# Founding improvement using geosynthetics at the Cape Town harbour

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## BACKGROUND

In 2013, Transnet National Ports Authority (TNPA) commenced with upgrading of the existing fire-fighting system of the oil tanker terminals in the Port of Cape Town (Figure 1). This included the construction of a new pump station, which would house booster pumps on the ground floor and a 250 kilolitre water reservoir directly above the pump station on the first floor. The design bearing pressure exerted on the ground by this new structure would be 150 kPa.

The pump station site is located inside the Port of Cape Town. The fill material (the placing of which started in 1965) comprised hydraulically backfilled material derived from dredging activities, and highly variable end-tipped imported material.

The objective therefore was to design a stable and effective foundation capable of handling loads from a dynamic structure (the pump station) on a highly variable, weak soil deposit.

## GEOTECHNICAL CONSIDERATIONS

A geotechnical site investigation was conducted using a small-diameter rotary core barrel with standard penetration tests (SPT). The exploratory borehole was drilled to a depth of 23.5 m below the existing ground level. The schematic diagram in Figure 2 shows the subsoil conditions that were encountered during the investigation. These subsoil conditions can be summarised as follows:

- Variable fill materials in terms of composition, low consistency and thickness creating compressible soil conditions (problem soil)
- Presence of large obstacles, such as tetrahedron dollies and very hard boulders up to 1.5 m in diameter, as well as a rockfill layer at depth (quay construction), which could hamper piling installation
- Soft, variable marine deposits in the order of 6.0 m thick
- Weathered meta-sedimentary strata associated with Malmesbury rock,

Figure 1: Site location of the new pump station (Source: Google Earth)

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with occasional discontinuities filled with sand
- Significant depth to competent rock.

## GEOTECHNICAL OPTIONS

Based on the subsoil conditions the following three types of foundation improvements were considered:

1. **Deep compaction or re-compaction of the fill soils:** This option was ruled out due to lateral working restraints and the potential of damaging existing infrastructure in close proximity to the site.
2. **Piled foundation:** This option would only have been viable using percussive or oscillator piling techniques to penetrate through the large obstacles and the boulder layer (rockfill). The pile seating depths were estimated at 23.5 m below the ground level into the lower competent Malmesbury rock.
3. **Geosynthetic reinforced soil raft foundation:** This option would involve the installation of geosynthetic layers between suitably engineered fill materials to improve the bearing capacity of the subsoils.

After consideration of the geotechnical conditions, construction challenges and potential solutions, the geosynthetic reinforced soil raft foundation was found to be the most viable solution for the site conditions.

## GEOSYNTHETIC REINFORCED SOLUTION

The design technique is based on the distribution of vertical pressures through a geogrid reinforced layer (stiffened soil raft). The design method requires that the pressure at the top of subgrade is less than the allowable bearing pressure of the subgrade soil to provide an adequate factor of safety. This static method assumes that the vertical pressures are distributed through the platform soil layer, as outlined by the Boussinesq theory (Das 1990).

The design pressure of 150 kPa and the California Bearing Ratio (CBR) of 2% (in-situ bearing capacity of 15 kPa) were used for the design calculations. In unreinforced conditions the foundation thickness required was in the order of 2 m. However, through the use of geosynthetic reinforcements the thickness was reduced to 1.2 m, as shown in Figure 3, with one layer of woven geotextile (in polypropylene with an ultimate tensile strength of 80 kN/m in both directions) functioning

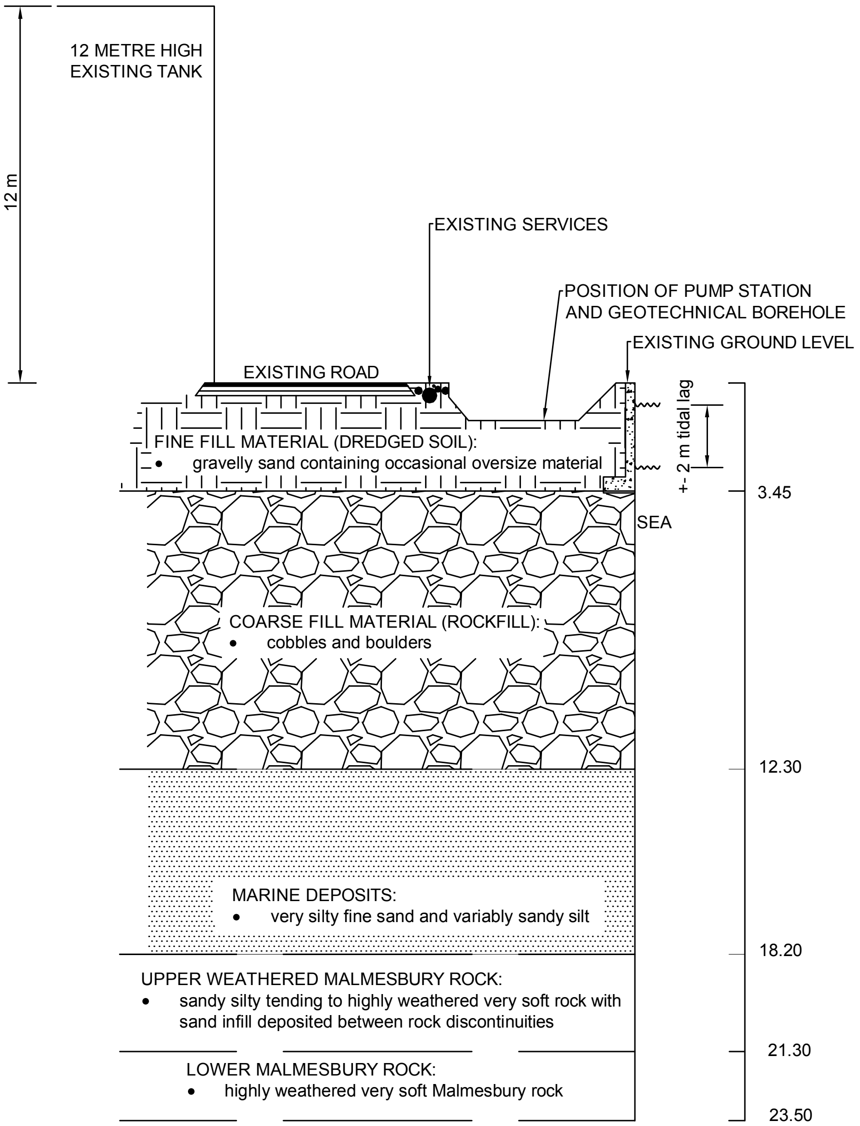

Figure 2: Schematic diagram of the subsoil conditions

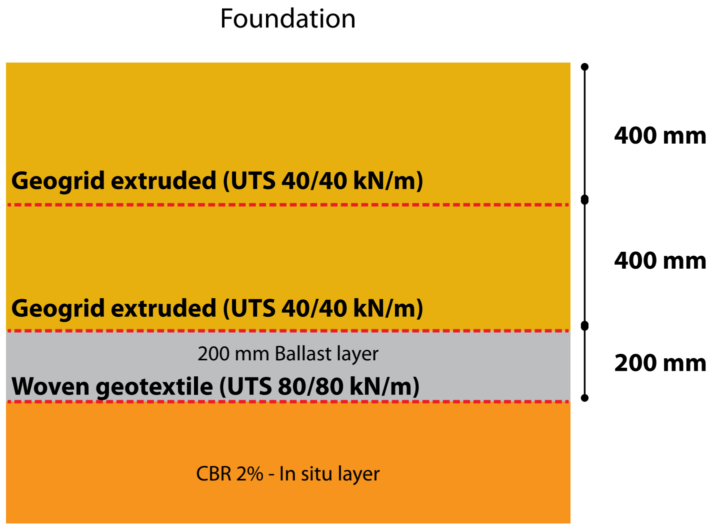

Figure 3: Section through the reinforced foundation

as a separator layer, and two layers of extruded geogrids (polypropylene bidirectional geogrids with an ultimate tensile strength of 40 kN/m) placed within 400 mm thick of a G5 material (TRH 14), which requires a minimum CBR of 45 once compacted to a minimum of 95% of the modified AASHTO density.

## CONSTRUCTION CHALLENGES

### Buried services

Attempts were made to identify the existing utility services prior to construction. However, due to the age of the port, the record drawings did not reflect the exact ground conditions upon excavation. Damage to these services could lead to safety risks for the construction team, as well as risks to the environment and commerce.

All services were therefore located by hand, and subsequently relocated to an area outside the footprint of the pump station structure. This was a time-consuming activity, because these services ranged from medium voltage electrical cables, freshwater pipelines, firewater pipelines, compressed airlines, and sleeves housing telecommunication cables (Figure 5).

### Influence of the tidal zone

It was established that the bottom of the excavation, in terms of the required depth of soil improvement, fell within the fluctuating tidal zone. During low tide the area would be dry and safe to work in, but during high tide the tidal water would rise up to 500 mm above the bottom of the excavation.

Because of the saturated founding conditions, a 200 mm pioneering ballast layer, using 26 mm single-size aggregate, was placed and statically compacted underneath the engineered layers to create a stable working platform above the influence of the tidal water level.

## QUALITY CONTROL

Plate load tests were undertaken on the in-situ subgrade using a 600 m plate diameter in the pioneering layer, as well as on the installed geosynthetic layers (Figure 7). The axial loads and the corresponding displacement were recorded at predetermined load increments, and the resulting data was then used to generate applied load versus deflection and subgrade modulus reaction curves (Figures 8 and 9).

Figure 4: Construction of the geosynthetic reinforced soil raft foundation

Figure 5: Locating the existing buried services proved to be a time-consuming challenge

Figure 6: Tidal influence – low tide (top) and high tide (bottom)

Figure 7: Plate load test undertaken during construction

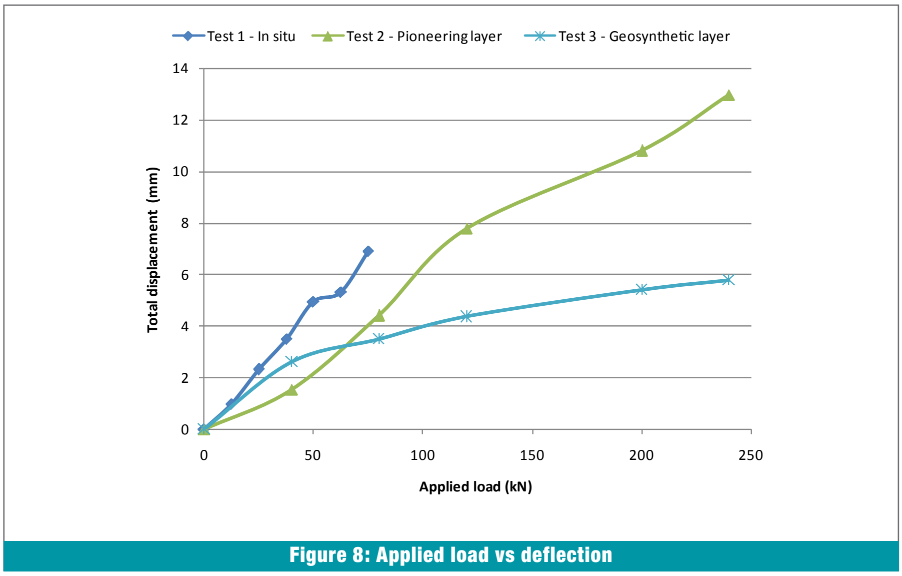

Figure 8: Applied load vs deflection

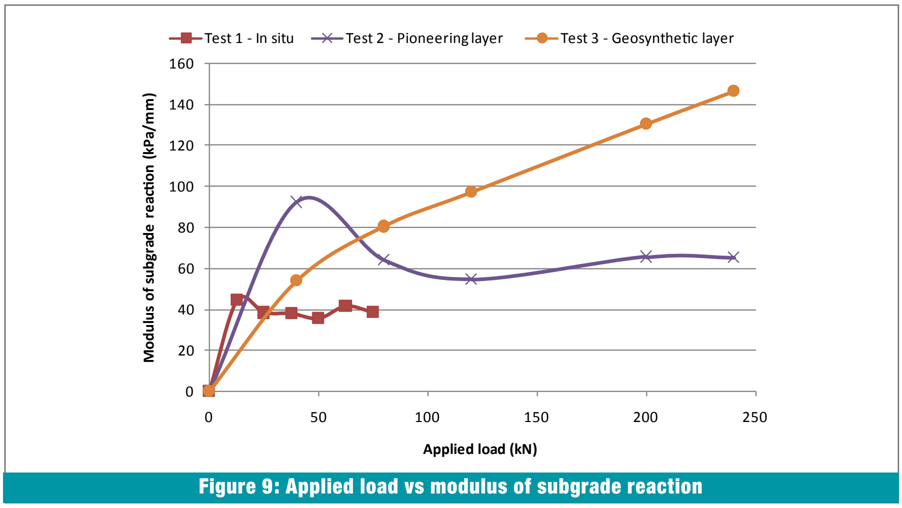

Figure 9: Applied load vs modulus of subgrade reaction

Figure 10: Booster pump station as of December 2015

The soil raft founding material (approximately 1.2 m below ground level) comprised loose, variably silty fine-grained sandy material. Test 1 confirmed that the in-situ material comprised generally low-strength soils (bearing capacity < 40 kPa), which necessitated the ground improvement. The plate loads test results at respective levels within the reinforced soil raft are presented in Figures 8 and 9.

During the construction phase the settlement of the pump station was measured on a weekly basis to record its average structure settlement. These readings confirmed that minimal settlement had occurred during the construction phases (with 95% construction completed). Following completion and leak detection testing, the structure settled uniformly and attained equilibrium with the ground.

## CONCLUSIONS

The importance of an adequate geotechnical investigation and retaining the geotechnical engineer during the construction phases remain the most effective methods of managing the subsurface risks where problem soils are encountered. Sadly, in most civil engineering projects, the involvement of the geotechnical engineer tends to terminate after the investigation phase.

The installation of the cost-effective geosynthetic reinforcement improved the bearing capacity of the ground, ensuring that the structural loading conditions were met, thereby essentially eliminating the requirement for expensive piling techniques.

Although this reinforced soil raft concept is commonly undertaken overseas, this solution is not regularly considered in geotechnical applications in South Africa from the perspective of a founding soil improvement technique to develop the ability of weak soils to support structures.

The behaviour of the layers indicates that, with adequate geotechnical investigation, and assessment and design interpretation, suitable geosynthetics are capable of supporting medium-loaded structures by transferring the stresses and applied loads through the layers. This 'transfer of soil strength' is the key to designing geosynthetic reinforced foundation pads. ☐

### PROJECT TEAM

**Client:** Transnet National Ports Authority
**Consultant:** AECOM SA (Pty) Ltd
**Contractor:** Stefanutti Stocks Marine