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INSTRUCTIONS

The Port of Townsville contributes to the North Queensland regional economy by servicing various industries including agriculture, mining, defense, retail and general cargo (Port of Townsville 2012). As with all marine ports, to improve navigational safety of vessels and to cater for larger ships with deeper draughts, the Port of Townsville has conducted a capital dredging campaign in 1993 to deepen its access channels and inner harbor from -10.7 m to -12.0 m Lowest Astronomical Tide (LAT). Dredging is generally characterised as a highly professional, capital intensive and risky industry, where, variations in soil and rock characteristics contribute the greatest cost uncertainty (Kinlan 2014). Thus, successful design, tendering and execution of a capital dredging project require adequate knowledge of dredging site subsurface conditions, beside bathymetric and environmental parameters in which dredging vessels will be operating (PIANC 2000).

In-situ soil geotechnical parameters that are essential for dredging works are those which assist in determining the optimal type of dredging plant to be used and help in identifying options for transporting, unloading, and using/disposing of dredged material (PIANC 2014). To determine stratification, physical and mechanical properties of material to be dredged, the Port of Townsville in collaboration with its geotechnical consultants has carried out offshore geotechnical site investigations.

ABSTRACT: In order to accommodate larger vessels with greater draughts, the Port of Townsville has conducted a major capital dredging campaign in 1993 to deepen its access channels and inner harbour from -10.7 m to -12.0 m Lowest Astronomical Tide (LAT). To determine the subsurface conditions of the dredging project site, the port has conducted offshore geotechnical site investigations. The factual information obtained on soil stratigraphy, classifications, and geotechnical properties has guided dredgeability assessment, cost estimates and dredging operations planning. Subsequent to provisions of guidance to design and tendering stages, the geotechnical site information reduced dredging project risk levels and contributed to a successful project execution without major delays or cost overruns for unforeseen ground conditions. This paper describes the geotechnical site characterisation for dredging works that were undertaken by the Port of Townsville, emphasising on site geological setting, scope of the investigations, field works, laboratory testing, and the obtained results.

1 SCOPE OF SITE GEOTECHNICAL INVESTIGATIONS

The main objectives of the geotechnical site investigations for dredging projects are to obtain the most complete and accurate estimates of the subsurface profile and dredgeability properties of soil material to be dredged (Spigolon 1995). These objectives can be achieved by evaluating volume and distribution of material to be dredged, soil physical and mechanical characteristics that derive dredgeability, and dredged material suitability for land reclamation (ISSMGE 2005). For the Port of Townsville’s clayey and cohesive silt soil profile, index properties, strength,
carbonate content, and particle shape dictate the dredgeability of the seabed material and its suitability as structural fill material (Table 1). To satisfy the necessary dredging site geotechnical requirements of identification of the successive layers below seabed, determination of in-situ soil geotechnical properties and sampling for laboratory testing, the port has undertaken the following field and laboratory testing works:

- Drilling of 49 bores,
- Six vibrocoring of near surface,
- Collection of soil samples,
- In-situ testing -Standard Penetration Test ,and
- Laboratory testing for soil: index, strength, carbonates content, particle shape, settling rate, consolidation and compressibility properties.

Table 1. Soil parameters relevant to dredging processes

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>Application to dredging process</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-situ density</td>
<td>Excavation, production, slope stability and dredged material reuse</td>
</tr>
<tr>
<td>PSD*</td>
<td>Excavation and dredged material reuse</td>
</tr>
<tr>
<td>Shear strength</td>
<td>Excavation, production, transportation and slope stability.</td>
</tr>
<tr>
<td>Carbonate content</td>
<td>Excavation, production, transportation and dredged material reuse</td>
</tr>
<tr>
<td>Particle shape</td>
<td>Excavation, transportation, unloading and dredged material reuse</td>
</tr>
</tbody>
</table>

* Particle Size Distribution.

3 FIELD WORKS

The geotechnical site investigations of bore holes drilling, vibrocore sampling, in-situ and laboratory testing of the Port of Townsville access channels and inner harbour deepening were undertaken during 1992. The boring, standard penetration test (SPT) and vibrocore works were performed from a cantilevered timber deck platform that mounted on the rear of a 25 m long X 10 m wide barge vessel (Douglas Partners 1992). The vessel was held on test positions by four anchors and associated air winches; satellite navigation system was used to establish bores and vibrocores locations. The boreholes were drilled at 250 to 300 m spacing (Figure 3) using a drill rig that deploys a floating head system. The boreholes were extended to depths range from 0.9 m to 8.95 m using rotary drilling with water or mud flush techniques through 100 mm diameter top casing. SPT or undisturbed tube samples of 50 mm and 70 mm diameter of strata were taken at 1 m depth intervals. The vibrocoreing was conducted using a 3 m long X 65 mm diameter sample tube, the sample tube was driven into the seabed by mean of a high frequency air operated vibrator attached to the tube top. On completion of the tube driving, negative pressure was applied to the top of the tube to facilitate withdraw. The vibrocoreing discontinued upon nominal refusal at depths of 0.45 m to 1 m below seabed level.

4 LABORATORY TESTING

The laboratory tests on disturbed and undisturbed samples collected from a site are integrals part of a site investigation exercise (Sivakugan & Das 2010). As complementary component to the geotechnical site investigations for dredging works, laboratory testing were conducted to assist in evaluating the likely engineering properties of the Port of Townsville's in-situ soils. Representative soil samples recovered from the bores were taken to a National Association of Testing Authorities (NATA) accredited laboratories for testing. The selected soil samples were laboratory tested for: index, shear strength, carbonates content, particle shape, settling rate, consolidation and compressibility properties.
The plasticity of the material to be dredged was evaluated by conducting thirty-nine Atterberg limits and thirty-six linear shrinkage tests, beside forty-three natural moisture content tests. For particle size distribution, forty-four wet sieving analyses and nineteen sedimentation (hydrometer) tests were performed to appreciate sand, silt and clay fractions of the soil. Undrained shear strength parameters of cohesion (c_u) and friction angle (\(\theta_u\)) were examined by testing seventeen undisturbed samples in quick, undrained, unconsolidated Triaxial compression test. Bulk density of these seventeen undisturbed soil samples was also investigated.

Six soil samples with known dry weight were tested for carbonate content by treating the samples with dilute (10% weight for weight) hydrochloric acid until visible chemical reactions are complete. The loss in weight that results from the chemical reactions represents carbonate content of each soil sample. The particle shape of sand fractions from the particle size distribution tests were inspected under a hand magnifying glass to observe the particle angularity. Four samples of dredged mud slurry for material collected from four different bores were poured into graduated cylindrical tubes; changes in water turbidity and solid accumulation at the tubes bases versus elapsed time were recorded to study sedimentation and solid accumulation at the tubes bases versus elapsed time were recorded to study sedimentation of these mud samples. Sedimentation and consolidation behavior of dredged mud samples that taken from the port’s inner harbour and access channels were simulated in laboratory. One dimensional consolidation (oedometer) tests on reconstituted dredged mud samples were performed to estimate the anticipated consolidation duration and settlement amount.

## 5 GEOTECHNICAL SITE INVESTIGATION RESULTS

### 5.1 Field investigation results

The bores and vibrocores encountered variable conditions over the Port’s access channel and inner harbour dredging project site (Table 2 & 3). The dominent subsurface condition was broadly found to be a thin veneer of soft grey clay at 0.1 m to 0.5 m, overlaying dense to very dense clayey sand and sand inter-bedded with stiff to hard sandy and silty clays.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Strata description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seabed level to 0.5 m</td>
<td>Very soft, grey clay</td>
</tr>
<tr>
<td>0.5 m to 3.5 m</td>
<td>Clayey sand and sand generally in dense condition.</td>
</tr>
<tr>
<td>3.5 m to 6.7 m</td>
<td>Stiff to very stiff sandy clays and silty clays, becoming hard with depth, some zones of dense to very dense clayey sand &amp; sand up to 1 m</td>
</tr>
</tbody>
</table>

### 5.2 Laboratory testing results

The plasticity test results showed that the Port of Townsville’s cohesive soil strata is generally of medium and high plasticity, while the non-cohesive clayey sand is of low to medium plasticity. The strength properties of un-drained cohesion (c_u) and the un-drained angle of internal friction (\(\theta_u\)) are presented on (Table 4). The coefficient of vertical consolidation (C_v) of the soft clayey dredged material was estimated to be in order of 4 m^2/year and reclaim land total settlement of 400 mm to 480 mm is expected for 6 m high fill material on natural firm clay at 50 kPa loading condition.

### Table 3. The port’s access channel subsurface stratigraphy

<table>
<thead>
<tr>
<th>Chainage (km)</th>
<th>Depth (m)</th>
<th>Strata description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 1.7</td>
<td>0.4-1.3</td>
<td>Soft clayey silt</td>
</tr>
<tr>
<td>1 – 1.7</td>
<td>1- 3.05</td>
<td>Dense clayey sand &amp; sand</td>
</tr>
<tr>
<td>1.7 – 3.5</td>
<td>0.2- 0.7</td>
<td>Soft clay silt</td>
</tr>
<tr>
<td>1.7 – 3.5</td>
<td>0.8 -3.0</td>
<td>Stiff to very stiff sandy clays &amp; silty clays</td>
</tr>
<tr>
<td>3.5 -5</td>
<td>0.1-0.5</td>
<td>Soft clayey silt</td>
</tr>
<tr>
<td>3.5 - 5</td>
<td>0.6-5.0</td>
<td>Dense sand &amp; clayey Sand</td>
</tr>
<tr>
<td>5.0- 6.1</td>
<td>0.2 -0.4</td>
<td>Soft clayey silt</td>
</tr>
<tr>
<td>9.5 -13.7</td>
<td>0.1- 2.8</td>
<td>Loose clayey sand &amp; clayey silt</td>
</tr>
</tbody>
</table>

### Table 4. The Port’s access channel soil strength properties

<table>
<thead>
<tr>
<th>Bore ( #)</th>
<th>Depth (m)</th>
<th>Soil description</th>
<th>Strength c_u (kPa)</th>
<th>(\theta_u) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>0.2-0.8</td>
<td>Clayey sandy</td>
<td>32 -102</td>
<td>2 - 3</td>
</tr>
<tr>
<td>9-11</td>
<td>0.1 - 5</td>
<td>Clayey sand</td>
<td>37</td>
<td>19</td>
</tr>
<tr>
<td>12 -15</td>
<td>0 - 0.2</td>
<td>Clayey silt</td>
<td>48 - 79</td>
<td>11</td>
</tr>
<tr>
<td>12 - 15</td>
<td>0.3 - 3</td>
<td>Clayey sand</td>
<td>37</td>
<td>19</td>
</tr>
<tr>
<td>16 - 27</td>
<td>0 - 4.5</td>
<td>Clayey sand</td>
<td>87- 89</td>
<td>3-14</td>
</tr>
<tr>
<td>28 -36</td>
<td>0 - 4.0</td>
<td>Clayey sand</td>
<td>50 - 64</td>
<td>2-19</td>
</tr>
</tbody>
</table>
cutter suction dredge plant as the optimal vessel for
the port’s inner harbour dredging and trailer suction
hopper dredge for the access channel dredging.

Figure 4. Inner harbor material hardness contour

7 CONCLUSIONS

The site geotechnical investigation results provided
knowledge of the volume, distribution, classification
and physical characteristics of material to be dredged
has enabled the following practical applications:
• Determination of optimal dredge plant and
dredging methods,
• Derivation of dredging production rates, project
cost estimate, and dredging project risk levels
assessment,
• Reduced the dredging project geotechnical risk
levels and subsequently contributed to overall
success of the dredging campaign.
• Slope stability analysis, dredged material suitabil-
ity as structural fill assessment, estimation of re-
claimed land consolidation duration, expected
settlement amount and reclaimed land ground
improvement alternatives.
• Comparison of actual dredging production rates
with estimates and the actual dredged material
properties with the site investigation findings to
appreciate adequacy and comprehensiveness of
the geotechnical site investigations plan.

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