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A discussion on piling supervision for rock socket design verification

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ABSTRACT: The transition from being an office based design engineer to having a site based role in construction phase support is a common occurrence for Geotechnical professionals in the first five years of their careers. This paper addresses piling inspections for the verification of rock socket designs for bored piles. The general methods of pile socket verification are discussed, with attention also given to safety observations and hazards for the Geotechnical Engineer whilst on site. A case study is presented for bored piles in Landsborough Sandstone, with specific reference to the procedures and processes employed for Department of Transport and Main Roads, Queensland projects.

1 INTRODUCTION

Presented is a discussion of the design method for bored piles socketed into rock, using Pells (1999) and Rowe and Armitage (1987), specific to the requirements of the Department of Transport and Main Roads (DTMR), Queensland. Outlined is the design method applied for rock sockets and process used on site, to verify the design assumptions during the construction phase. A case study is presented which discusses the process used in this instance following the DTMR Specification MRTS63 for Cast-In-Place-Piles (2016). The case study is specific to bored piles socketed into rock for bridge foundations, and to the ground conditions encountered on this site, on the Sunshine Coast in South Queensland. However, its specification and the methods and scrutiny for pile verification may be transferred to other regions with similar ground conditions and design practices for pile socket verification.

As part of the verification process it is important for the Geotechnical Engineer on site to understand the process and assumptions made at the rock socket design stage. This allows the Geotechnical Engineer to fully understand the key design assumptions in order to verify the rock socket design during site observations. Therefore, this paper will outline the key design aspects as part of this case study.

A high-level discussion of safety observations and hazards for the Geotechnical Engineer on site is also included. Although site specific hazards will vary from each site, and also may change daily or throughout the day, it is important to recognise the risks associated with the piling verification process, especially for individuals not accustomed to working in a site environment.

2 DESIGN

2.1 *Geological background*

Published geological mapping (Moreton Region – Regional Surface Geology 1978 (1:500000)), from the Geological Survey of Queensland indicates that the case study area lay within the Landsborough Sandstone sequence, covered in a few specific areas by deep floodplain alluvium. As well as an initial desktop study, including a review of historic site investigations, an extensive geotechnical investigation was undertaken (with investigations at tender and detailed design). This allowed a site-specific ground model to be established in the study area for each bridge location. Investigations were undertaken at every bridge abutment and pier location, to a minimum depth of 5m into moderately or slightly weathered rock, as outlined in the DTMR Geotechnical Design Standard – Minimum Requirements. However, based on having an established ground model and the extent of the site investigations available over the whole study area, an exception was granted by DTMR to reduce the number of boreholes from two to one, at abutments and pier locations. This extensive site investigation confirmed the findings of the desktop study, that the geology consisted of predominately Sandstone, with some bands of Conglomerate, Siltstone and interbedded Sandstone and Siltstone laminations. Varying degrees of weathered rock, with differing strength profiles were found throughout the study area with logging done in accordance with the Australian Standard for Geotechnical Site Investigations; AS1726-1993.

2.2 *Bored pile design method*

For this case study, bored piles (cast-in-place), were adopted as the preferred foundation type. The bored pile design was undertaken to the DTMR Geotechnical Design Standard – Minimum Requirements, for axial and lateral pile design. Design requirements were to ensure adequate ultimate geotechnical strength and serviceability requirements were met. Only the axial design will be discussed here. The socket lengths were determined based on the design methods as outlined in Pells (1999), incorporating the work of Rowe and Armitage (1987). The design method is chart based, allowing for non-brittle sidewall slip and considering differences between rockmass stiffness below the socket base and sidewalls.

To determine the minimum socket length required, the design charts from Pells (1999) were used for elastic design (no allowance for side slip), or the charts from Rowe and Armitage (1987) were used for a side slip design solution (allowing for displacement), which considers a socket length to diameter ratio between base load and total load on the design charts. The proportion of total load distributed to the base was limited after a design review of the preferred construction process, which was for piles being cast in wet conditions. A reduced skin friction was also assumed for piles which were not able to be cast in dry conditions. All piles were initially treated as wet piles without video inspection, and a capacity reduction factor was used as required by MRTS63 (2016).

A project wide correlation between uniaxial compressive strength (UCS), and point load index ($I_{s(50)}$), was established by comparison and analysis of data on testing of similar rock types and from published correlations and data analysis on Landsborough Sandstone from Roche and McCallum (2015).

The socket roughness was based on the classifications outlined by Pells (1999). A design assumption of a roughness class of R2 (grooves of depth 1 to 4mm, width greater than 2mm, at spacing 50-200mm) or better (i.e. R3, where grooves of depth 4 to 10mm, width greater than 5mm, at spacing 50-200mm) was made. Socket roughness affects the side shear resistance, therefore to account for this, differing equations for the expected side shear resistance were used as determined by Pells (1999). Haberfield (2013) discusses the suitability of the socket roughness classification for material other than Sandstone, however since the material encountered in this case study was predominately Sandstone, Pells (1999) is believed to be a suitable method.

As suggested by Haberfield (2013), negative skin friction was included in the pile designs where appropriate, depending on the bridge specific construction sequencing. This was included with the serviceability loads if applicable.

The design aspects outlined above will become important when understanding the bored pile verification process on site.

3 GEOTECHNICAL CONSTRUCTION SUPPORT

3.1 *Bored pile construction process*

Described in this section is the general process that was followed for the bored pile (cast-in-place) installation specific to this case study. The method generally contained the following steps: preboring, installing the liner, filling the resultant annulus between the liner and prebore, drilling of the rock socket and mechanical cleaning of the base.

Prebore: As outlined in the specification MRTS63 (2016), where stability of the hole can be maintained prior to inserting the liner, preboring can be acceptable to a depth of 3m, and designer approval is required for depths greater than this. When this approval was requested by the subcontractor, the Geotechnical Engineer reviewed the expected ground conditions, especially making note of any loose sand layers or groundwater, which may result in instability of the hole; and provided advice based on this assessment. Any resultant space between the liner and the prebored hole was to be filled with a “flowable fill”, or a low strength concrete. The motivation for the subcontractor wishing to increase prebore depths was to decrease the time required for liner installation to the top of socket and therfore reducing costs. A deeper prebore could also potentially reduce splicing lengths of the liners. Increasing the prebore depth also reduced the risk of splicing and suspending liners at height close to the motorway, which was undesirable due to safety concerns.

Installation of Liners: Liners were installed by progressively removing material from within the liner only and applying force and rotation, advancing down until refusal. Liner lengths had been anticipated to refuse on highly weathered to moderately weathered rock, which would avoid any potential collapse or instability of material above liner termination. During excavation, the liner foundation material would be inspected to verify the material would be self-supporting below the liner termination level. Due to the nature of the ground conditions some variations were found to the design of the liner termination depths, with situations of early refusal and also cases where the liner lengths were required to be increased. Once the liner was at refusal the resultant space between the liner and prebore was filled with flowable fill.

Drilling of Socket: On completion of the liner installation, drilling below the liner commenced, with an expectation that the rock walls would be self-supporting. The drill operator used different boring techniques depending on the strength of the material encountered. This included the use of an auger, coring bucket, digging bucket or a combination of the three to drill through weathered rock. As a result, there were significant differences between drilling rates through different rock strengths.

Base of Socket: When reaching the target designed rock socket depth, or at a final depth as instructed by the Geotechnical Engineer, the base of the socket would be cleaned with a mechanical "cleaning bucket", which removed debris and sediments from the base. This bucket would be put down the pile several times (generally two to three time after reaching the final drill depth), until no or very little debris was encountered.

For the case of piles cast as wet, the tremie method for the concrete pour was used, outlined in the specification MRTS63 (2016).

3.2 *Pile verification*

The pile verification process requires the Geotechnical Engineer to verify, on site, that the shaft and base capacities meet the design requirements. The design assumptions are also required to be verified, including the socket roughness, base cleanliness and the minimum design depth is met.

The process used for pile verification for this case study was developed in consultation with DTMR. It was proposed that a Geotechnical Engineer was to carry out the site inspections and then a remote, offsite Registered Professional Engineer Queensland (RPEQ), Assessor was used to confirm the assessments made on site. The Assessor was always in communication with the Geotechnical Engineer and fully aware of site activities being undertaken, as part of the certification process. The Assessor had a prior understanding of the geological background and design requirements for the pile sockets. The Assessor was involved much more heavily at the start of the piling process for each new bridge. A review of the design reporting, borehole information and design requirements were undertaken prior to the site supervision commencing.

The process for verifying that the socket met design requirements involved taking rock samples from the spoil of the drill rig bucket or off the auger. Samples were then point load tested on site for comparison with the design requirements. Three samples would normally be taken per metre along the shaft and three at the base of the socket. These were tested, and the point load value was converted to an $I_{s(50)}$ value, normalised for the size of the sample. Point load testing was undertaken in accordance with AS4133.4.1-2007 Rock Strength Tests - Determination of Point Load Strength Index. However, it was not always possible to take conforming sized samples due to the nature of the drilling method, where generally smaller samples were obtained from the auger and larger samples from the coring bucket. Any failure along bedding planes or irregular failures were disregarded, as they were not representative of the intact rock strength.

As drilling progressed the piling rig operator would communicate depths to the Geotechnical Engineer, which were given as a depth below top of liner level. When at the design socket base or at a depth as directed by the Geotechnical Engineer, and after the design base and shaft capacities had been achieved, the actual drilled depth would be verified, and the base would be cleaned several times. To verify the socket depth a weighted tape measure was dropped down the pile excavation; the depth would be checked and then the tape would be moved around the base of the pile to confirm that there was minimal or no debris on the base of the socket. Cleaning of the base, with the drill rig's cleaning bucket would be requested until minimal or no further debris was brought to the surface. If the design criteria was not met, the socket length was extended until the design capacities were achieved. As Rowe and Armitage (1987) suggest, the time between final base clean out and pouring of concrete should be minimised. This is to avoid potential softening of the rock, minimise sediments on the base and also if Siltstone is present within the socket material, to avoid potential swelling due to water exposure.

Where possible camera inspections of the socket base would be undertaken. In some cases, before commencing the inspection, dewatering of the pile was necessary to allow for a clear image downhole. A GeoVision downhole camera was used for the socket inspections, which could be moved and rotated to view the sidewalls and downhole. During the camera inspection the sidewalls were checked to verify the socket roughness design assumptions. During these inspections good sidewall socket roughness was noted, meeting the design requirements for an R2 or R3 socket roughness. The grooves imposed by the drilling technique and equipment could be clearly seen on the sidewalls and it was also observed that moderately weathered material tended to be rougher than slightly weathered. Socket roughness is also discussed in Haberfield (2013) noting the importance of roughness to the socket's shaft resistance design. During the camera inspections the sidewalls were checked to be clear of smear or mud. Haberfield (2013) notes the importance of this to ensure good bondage between the socket and concrete. As Pells (1999) outlines, side smear can be reduced by drilling underwater. The majority of sockets for this case study were cast as wet piles, as groundwater was encountered. At the design stage, piles were assessed for also being cast in wet conditions, where the design load transferred to the base of the socket was limited.

For the socket design the Geotechnical Engineer kept a record of; the top level of the liner, liner length, toe of liner, top of socket, toe of socket, any prebore depths, water levels in the pile, rock socket weathering profile and strengths, shaft and end bearing capacity, and any additional notes including installation dates and progress.

The piling process can only be progressed beyond this stage when the Geotechnical Engineer is satisfied the design requirements have been met and the Assessor has provided the final approval.

3.3 *Safety*

It is important to note some of the safety aspects involved with the verification process of the rock socket design, as well as the general safety aspects associated with any construction support roles. These include proximity to moving site plant, working outside with the elements such as sun and heat, driving within a working site, driving to and from site and fatigue.

In particular, the Geotechnical Engineer will need to work in close proximity to the working drill rig to be able to obtain samples for testing. They will need to watch for any flying debris from the drill bucket and watch other plant on site such as the excavator, crane movement and swinging loads. Positive communication with other personnel on site is key, especially with the drill rig operator. There should also be a good understanding of the day's activities, where overhead loads may be moving that day and a safe work area for the Geotechnical Engineer should be agreed. The other major safety hazard is open holes, which should be immediately and securely covered overnight or when not in use. Barriers and exclusion zones around the pile area should also be set up. To eliminate open holes other methods of pile installation (e.g. driven) can be considered if appropriate.

Finally, it is suggested that a fatigue management plan is in place to avoid excessive working hours, to ensure suitable breaks are given to the Geotechnical Engineer and when nightworks are encountered, that they are managed appropriately.

4 CONCLUSION

In conclusion it is important for the Geotechnical Engineer and Assessor to work closely together to verify the rock socket design. The site assessment should verify the design shaft and base capacities of the pile. A process should be in place for communication between the Geotechnical Engineer and Assessor, with particular discussions occurring when ground conditions differ from design and when the Geotechnical Engineer proposes a change in socket depth. Both should have a good understanding of the geological model and design background prior to commencing site activities.

Although not always possible, being part of the design team can be very valuable when transitioning to a construction phase support role. At the design stage it is important to have an understanding of the construction methodology of the piles as this may affect some design considerations and assumptions. For example, the transfer of load to the base of socket, if the pile is likely to be cast as dry or wet, the roughness classification for the sidewalls of the rock socket or how likely the socket is to be free from smear or mud.

In the construction phase support role, it is important to have an understanding of design and assumptions made, in order to be able to verify these during the construction process of the pile. The verification process not only includes checking that design shaft and base capacities are met, but also design assumptions are appropriate, such as the socket roughness assumption and checking of base cleanliness.

Safety should always remain at the forefront of all site personnel's minds and individuals should feel empowered to speak up when necessary if it is believed safety is compromised.

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