DYNAMIC COMPACTION OF A LOOSE ROCKFILL
FOR THE DARTMOUTH WASTEWATER TREATMENT PLANT

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ABSTRACT
The $300M Halifax Harbour Solution Project in Halifax Nova Scotia Canada is scheduled for completion in the fall of 2008. The design and construction of the sewage collection systems and of three wastewater treatment plants have resulted in interesting geotechnical issues throughout the project. The Dartmouth wastewater treatment plant is one such example where a 2 m to 10 m thick loose to compact rockfill material, identified from desktop studies and site investigations, presented challenges with respect to settlement of the treatment plant foundations. This paper describes the dynamic compaction process used on the site to increase the density of the rockfill. Also included in the paper are results of full-scale footing load tests used to verify the dynamic compaction performance.

1 INTRODUCTION
At present, the Halifax Harbour, in Halifax, Nova Scotia, Canada, receives over 180,000,000 litres per day of untreated wastewater. Documents prepared by Halifax Regional Municipality (HRM) for the Canada Environmental Assessment Act process (JW, 2001), note that water quality is poor along the harbour shorelines. Contaminated sediment exists adjacent to approximately 40 outfalls emptying into the harbour; bacteria, suspended sediment and odour are present near these outfalls. In the fall of 2003, final design, and construction was initiated on a three treatment plant solution, referred to as the “Halifax Harbour Solutions Project”. The overall project includes the construction of three new treatment plants and associated collection systems. The $300M project is scheduled for completion in the fall of 2008.

Each of the three treatment plants presents interesting geotechnical challenges due to existing site conditions and/or design constraints. The focus of this paper is the Dartmouth treatment plant. This site consisted of a thick layer of compact to loose rockfill. Due to settlement tolerances of treatment plant components, deep foundations or dynamic compaction were viewed as two feasible options for the project. After the preliminary design process, dynamic compaction was deemed to be the most cost effective option for the site. The purpose of this paper is to provide details of the geotechnical site conditions encountered during the preliminary design phase of the project, describe the dynamic compaction process used to densify the loose to compact rockfill distributed over the majority of the site, and present results of two full scale footing load tests utilized to verify the performance of the dynamic compaction process.

2 DARTMOUTH TREATMENT PLANT SITE CONDITIONS

The site of the proposed Dartmouth Sewage Treatment Plant is near the Halifax Harbour shoreline in Dartmouth (see Figure 1). The site was developed in 1992-1993 by rockfill placement. At the time of placement, the quarried quartzite rockfill was placed to create a lay-down area for storage of various equipment, and not for the support of
buildings or structures. As a result, the rockfill was end-dumped from trucks with limited compaction. Most of the rockfill was placed below tidal levels. As a result, it was assumed that the rockfill would be loosely compacted at depth, with moderate compaction near the surface. As discussed by Lewis et al (1998), local experience with site investigations near the shoreline of the harbour also suggested that compressible marine sediments may have been present on portions of the site.

Based on previous knowledge of this site, topographic and bathymetric maps, and knowledge of the planned location of the treatment plant structures, two geotechnical site investigations were initiated; the first in 2000 and the second in 2005 (JW, 2000; JW, 2005a). The locations of boreholes and test pits are shown on Figure 1. The boreholes and test pits performed in the vicinity of the proposed treatment plant structures showed subsurface conditions to consist of 2 to 10 m of rock fill over 2 to 9 m of native sandy and gravelly soils of glacial origin underlain by Meguma slate bedrock at depths ranging from 6 to 18 m. Approximately 80 percent of the rockfill was visually observed to be smaller than 300 mm and 50 percent finer than 150 mm. As expected, the rock fill was typically compact near ground level but looser with depth (based on SPT results and visual test pit observations). The native sandy soils were generally compact to dense directly below the fill and very dense with depth. Because of the pervious nature of the rockfill, groundwater levels were essentially tidal. In the treatment plant area, there was no evidence of compressible marine sediment under the rock fill. Local experience on similar sites has observed displacement of soft sediments during fill placement. A simplified cross-section of soil, rock and groundwater conditions from Figure 1 is provided in Figure 2.

Based on estimates of the elastic modulus of the loosely compacted rockfill, settlement analyses were performed utilizing the methods outlined in the Canadian Foundation Engineering Manual (2006). Based on the tolerable settlements for the proposed sewage treatment plant (i.e. 12 mm total and 6 mm differential), the loose condition of the deeper portions of the rockfill were judged to result in excessive settlements under anticipated loads. Piled foundations were an option for reducing settlements to tolerable levels but dynamic compaction was deemed to represent an equally effective and more cost effective option for preparation of the site for shallow foundations.
3 DYNAMIC COMPACTION OF THE DARTMOUTH SEWAGE TREATMENT PLANT SITE

After recommendation of dynamic compaction at the site of the proposed Dartmouth Sewage Treatment Plant, the following tasks were performed:

1. detailed specifications were prepared for the design and performance of the dynamic compaction by a specialist contractor;
2. the specialist contractor's proposed equipment and procedures were reviewed;
3. the performance of the dynamic compaction work was inspected, and;
4. results of two large-scale load tests carried out to assess the adequacy of the dynamic compaction performed were obtained and analyzed.

As discussed by Lukas (1995), dynamic compaction consists of repeatedly raising and dropping a heavy weight on a grid pattern over the area to be improved. The degree of improvement (densification) depends on the energy applied (i.e. the mass of the drop weight, the drop height, the grid spacing, and the number of drops at each grid point location). The energy is generally applied in phases using multiple passes. Following each pass, the craters formed by the drop weight are either levelled with a dozer or filled before the next energy pass is applied.

Table 1. Number of tamper drops applied in each area.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Number of Drops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area A</td>
</tr>
<tr>
<td>1 (▲)</td>
<td>13</td>
</tr>
<tr>
<td>2 (○)</td>
<td>7</td>
</tr>
<tr>
<td>3 (△)</td>
<td>5</td>
</tr>
</tbody>
</table>

The requirements of the dynamic compaction work were outlined in a design and performance specification. With this approach, the specifications indicate the required degree and depth of improvement while allowing the contractor to select the equipment and procedures to achieve the required results. The specifications required that a suitably qualified specialty geotechnical contractor be retained to design and perform the dynamic compaction work. The specifications included the following: general details on the proposed treatment plant and the objectives of the dynamic compaction; the required experience and qualifications of the proposed specialty contractor; general requirements for the protection of persons and properties; requirements on the design and implementation of the dynamic compaction work; and requirements on record keeping and acceptance tests.

To design and implement the required dynamic compaction work, the general contractor for the project, Dexter Construction Company Limited (Dexter) retained Geopac Tech Inc. (Geopac) of Boucherville, Quebec. Based on subsurface site conditions and the design and performance specification, the contractor developed a detailed program for the dynamic compaction work. The site was split into two Areas, "A" and "B." This was done to accommodate the variance in the thickness of the rock fill layer as shown in Figure 2. A schematic of the compaction program for the treatment plant area is shown in Figure 3, with number of drops for each phase provided in Table 1. Squares denote phase 1 compaction, circles phase 2 and triangles phase 3. The compaction sequence shown does not include the "ironing" phases.
The dynamic compaction field work was carried out during October 2005. Photographs of the dynamic compaction operation are included in Figure 4.

Monitoring of dynamic compaction activities included measurement of ground vibrations, recording of applied energy (tamper weight, drop height, number of drops), and measurement of induced settlements. The main dynamic compaction work was performed with a 13.9-tonne tamper and a drop height of 18 m. The energy applied at each grid point was recorded to ensure that it conformed to the specialty contractor’s design, and the induced settlement was measured to permit ongoing assessment of the general effectiveness of the dynamic compaction operation. The equivalent settlement at each grid point was calculated from initial and final elevation measurements at the grid point with adjustment for fill material used to level the crater formed by the impact of the drop weight. Based on information provided in JW (2005b), the applied energies (excluding the final ironing pass) and average induced settlements from the dynamic compaction were as shown in Table 2. Larger induced settlements were produced in Area A due to the thicker fill layer and the higher energy application.

<table>
<thead>
<tr>
<th>Area</th>
<th>Applied Energy (KJ/m²)</th>
<th>Induced Settlement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1600</td>
<td>425</td>
</tr>
<tr>
<td>B</td>
<td>1100</td>
<td>215</td>
</tr>
</tbody>
</table>

Ground vibration measurements were taken with seismographs at adjacent properties and at the site at the beginning of the work and at various times subsequently. Ground vibrations recorded at adjacent properties were less than 10 percent of the allowable level of 30 mm per second.

4 PERFORMANCE VERIFICATION: FULL SCALE FOOTING TESTING

To assess the adequacy of the dynamic compaction operation, two full-scale footing load tests were carried out. Test locations were selected based on the original fill thickness, applied energy, and induced settlements. The load tests were carried out on 2.5 m square, concrete footings, founded at about elevation 1.5 m (i.e. about 1 m below the compacted fill surface). The approximate
locations of the load tests are shown on Figure 3. The load tests were carried out in general accordance with ASTM D1194 “Standard Test Method for Bearing Capacity of Soil for Static Loads and Spread Footings”. The footings were loaded to 205 kPa (the design pressure for the treatment plant foundations was 200 kPa) and maintained at this loading for 18 to 24 hours. Following this, the loading was increased to about 300 kPa and then unloaded. Plots of applied pressure versus settlement are shown on Figure 5 for load test 1 and a plot of settlement versus time is shown on Figure 6 for load test 1 at 205 kPa. Back-calculated drained elastic modulus values using the methods outlined by Mayne and Poulos (1999) are provided in Table 3.

![Graph](image)

Figure 5. Applied pressure versus settlement for load test 1, as shown in Figure 3.

![Graph](image)

Figure 6. Settlement versus time for full scale load test 1, as shown in Figure 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drained Elastic Modulus (v=0.3)</td>
<td>300 MPa</td>
<td>380</td>
</tr>
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</table>

Table 3. Drained elastic modulus parameters obtained from full scale load testing (from Mayne and Poulos, 1999).

Based on the field monitoring and the results of the load tests performed, the dynamic compaction process was deemed to be effective in increasing the density and reducing the compressibility of the existing rock fill at the treatment plant location. Plant foundations were designed for an applied bearing pressure of 200 kPa. At this applied pressure, the load tests indicate maximum short term settlements of less than 2 mm for 2.5m square footings. Some additional long term settlement may be expected due to creep effects (see Figure 6). Total long term settlement for footings up to 4m in width are estimated to be less than 5 mm. Differential settlement, mainly due to the difference in the thickness of the fill and native soils across the site, was estimated to be less than 4 mm. To ensure minimal total and differential settlements, excavation bases/bearing surfaces were re-densified after excavation by compacting with a minimum 8 tonne vibratory roller or plate tamper delivering a minimum dynamic force of 90 kN.
5 CONCLUSIONS

The Dartmouth sewage treatment plant site for the Halifax Harbour Solutions Project represented interesting geotechnical challenges. As shown in this paper, a loose to compact rockfill material represented risk of settlement for structures on the treatment plant site. Dynamic compaction of the rockfill was shown to be an economical solution to minimizing future settlement of the treatment plant structures. Full scale footing load testing verified performance of the dynamic compaction process.

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REFERENCES


