DEVELOPMENT OF A DESIGN, INSTALLATION AND TESTING FEEDBACK MODEL FOR MICROPILES IN PROJECTS WITHOUT EXTENSIVE GEOTECHNICAL INFORMATION

Upgrade of 132kV transmission tower foundations between Woree and Kamerunga – Cairns, Australia

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ABSTRACT

The Australia State of Queensland covers a vast area with population centres that are divided by great distances through terrain that varies from desert regions to tropical rainforest and valuable agricultural land.

Building and maintaining transmission line infrastructure can be an expensive burden on governments and utility companies particularly as a significant portion of the infrastructure approaches its intended design life. Many of the transmission towers built in the 1950's and 1960's are in need of replacement or refurbishment. A large proportion of these assets are in remote locations stretching over hundreds of miles while others were once standing in fields and farmland, but are now in the midst of built up urban areas creating challenges in terms of access.

The Woree to Kamerunga 132kV transmission tower line near Cairns in Queensland, Australia, consists of 38 lattice tower structures that are approaching their design life. The cost to replace the line is currently prohibitive due to a variety of factors. Due to the tropical location which is subject to severe cyclone events, a decision was made by the State utility company to extend the life of the current asset by 15 years via a refurbishment program that included replacement of the existing grillage foundations. A similar aged line with the same grillage foundations system took a direct hit from a Category 5 cyclone in February 2011 which resulted in failure of some foundations and it was feared that a similar event near Cairns could cause major problems for the Woree to Kamerunga line if no work was done.

In mid 2011, a series of trials were undertaken to determine if self drilling hollow bar micropiles could be used to upgrade the foundations on the Woree to Kamerunga line. The location of the towers ranges from built up urban areas, to steep hillside and boggy sugar cane fields which precluded both detailed geotechnical testing and heavy piling machinery. With no parallel transmission line serving the region, the conductors had to remain live during construction which also put limitations on machinery for foundation construction and geotechnical testing.

The aim of the testing was to create a design approach that matched drilling observations during installation of micropiles to static load test results and to use this data to provide a flexible design that could be used in the field by the supervising engineer in lieu of traditional geotechnical testing.

This paper covers the development of a design, installation and testing system for micropiles that was used successfully in the Woree to Kamerunga foundation refurbishment project under live 132kV transmission towers through difficult terrain and varied ground conditions without any traditional geotechnical testing. The project received a “High Commendation” in the 2013 Engineers Australia Queensland Division Awards for Excellence for its innovation and contribution to power infrastructure maintenance. The system has become part of the standard procedures by the State power utility company for other similar projects which has significantly reduced maintenance costs of old and damaged power transmission assets.

PROJECT OVERVIEW

The 132kV transmission line between Woree and Kamerunga was constructed in the 1960’s using a foundation system consisting of triangular steel “grillage” frames. Figure #1 is a scanned copy of an original drawing of a grillage foundation that is typical of the several types used on the Woree to Kamerunga line.

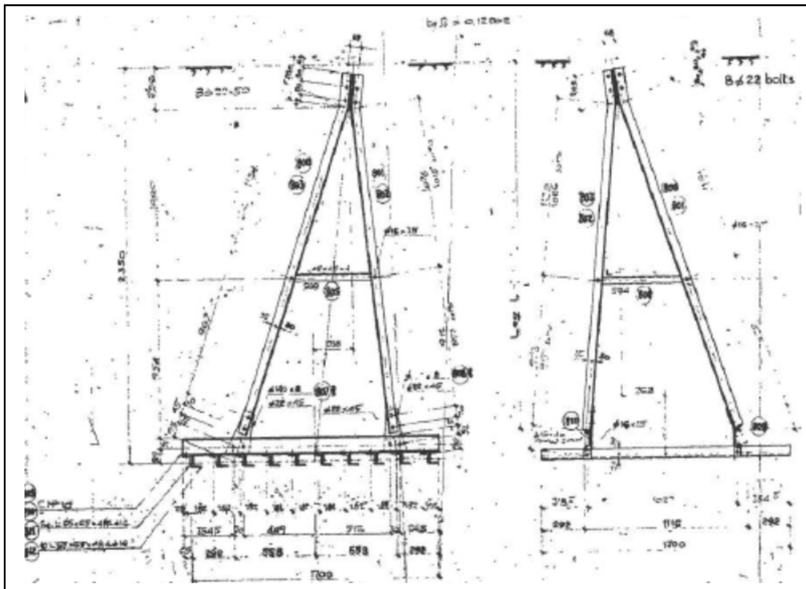

Figure #1 Original drawing of a typical grillage foundation

The grillages were manufactured from various sizes of galvanised steel angle sections bolted together to form a four sided pyramid with a slatted square base. The size of the base and the depth are varied depending on the height of the tower and the load requirement of the tower foundation.

Grillage foundations are designed for tension, compression and shear loads from the transmission towers with the critical load case being in tension from uplift forces generated by wind loads on the structure and the conductors. Ultimate design loads for the grillage structures supporting the Woree to Kamerunga line range from between 360kN to 800kN per tower leg with a shear load of 60kN.

An investigation of the transmission line by the asset owner determined that the existing foundations were nearing the end of their design life. However, due to the urbanisation of the region, a large number of the towers were situated in residential areas and the cost to replace the line was prohibitive. The decision was made

by the asset owner to find a method of extending the life of the transmission towers for 15 years to enable more detailed planning of a future replacement for the line.

Figure #2 Urbanisation has resulted in tower foundations being located in residential areas

Due to the location of the towers, the asset owner was very sensitive to the impact on the many stakeholders who would be affected by the life extension works. This sensitivity extended not only to the construction works but also to the aesthetics of the solution.

The project therefore required a solution that could;

1. Replace the existing foundations insitu
2. Utilise a construction method that produced minimal impact on stakeholders during construction. Size of machinery and minimal visits to site were key components of the desired solution.
3. Was not visually offensive
4. Utilise equipment under limited height conditions due to live overhead conductors

Due to the criticality of the structures and the consequence of damage during construction, there was a caveat put on the design that damage to the existing grillage foundation had to be minimal or preferably none existent.

Construction equipment used for the foundation system also had to be flexible and have the ability to work in a wide variety of site conditions such as;

1. Residential back yards
2. Cane fields with boggy access tracks
3. Commercial premises
4. Traffic lanes such that the road could remain open at all times
5. Environmentally sensitive rain forests
6. Mountainous areas with steep access tracks and limited access to all four tower legs.

Figure # 3 Tower adjacent to road with sloping access

Figure # 4 Tower with steep access in environmentally sensitive location

Figure # 5 Tower located in residential front yard with a makeshift greenhouse constructed around the base.

These limitations precluded the use of traditional piling methods that had been utilised by the asset owner in past projects such as bored, CFA and helical screw piles.

In addition, the sensitive nature and difficulty in accessing the various tower locations prevented any substantial geotechnical investigation being undertaken. The project brief required a design and construction approach that was flexible in application and able to be verified through installation and testing methods without relying on detailed pre-design geotechnical information.

PRE PROJECT CONSTRUCTION TRIAL

Hollow bore (HB) grout injected micropiles are a relatively new technology for the Australian market. They are used widely in Europe and the United States of America to underpin and repair foundations which are toward the end of their design life. Using rock drilling technology and specialised drill bits, HB grout injected micropiles can be installed through most naturally occurring materials.

In the case of the Woree to Kamerunga project, the HB grout injected micropiles were required to be installed through a grillage foundation that is manufactured from various sized steel sections. There are several types of grillage that were used at the time the transmission towers were built and no records exist regarding which grillage type was used under the towers.

Adding to the complexity is that grillage foundations could be installed with the gridded base being as drawn in Figure # 1 or at 90 degrees to the drawing. Hence, it is extremely difficult to find a predetermined gap in the grillage base through which a micropile could be installed.

An installation trial on several grillage bases was conducted prior to project commencement. The aim of the trial was to determine if there was a “sweet spot” through the grillage that would minimise contact with grillage members. In conjunction with the asset owner’s engineers, a 3D CAD model was created of a grillage foundation from historical drawings. By referring to the machinery specifications, several potential pile locations were proposed to minimise the potential for refusal on the steel grillage base and to enable enough room for the piling rig to operate. Below are examples of the 3D modelling that was carried out prior to the installation trials.

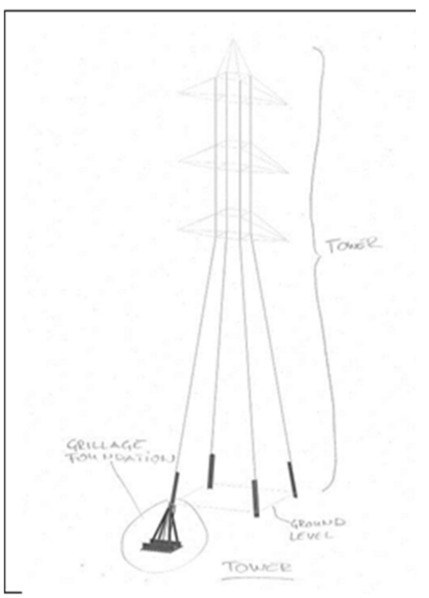

Figure #6 Typical Grillage foundation model

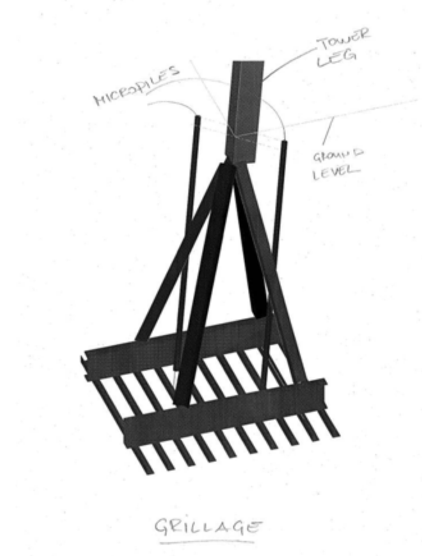

Figure # 7 Example of 3D grillage and pile model

Although the 3D modelling was carried out, there was potential for piles refusing on the grillage bases during installation. As a result, a specialist tool was designed and manufactured which could be used on the hollow drill steel as a temporary replacement for the sacrificial drill bit which could drill through the grillage base if required. The asset owner’s preference was to keep the grillage base intact during installation, however, the tool was trialled to determine the degree of damage to assess the use of the tool during production piling.

Figure # 8 Exhumed grillage after use of specialist tooling

A detailed method statement was created for use of the specialised tooling and submitted to the asset owner for review. Conditional acceptance was provided for use of the tool in circumstances where no other method was successful in penetrating the grillage and vibration of the tower during use was closely monitored.

Acceptance of the method for dealing with potential pile refusal cleared the way for the selection of a single pile layout for all tower types which decreased design costs and simplified construction.

Trials were also carried out using a standard 115mm steel drill bit with excellent results. Of the eight tower legs which were selected for the trial, none of the test piles refused on the grillage base and a design using grout injected micropiles within 150mm of the tower leg was adopted.

Figure # 9 Micropiles successfully installed within 150mm of the tower leg

By installing the micropiles close to the tower leg, the concrete pile cap design was minimised which reduced both the construction costs and the impact on the residents and stakeholders involved in each tower site.

In addition to the construction trials involving grillage foundations, four nearby sites were identified containing saturated alluvial soils for a series of ultimate geotechnical strength tests. The sites were specifically chosen with a range of saturated loose sands and plastic clays that would be expected on some of the poorer sites on the Woree to Kamerunga project.

Four test micropiles piles were installed at each site using Ischebeck 52/26 hollow bore micropiles. After allowing 14 days for the micropiles to cure, a specially designed load test frame was suspended on a series of reaction piles to allow the micropiles to be tested to their ultimate capacity.

The test method chosen by the asset owner was a single cycle test in tension with a series of load increments where the load on the micropile was held until there was no noticeable creep. Measurements of pile head displacement were taken using two LVDT instruments connected to a data logger taking 10 measurements per second.

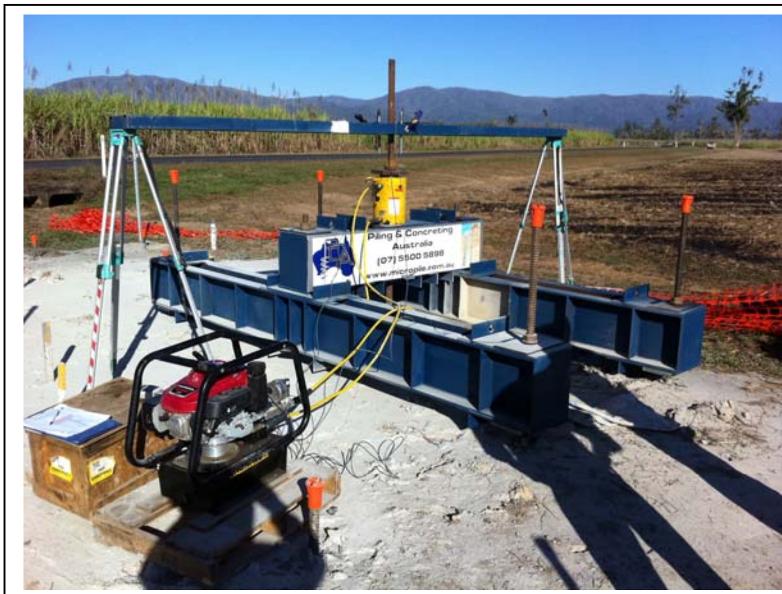

Figure # 10 Load test frame mounted on reaction piles

Each of the test piles were installed to different depths (9m, 12m, 15m and 18m) and loaded to failure or to the yield strength of the 52/26 hollow bar (720kN). Prior to testing, each site had been subjected to a cone penetrometer test (CPT) test to determine the strength properties of the soil for the full depth of the piles. Using proprietary values for skin friction from information provided by Ischebeck for their hollow bar system as they relate to the CPT test results, a calculation was made of the ultimate strength of each pile and compared against the test result. For the piles that failed during the test, a calculation was made of the ultimate skin friction of the pile.

The piles were tested in a single cycle to either steel yield or geotechnical failure in accordance with the test program specified by the client. Examples of the load test results for two 9m long piles in different soil conditions are contained in Figures 11 and 12 below.

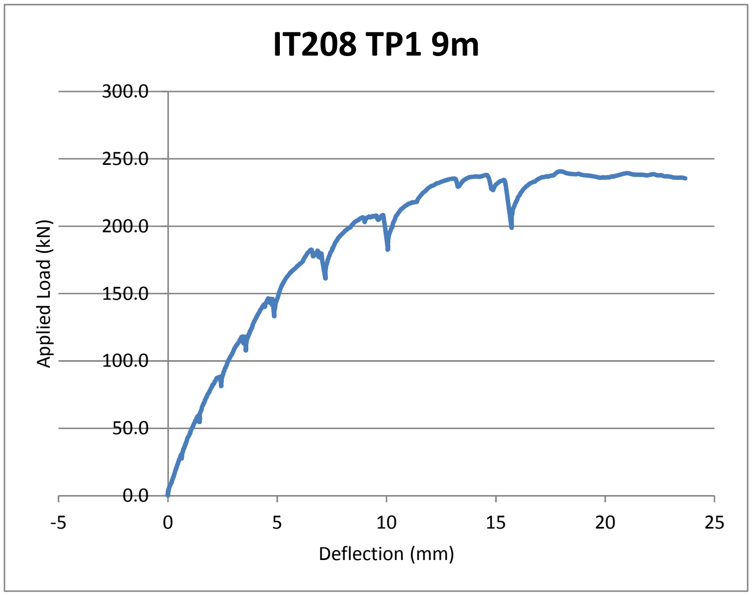

Figure # 11 9m pile demonstrating geotechnical failure

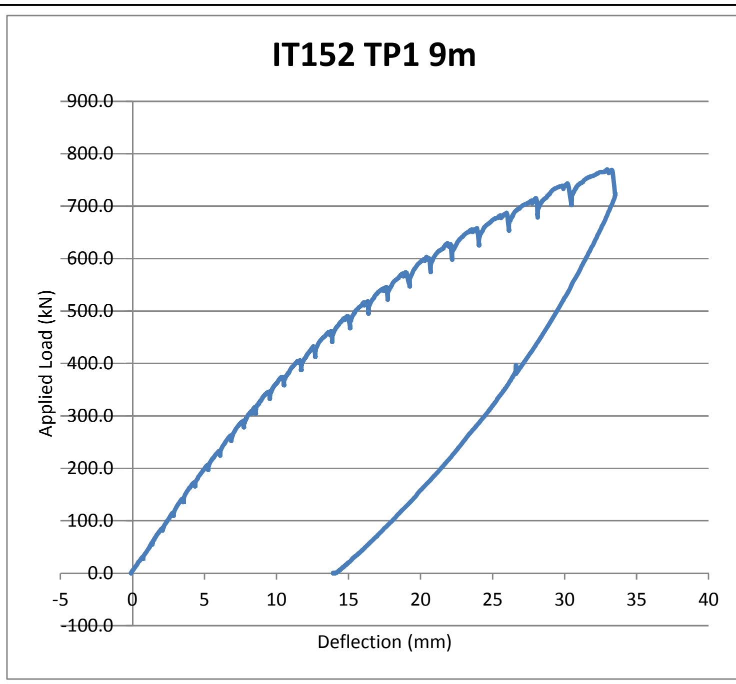

Figure # 12 9m pile loaded to yield strength of the steel

An analysis of the results determined that the calculated average skin friction values of the piles fitted well within the range of values provided by Ischebeck for the various soil types. However, where the Ischebeck values generally ignore the contribution of loose sands, soft clays or silts, it was found that these soils had a contribution although the pile head creep during the hold cycles was noticeably larger than for piles that were in a better class of material.

During installation of the test micropiles, information was recorded for each lineal metre drilled in relation to the drilling advance rate and the degree that the top hammer was used (if at all). The drilling logs were then compared against the CPT plot for each site with clear correlations being observed between the drilling log and the various soil layers in the CPT report.

DESIGN FEEDBACK MODEL

The generally accepted limit state approach for the design of piled and deep foundations is to assess and compare the design geotechnical strength (Rd,g) of the soil with the design action effect (Ed) from the structure. In a typical project, this would involve a review of geotechnical data to assess the ultimate geotechnical capacity (Rd,ug) which is then factored down by the appropriate geotechnical reduction factor (ϕg) in accordance with section 4.3.2 of ***AS2159-2009 Piling Design and Installation***. This is represented by the formulae below;

$$\mathrm{Rd,g} \geq \mathrm{Ed}$$

And

$$\mathrm{Rd,g} = \phi\mathrm{g}\ \mathrm{Rd,ug}$$

Due to the sensitivity and difficulty in gaining access to tower locations along the Woree to Kamerunga transmission line, no geotechnical information was available and hence no assessment of Rd,ug was possible at any of the tower locations.

To solve this problem, a design and construction procedure was devised using the knowledge gained during the load testing program whereby factored down empirical data from the static load tests were linked to observations made of the drilling process during installation. This method requires an experienced driller and a supervising engineer who is intimately familiar with the installation procedure for hollow bore bar micropiles and the equipment being used for the installation process. There are inherent problems in identifying the subtle differences when the pile is being drilled through a hard clay or a weathered rock or cemented sand.

To overcome this problem, prior to production piling, a sacrificial test pile was installed at each tower location with drilling information such as the use of the drill's top hammer, rotary function and advance rate being recorded for each lineal metre of pile installed. Since the micropiles are friction piles which develop their geotechnical capacity along the pile shaft, a factored down value for load capacity per lineal metre was assigned from the previous empirical test data for various drilling conditions. The test pile installation was then terminated once the pile reached a depth corresponding to the required load capacity per lineal metre that was assumed in the design.

The test pile was then allowed to cure for a minimum of three days before being proof load tested to the ultimate structural strength (Rus) required by the pile.

This design approach is best represented below:

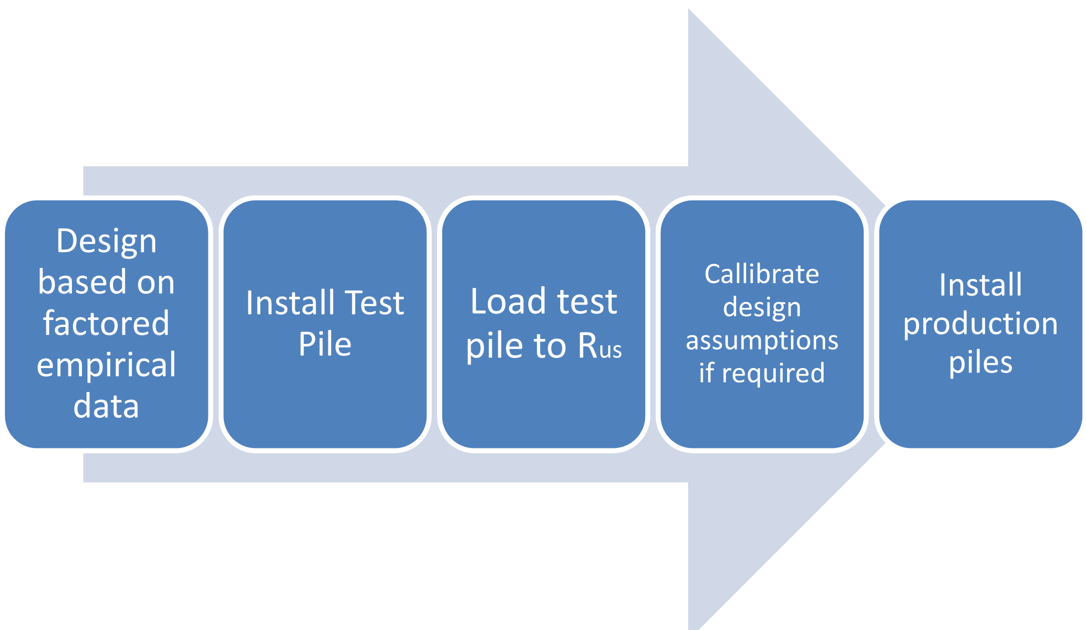

Figure # 13 Design process with feedback from testing used to calibrate the model prior to installation of production piles at each tower.

The design procedure in Figure # 13 allowed for feedback from the installation process being looped back into the design enabling the assumptions for load capacity based on installation observations to be confirmed and calibrated at each tower location. From this process, each pile at each tower could be installed to a custom design length based on the amount of load each pile was required to carry.

CONCLUSION

This innovative approach to design and construction enabled the project to go ahead without the expense or time delay of detailed geotechnical investigations of each of the 38 tower locations. Just as importantly for the asset owner, the design approach minimised the impact on residents and stakeholders along the transmission line which is one of the asset owner's core objectives during maintenance on their transmission line network.

The use of observations of the drilling conditions during installation requires an experienced driller and a supervising engineer who is familiar with the drill and the drilling crew. Different drills and different drill bits will produce different outcomes. However, the installation of a test pile prior to production piles being installed mitigates the risks and allows the drilling observations to be a guide while the test results verify the assumptions and observations.

In addition, the design engineer must have access to a wide library of load test results where the drill was monitored during installation. Without the test data, it would not be possible to make an estimation of the load capacity of the micropile based on the drilling conditions.

The method used in the Woree to Kamerunga project also had a degree of conservatism with lower bound values for skin friction used based on results from the pre-project tests being drawn from mostly cohesive soil conditions. Feedback from the drill was assumed to be from drilling through cohesive soils such as firm, stiff or hard clays rather than cemented sands or gravels which would have a higher skin friction value even though both materials can provide the same type of drilling feedback. That said, the end result was a few metres of additional pile length than what was probably required in some instances. These additional few metres of piles on each tower were a cost effective and far less intrusive alternative to conducting an extensive geotechnical investigation prior to design.

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