process for the particular piling scheme/s under consideration. Geotechnical consultants must be given a sufficient budget to properly meet the project requirements and should be required to demonstrate that the scope of the investigation they propose is adequate.

The wider engineering community and our clients must become better informed in relation to the value of good geotechnical information to their projects.