GEOTECHNICAL ASSESSMENT OF FOUNDING CONDITIONS FOR LARGE WIND TURBINES TARARUA RANGES, NEW ZEALAND

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ABSTRACT

The Tararua Windfarm is one of the world's top three wind farm sites. Its owner has committed to a stage 3 extension involving construction of 35 large wind turbines standing 65m, producing 3MW each.

The Tararua Ranges are located immediately adjacent to an active fault zone and have recently been up-thrusted. The ranges consist of shattered greywacke sandstone with a complex capping of Tertiary and Quaternary marine deposits, along with re-worked loess.

Proposed sites for the turbines are generally challenging as 'easier' sites are already occupied by in excess of 100 smaller turbines.

Though theoretically relatively low strength material is required to support the turbine weight resting on 15m diameter octagonal pads, cyclical rocking under wind and possibly seismic load, requires strong material of high stiffness. Thus, greywacke rock is the preferred founding material.

In January 2006 construction of the stage 3 extension commenced. Large earthworks are required to form foundations and adjacent crane platforms. Excavations to date have generally been consistent with conditions inferred from the geotechnical investigation, however, some sites have revealed geology more complex than envisaged, such as localised low strength gully fills on ridge crests. Thus, foundation designs have been adapted to the subsurface conditions encountered.

1. INTRODUCTION

To meet the growing electricity demand New Zealand generation companies have been identifying potential new sources of power. Whilst hydro and fossil fuels provide the majority of New Zealand's electricity needs wind is becoming increasingly important. With the Resource Management Act of 1991 in New Zealand law and the international Kyoto Protocols, establishing new hydro or fossil fuel generation schemes is increasingly difficult.

TrustPower Ltd, a private New Zealand owned generation company, has committed to a stage 3 expansion of an existing wind farm on the Tararua Ranges, east of Palmerston North city. A general view and location is shown in Figures 1 and 2.

Figure 1: View of pre-existing Tararua Windfarm looking northeast.

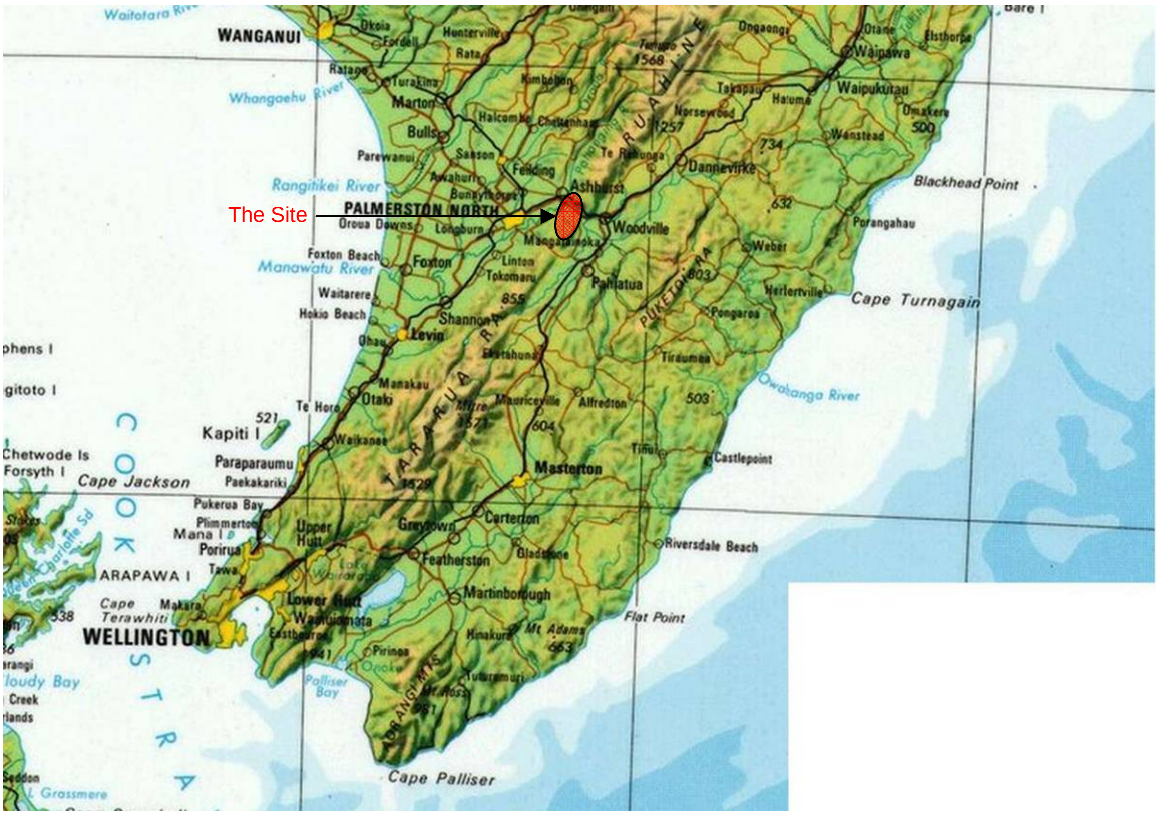

Figure 2: Location plan.

The existing wind farm comprising the original two stages of construction has approximately 105 turbines each producing a maximum of 0.6MW. Stage 3 expansion includes a further 35 wind turbines producing 3MW each. These new machines are significantly larger than the older standing 65m high, supported on an octagonal foundation 15m in diameter. Each foundation pad is approximately 2m thick.

2. SITE DESCRIPTION

The existing wind farm spans a generally broad ridge which steeply rises above the flat Manawatu plains to the west and the alluvium filled Woodville valley to the east. The plains either side of the Tararua Ranges are approximately 100m above sea level whilst the Ranges are in the general order of 400 – 600m above sea level. The wind farm is located on a relative low point on the Ranges (a saddle) immediately south of the Manawatu Gorge, where the Manawatu River flows east to west through the Ranges. Upon this low point, approximately 9km in lateral length, two wind farms have been located either side of the Gorge.

The subject site extends 5.3km along the Tararua Ranges and was selected because of high annual mean wind speed of around 10m/s at hub height. The Tararua Windfarm is recognized as one of the best generation sites in the world.

The earlier smaller turbines typically occupy flat to gently terrain at the crest of the Ranges. Subsequently the sites for the newer and larger turbines are often on smaller, local ridge spurs flanked by steep slopes. The elevation of the new turbine bases is typically 340 – 580m above sea level. The site encompasses many different landowners all of whom use it to raise livestock.

3. GEOLOGY

The predominant material forming the Tararua Ranges is Mesozoic age greywacke sandstone and argillite. Overlying this is localised Tertiary sedimentary deposits and later Pleistocene/Holocene alluvial material forming terraces and filling gullies in older deposits. A general geological plan is shown in Figure 3.

The Tararua Ranges are bordered to the immediate east by the Wellington Fault which divides into the Ruahine and Mohaka Faults to the north. These faults are considered geologically active and have in recent times uplifted and tilted the Tararua Ranges. During the initial period of uplift it would appear the Manawatu River meandered across the saddle area of the Ranges (where the existing wind farm is sited) until settling and eroding a gorge in its present position.

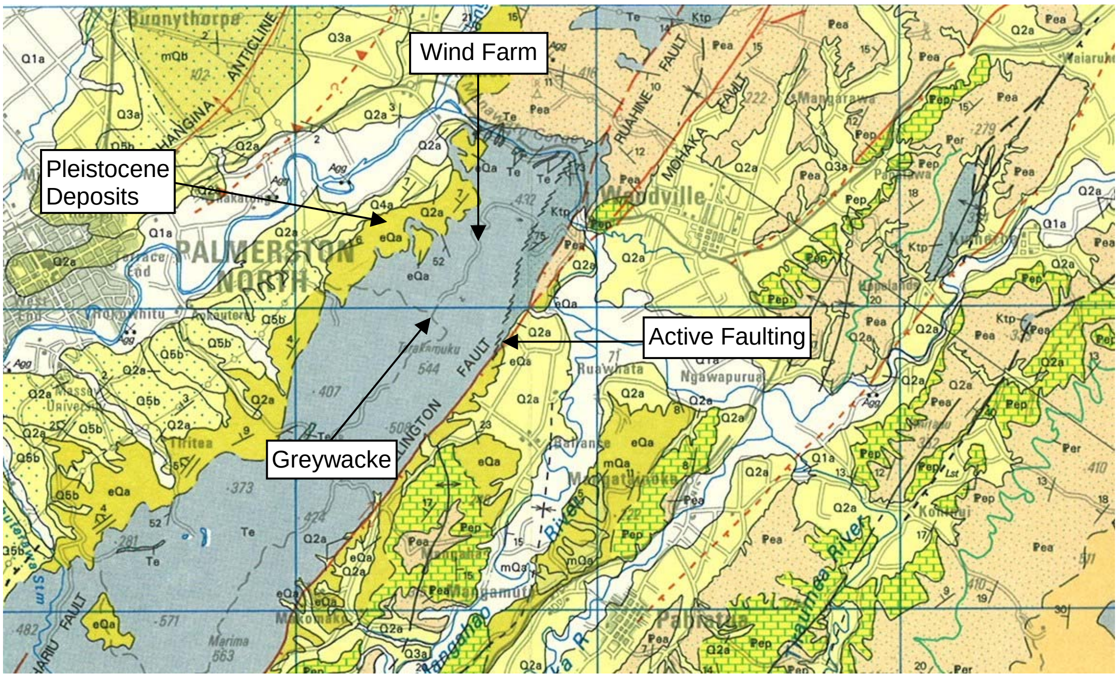

Figure 3: General geology of the TrustPower Ltd Tararua Windfarm and surrounding area. Geology encountered on site was considerably more complex than shown on large scale published plans.

3.1 FAULTING

Though no active faults are publicly mapped directly crossing the wind farm site, many lineaments (lineations in the ground surface) of varying length (hundreds to thousands of metres) have been observed from site walkovers and study of aerial photos to cross the site.

3.2 GREYWACKE

The Mesozoic age sandstone and argillite beds are generally referred to as 'greywacke,' which more correctly refers to the sandstones. These deposits have generally undergone low grade metamorphism and have been subject to multiple phases of mountain building. Bedding is often difficult to determine and when distinguishable is typically subvertical or steeply dipping. Localised bodies of chert are also found within the greywacke. Argillite is also occasionally present generally exhibiting lower strengths than greywacke.

The greywacke is typically moderately to very closely fractured and has tested unconfined compressive strengths near surface of 3MPa to 24MPa. It is common for the greywacke to be crossed by steeply dipping clay filled defects extending 10m+ in horizontal extent.

3.3 TERTIARY DEPOSITS

Tertiary age sedimentary deposits south of the Manawatu Gorge are relatively uncommon although common north of the Gorge. They occur sporadically both on ridge crests and stream bases, typically comprising fine grained, very weak, calcareous and non-calcareous mudstones. Some deposits exhibit rock strength when dry, but when saturated and vibrated by machinery become soil like.

3.4 PLEISTOCENE DEPOSITS

These younger materials consist of complex layering of silts, sands and gravels exhibiting varying densities from loose to very dense. These deposits cover approximately half of the existing wind farm site becoming thicker to the north (exceeding 20m depth adjacent to the Manawatu Gorge). Though probably laid down relatively flat these deposits on the western side of the Ranges have now been tilted westward by 4º to 9º due to uplift.

3.5 HOLOCENE DEPOSITS

These recent deposits comprise clays, silts and occasional fine sands typically constrained to filling of old gullies or at the base of modern streams. Surficial loess (wind blown) deposits were also encountered sporadically mantling the surface across the wind farm, varying from 0.5 – 3.0m thick.

4. INVESTIGATIONS

Riley Consultants Ltd was engaged by TrustPower Ltd to investigate geotechnical conditions for 40 proposed turbine sites. With tight construction timeframes the majority of investigation and reporting was undertaken in January and February 2005 with additional work performed on selected sites in March and April 2005. Geotechnical investigations at each site typically comprised a site walkover by an engineering geologist, followed by subsurface investigation consisting of at least 3 – 4 test pits and either machine boreholes or hand auger boreholes. At many sites depth to rock strength material was highly variable and additional relatively inexpensive percussion boreholes were sunk.

5. STABILITY

With much of the gentle terrain occupied by the older existing turbines, the proposed turbines were often sited on relatively narrow, steep sided ridges. In many situations the proposed foundations were of a similar size to the width of the ridge crest. Earthworks associated with the creation of construction platforms and roading meant the ridgelines were typically cut down by up to 6.0m creating broader ridge crests. However, steep slopes were still in close proximity to some proposed foundations. Mapping and subsurface investigation of these slopes was undertaken often followed by computer based stability analyses to assess the current and post earthworks stability of the slope, along with any setbacks or protection measures.

For practical design purposes a setback of 15m was adopted between the edge of a proposed turbine foundation and steeper slopes (typically >13º). The 15m setback is based on a local geology review, inspection of past slope failures, computer based analyses and experience with similar materials and slopes at other locations. This setback would typically allow a Factor of Safety against instability of exceeding 1.5 for the foundation.

In some situations, minimum setbacks from steeper slopes, or those considered a stability risk, could not be achieved. Either palisade (inground) retaining walls, rock anchors or a combination of both were recommended. Of 40 sites investigated eight were recommended for either palisade walls and/or ground anchors following geotechnical investigations.

6. FOUNDATIONS

The relatively large size of the proposed turbine foundation means the turbine weight can generally be supported on stiff soils, with an undrained shear strength of approximately 80kPa. However, cyclical rocking under wind and possibly seismic load, requires strong material of high stiffness with an equivalent Youngs Modulus of 200MPa. Thus, rock strength material is the preferred foundation support. For some sites greywacke rock was present 0.5m to 2.0m below the proposed foundation base. In these situations it was proposed to undercut to rock and replace excavated material with ‘as-dug’ greywacke gravel compacted into place. This was later changed to AP65 crushed alluvial gravel.

Substantial depths of Pleistocene granular alluvium underlay some of the western sites with greywacke at substantial depth (10m+). In these situations it was anticipated the turbine foundations would bear on dense gravels and sands, encountered during the geotechnical investigation.

7. CONSTRUCTION

In January 2006 construction of TrustPower’s stage 3 Tararua Windfarm expansion commenced. Three earthworks contractors constructed roads and platforms at the turbine sites, then 19m diameter by 2m deep foundation excavations.

The holes are inspected by representatives of Riley Consultants Ltd to check bearing capacity, depths of undercut if required, significant defects and any potential stability risks to the proposed foundation.

Testing of the rock at the excavation base is an important component to ensure stiffness requirements are met. Methods for testing have included Clegg hammer, Schmidt hammer and Scala penetrometer. The most convenient and efficient testing method has proved to be systematic use of the Clegg hammer. Clegg Impact Values can be related to Young’s Modulus in a fairly direct manner. Where CIVs identify weaker areas Scalas are often performed to estimate depth to more competent material. The Clegg was found to be convenient, easy to operate and sufficiently sensitive to small variations in rock strength. Care must be taken though as surficial fracturing and water affect recorded CIVs.

With some sites, particularly on alluvial materials, materials of insufficient strength were encountered at the time of platform formation. In this situation additional percussion and Standard Penetration Testing (STP) were performed by drilling contractors along with test pits.

The majority of foundation excavations have exposed closely jointed greywacke rock with minor argillite, chert and breccia. In some excavations defect mapping can identify ‘sets’ to the jointing, however, other excavations reveal random orientations or very local sets. Jointing is predominantly steeply dipping (50º+) to subvertical. Within nearly all excavations in greywacke can be observed clay lined joints or faults, often of 1 – 5mm aperture. These are typically ‘wavey’ in their orientation, and are inclined at angles less than the jointing but usually steeper than adjacent slopes (25º+).

At many of the sites, particularly where adjacent to steep slopes, detailed defect mapping followed by stereonet construction was undertaken. This allowed an assessment of potential defect controlled slope failures. In rare occasions potential defect related failures were identified and either the foundation position adjusted or protection measures such as palisade wall or rock anchoring recommended.

There was awareness of potentially active faults either crossing or in close proximity to the turbine foundation given the proximity of the adjacent Wellington fault zone. To date, with the exception of one site (site 9 discussed below), no excavations have revealed any obvious faults that may be active.

Groundwater entering the foundation excavations has generally not been a problem, particularly as the majority of excavation was in late summer and autumn. Through winter more groundwater has been encountered but this has not significantly affected construction.

8. EXAMPLES OF FOUNDATION EXCAVATIONS

Presented below are examples of foundation excavations ranging from typical (sites) to the extraordinary (Sites 9 & 34).

8.1 SITE 5

The foundation excavation exposed highly to moderately weathered, closely jointed, greywacke with no major argillite exposed. There were virtually no steep slopes in close proximity to the foundation, with the exception of a slope to the northwest of about 20º leading down to a stream (shown in Figure 4 below).

Figure 4: Site 5 foundation excavation and adjacent stream.

Mapping of major defects in the excavation and detailed measurement of joints at the northwestern corner were performed. Analysis indicated two potential wedge type failures that could daylight to the northwest. Dip of the wedges (<19º) and the nature of the defects which formed this wedge (rough, zeolite filled) indicated failure was unlikely.

Rotational and translational type failure of the northwestern slopes was also considered. Computer based stability analyses were performed indicating a Factor of Safety against instability of >1.4 under extreme conditions (generally >1.3 was acceptable under extreme conditions). Erosion of the slope toe by the stream was also considered. With a sufficient setback between the steeper slope and foundation edge it was considered enough warning time would be available to implement protection measures should erosion advance up the slope.

8.2 SITE 9

The concrete foundation at this site was eventually poured at the second foundation hole excavated. Within the first 19m wide hole was exposed weak argillite and breccia forming approximately 50% of the excavation in a northwest-southeast orientation, displaying evidence of significant crushing. This zone was parallel with lineaments in the general area. The site is approximately 500m from the Wellington Fault.

The argillite was of low strength and although this zone could not be proved to be associated with active faulting, it was considered the risks were too high and an alternative position for the turbine should be identified. Resource consent conditions limited any alternative site near the first excavation. Shallow investigative trenching immediately north of the existing hole identified suitable rock with no obvious crush zone(s).

Excavation of the second hole revealed a clay pug filled lineament crossing the southern part of the foundation hole and continue through the platform in an east-west orientation (Figure 5). This feature appeared to be an off-shoot of the crush zone, or alternatively obscured in the crush zone exposed in the first hole.

Figure 5: Clay filled lineament through second foundation excavation at site 9.

Approximately 100m to the north of the site was known to be Pleistocene alluvial deposits overlying greywacke. A trench of approximately 60m in length was dug in an attempt to intercept the inferred fault and identify whether it offset the overlying alluvial deposits. The inferred fault was not encountered and careful measurement and plotting of the fault indicated it curved away to the south, avoiding the practical limits of trenching.

Detailed aerial and on-ground study of lineaments was performed. This work suggested the inferred fault was inactive as it would appear this lineament had been offset by later faulting that is now considered inactive. The presence of faults and relative periods of activity were primarily established through valley locations and offsetting of streams.

The foundation was subsequently constructed at this location. Slopes to the immediate north of the foundation were noted as being affected by past instability and considered at risk of further movement. A palisade wall was recommended along the northern edge of the foundation.

8.3 SITE 34

Though excavated on a ridge crest this foundation encountered inferred Holocene/Pleistocene gully alluvium and minor Tertiary sedimentary weak rock. It was evident from the excavations that an incised gully cut through the greywacke at this location. The softer alluvial deposits were undercut until very weak greywacke rock was encountered. This resulted in a relatively large undercut of up to 4m+ in the northwestern corner. The undercut was backfilled in 200mm compacted layers of AP65 crushed alluvial gravel. Figures 6 and 7 show the excavation and backfilling.

Figure 6: Site 34 excavation and undercut concrete pad. Founding level is approximately at the PVC pipe level.

Figure 7: Backfilling of undercut at Site 34.

9. CONCLUSION

Though the Tararua Windfarm development is located on a principally greywacke ridge the surficial geology is often challenging for the founding of large turbines, further complicated by the nearby presence of active faulting.

Relatively simple, but systematic, exploration and verification testing in combination with careful observation has proved successful in geotechnically developing the wind farm.