Steel screw settlement reduction piles for a raft foundation on soft soil

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ABSTRACT

The new Gisborne Police Station building was built on a soft site occupied by a historical retail building. The façade of the historical building had to be retained, and the building demolished. Based on complex geotechnical investigations and consideration of various foundation options, Opus recommended that a piled raft foundation be adopted. For the first time steel screw piles were used as settlement reduction piles in soft soil. Due to the soft nature of soils, the piles were not capable of supporting the total building load, but took only a proportion of it, with the rest of the load being supported by the reinforced concrete raft. A full scale pile load test was undertaken on 12 m, 18 m and 24 m long screw piles. Finite element (FE) analysis was undertaken to assess the performance of a single screw pile and of the raft-pile-soil system. The FE analysis also allowed to assess settlement and the proportion of load taken by the piles and by the raft. Post construction settlement monitoring indicated that the actual settlement of the building was close to the predicted settlement. The innovative foundation design eliminated most of the construction risks, speeded up the construction and resulted in substantial ($1M) cost saving compared to other foundation options. The new police station building has been constructed and performed adequately under static load; it also survived the December 2007 Gisborne earthquake, which measured 6.8 on the Richter Scale, without any damage.

1 INTRODUCTION

A new Gisborne Police Station building had to be built at the site occupied by a historical retail building. The proposed building has two suspended concrete floors and concrete shear walls. The 40 m x 40 m footprint of the proposed Police Station building is larger than the footprint of the existing retail building. Under AS/NZS 1170 Australian / New Zealand Code for Structural Design Actions, Police Stations are classified as Importance Level 4 structures, the category of most important structures with special post-disaster functions. Importance Level 4 structures need to be designed for significantly greater loadings resulting from events such as earthquakes, wind, etc. The historical building, founded on small pad foundations demonstrated signs of damage due to large total and differential settlement and had to be demolished, but the Gisborne District Council required the old façade of the building to be retained.

2 SITE CONDITIONS

The site is located in the centre of Gisborne and was occupied by a historical retail building that had to be demolished, with its facade retained and supported by the new building structure. Therefore during investigations boreholes and cone penetration tests (CPT) were undertaken only around the perimeter of the retail building. Geotechnical investigations indicated that the site is formed by alluvial materials and the subsurface soil profile comprises:

- 3 m of very loose to medium dense sand and silty sand, overlying
- more than 25 m thickness of soft, insensitive to moderately sensitive silt. This layer extended to a depth below the end of our borehole and CPT tests.

The silt underlying the sands has an undrained shear strength ranging from 11 kPa at shallow depth to 35 kPa in deeper layers. At the time of our site investigation, groundwater was encountered at a depth of between 2.2 m and 2.5 m below existing ground level. The site soils have a potential for large deformation and settlement. Differential settlement would be likely due to soft soil, and would further increase if the loads from the proposed building varied across the site, or part of the proposed building was built on the preloaded area of the site (i.e. the area preloaded by the historical retail building), with the other part founded on virgin ground.

3 FOUNDATION OPTIONS

The following foundation options were considered:

A) Shallow pad or raft foundation
Pad foundations were assessed to have unacceptably large settlements due to the soft nature of soils. A raft foundation was also assessed to have large settlement due to consolidation of the soft silt layer. As shallow foundations would sit on top of the sands, they would be susceptible to settlement due to densification of the sands under seismic shaking. Construction of shallow foundations is a simple and low cost process, without any risk mitigation measures for the existing façade and the adjoining buildings as the required excavation would be less than 0.3 m below the present ground level. However, due to large settlement associated with densification of sand and soft nature of the silt, this option was not feasible. There was also the risk of damage to adjoining buildings due to ground settlement beyond the footprint of the police station building.

B) Shallow concrete foundations on improved ground
A number of ground improvement options were considered. These included:

- stone columns installed by driving steel pipes with a sacrificial cone at the bottom,
- vibroflotation,
- dynamic compaction,
- deep soil mixing (cement or lime stabilisation),
- replacement of soft and liquefiable materials with better quality material, preloading of the site.

All of these ground improvement options are costly and some of them have the risk of causing settlement of the adjacent buildings/pavements due to vibration or static settlement effect.

C) Conventional pile foundation
Conventional pile foundation options were considered but discounted as piles founded in soft materials would not have sufficient bearing capacity to support the total load. Also there was no competent soil layer within 30 m depth to pile into.

D) Compensated cellular raft
The overall depth of the cellular raft would be about 2.6 m to 3m. The raft would provide a very stiff foundation which would distribute the building load uniformly and because of its hollow nature would reduce the load on the underlying soil to no more than the existing soil provided prior to construction (i.e. a compensated foundation). The cellular raft would be the most expensive option due to the need for construction dewatering, large excavation and concrete volumes and the temporary retention of the excavations being required. It is also the most risky option, as a deep excavation would be required right alongside the existing façade (which had to be retained), and could cause damage to the façade and to the adjoining building.

E) Reinforced concrete slab on the ground with conventional piles for settlement reduction
To reduce the raft foundation settlement, timber or concrete piles could be driven or bored into the soft silt beneath the raft. The piles would be designed as settlement piles (i.e. the piles would be loaded to substantially higher levels than conventional piles), and substantial part of the load would still be taken by the concrete raft. The settlement piles would share the building load with the raft and would distribute some load to the deeper soil layers mostly by friction, thus

reducing the expected settlement of the building. However, the settlement reduction would not be sufficient, as, with conventional driven or bored piles in soft materials, only a small proportion of load can be transferred to deeper layers. Also, durability of the timber piles was considered to be inadequate and reinforced concrete piles were too costly.

F) Reinforced concrete slab with screw piles for settlement reduction (preferred option)
This option is similar to Option E but would utilise steel screw piles on a regular grid screwed into the silts to a depth of 12m to 24 m depth. The tip of the pile has a large helix (900 mm diameter) and therefore can transfer a higher proportion of load to deeper layers compared to the conventional pile option. Settlements can be reduced compared with the previous options as most of the load will be transferred to a larger depth where the strength of silt is slightly higher compared to that of the near-surface silt layer. The construction risks for this option are low, as no excavation works would be required and no vibration would be generated. This option would have moderate cost and lowest settlement. Therefore, this option was adopted. However, the use of screw piles in soft materials or as settlement reduction piles is not common. The load-settlement behaviour of the screw piles loaded above commonly accepted load levels in soft material was uncertain. Therefore a full scale pile load test was recommended and undertaken.

4 BASEMENT OF THE EXISTING RETAIL BUILDING

A problem with all of the foundation options was the existing retail building basement which covered about 25% of the building area and was about 2.5m deep. As the basement was empty, the load on the soil there was lower than on the rest of the site. If the basement is backfilled before placing the new ground slab, additional stresses would be placed on the soil leading to more settlement. In the existing basement area light-weight polystyrene blocks and foamed concrete were used to reduce the backfill load and provide load transfer between the raft and the soil, and the reinforced concrete raft was built over the polystyrene.

5 SCREW PILES

A full scale load test was undertaken for 12 m, 18 m and 24 m long piles (Figure 1).

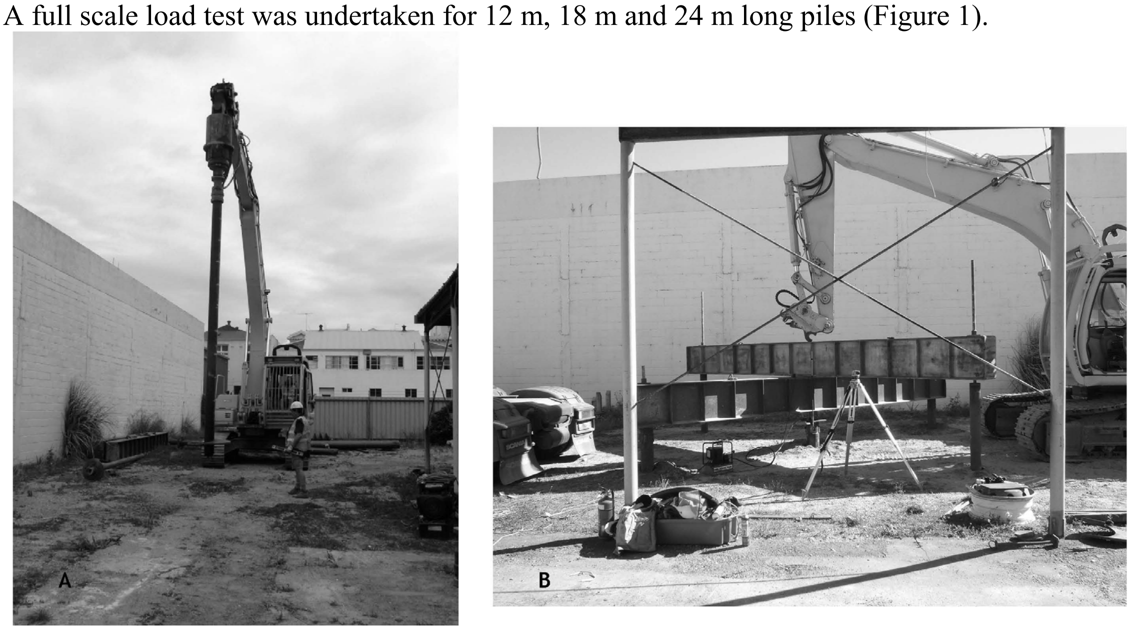

Figure 1: Full scale pile load test: A-Installation of a test screw pile, B-Pile testing

The standard testing procedure recommended by Australian piling code AS 2159 was not appropriate for our test, as the pile had to be loaded to loads higher than recommended in AS 2159, when yield zones around the helix become large, and it therefore takes a long time for creep to die out and for settlement to stabilise. Therefore the AS 2159 creep criteria was