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Designing Geotextile Support for Submarine Power Cables

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SYNOPSIS: Six 36cm diameter submarine pipe-cables were buried in a 1.2 km long, fabric-lined trench in the soft river mud under 17m average water head across the Hudson River about 4.8km north of the Newburgh Bridge, New York. This paper describes the design considerations based on geotechnical point of view using geotextile to support submarine power cables.

INTRODUCTION

Field and laboratory test results indicate that the upper river sediment is extremely soft and is thermally unstable (G/C, 1984). Thermal sand was required as backfill because its heat dissipating qualities prevent the conductors from over-heating.

Three alternatives to improve the stability of the trench were considered during design stage:

- Increase the trench depth to 2.44m and maintain the thickness of thermal sand at 1.83m.
- Maintain the 1.83m trench depth, and backfill with lightweight aggregate instead of the originally proposed thermal sand.
- Maintain the 1.83m trench depth, and place filter cloth in the trench prior to the placement of the thermal sand and pipes.

Environmental concerns prohibited river or ocean disposal of the dredged waste. A deep trench disposal plan was cancelled because of the volume and cost limitations of the upland disposal site. Cost comparisons indicated that the use of lightweight aggregate to replace the thermal sand was more expensive and less reliable than the fabric alternative. The filter fabric was therefore selected to line the trench, to help stabilize the trench bottom, and to prevent the river muck from mixing with the sand backfill.

SEDIMENT CHARACTERISTICS

Borings, samplings, in-situ vane shear tests, and laboratory tests such as classification, strength, sensitivity, consolidation, thermal resistance and chemical tests were performed to study the engineering properties of the soft river sediments. The results were evaluated.

Drilling in the river was conducted from a 18.3 by 7.6m barge. A special submersible platform which supported the drilling casing and the geonor vane shear device was provided by the contractor to isolate the testing from the operation of the barge. In order to obtain relatively undisturbed soil samples for laboratory testing, Osterberg samples were recovered at certain elevations at some borings.

The Hudson River sediments consist of gray soft plastic clay occasionally interbedded with silt layers. Shell fragments were also noted. The organic content of the sediments decreases as depth increases. The thickness of this clay varies from zero to 6m at the shorelines and 25m in the middle of the river. Crossing the clay is a layer of very dense silty sand. Project location and the subsurface profile along the submarine pipe crossing is presented in Figure 1. Figures 2 and 3 present the soil classification based on Unified Classification System and the gradation range for the sediment, respectively. Field and laboratory shear strength data, Atterberg limits, maximum dry stress, and consolidation data for the sediment with respect to depth are presented in Figure 4.

The undrained shear strength (Su) of the sediments varies from about 2.4 kN/m2 near the river bottom to 38 kN/m2 at depths of 19.8 to 21.3m below the river mudline. The 3m sediment is gray organic plastic clay and the natural water content ranges from 70 to 100%, which is higher than the liquid limit of the soil. The average liquid limit is about 60 percent. With natural moisture contents near and higher than the liquid limit, these clays are sensitive with a sensitivity value of 2 for the top 1.83m to 5 for a greater depth. Sensitivity is defined as the ratio of the undisturbed and the remolded shear strengths. The clays are slightly overconsolidated with the overconsolidation ratio (OCR) of 1.5 to 2 in the upper 9.1m and of 1.1 to 1.3 below 9.1m. Test data indicate that the submerged unit weight of the river sediment ranges from 0.45 to 0.51 g/cm3.

In order to select an adequate shear strength value for design of the foundation system, the field and laboratory strength data were evaluated and compared with typical values from available literature (Bjerrum, 1972; Duncan, 1973; Ladd, 1977 & Osterman, 1959).

For a normally consolidated marine clay, the ratio of undrained shear strength of the effective overburden pressure (Su/vo) is directly proportional to the plasticity index of the clay (Osterman, 1959). In this case, the ratio (Su/vo) for the normal consolidated soil is 0.22. Since the upper clay was found constantly disturbed by tidal action and currents and slightly overconsolidated, the shear stress ratio was adjusted based on the stress history (or overconsolidation ratio, OCR) according to the work of Ladd (1977). A normalized shear stress ratio curve incorporated with the stress history is also drawn in Figure 4. The shear stress ratio based on the field vane shear test results are...
also computed as shown on the same figure. A reduction factor of 0.9 on the vane shear test results to account for disturbance, rate of test, time delay during test, and vane size effects was applied in calculations (Bjerrum, 1972). Based on comparisons, a shear stress ratio \((\tau_s/\sigma_{vo})\) of 0.32 for the top 3m sediment was selected for design.

**STABILITY OF TRENCH BOTTOM**

The stability of the trench bottom is governed by the shear strength of the river sediments and the weight of the backfill material. During placement of the backfill, the ultimate bearing capacity, \(Q_{ult}\), underneath the granular fill can be expressed by the bearing capacity equation:

\[
Q_{ult} = N_o \sigma_u + \gamma' f D_s
\]

in which
- \(\sigma_u\) = Undrained shear strength of the sediment in psf
- \(\gamma' f\) = Average submerged unit weight of the backfill material in pcf
- \(D_s\) = Depth of excavation in ft (1 ft = 0.3048 m)

Let \(FS\) be the safety factor against the bearing capacity failure at the bottom of backfill. Then

\[
FS = \frac{Q_{ult}}{Q}
\]

**PLASTICITY CHART**

- Fig. 2 Soil Classification for Hudson River Sediment

The applied pressure \((Q)\) due to placement of the backfill is:

\[
Q = \gamma' f D_f
\]

in which
- \(\gamma' f\) = Average submerged unit weight of the granular backfill in pcf
- \(D_f\) = Depth of the backfill in ft
Using submerged unit weights of the granular backfill and the existing top sediment of 65 pcf (1.04 g/cm³) and 30 pcf (0.48 g/cm³), respectively, and substituting the design undrained shear strengths and the effective overburden pressure (σ'vo), the factors of safety for the stability of the trench bottom at the end of construction vary from 1.2 to 1.3. The result is based on the assumption that no variation of the backfill thickness during construction would occur. Should the shear strength of the sediment decrease for any reason such as disturbance during excavation to the remolded strength, the factor of safety against the bearing capacity failure of the trench bottom would become 0.87.

Due to uncertainties associated with the construction operation (nonconformity of the backfill thickness), the effects of currents and wave action, and the unknown soil strength of the top 0.61m of sediment, this upper bound safety factor (1.30) is considered to be too low. The rate of the secondary compression (creep), \( C_o = c (\Delta H / H) \log_{10} t \), has been found higher than 0.03 for the top 3m sediments. At
low factor of safety, creep to failure is possible for this soft marine clay. Furthermore, the remolded strength is used, the factor of safety is less than one. The most likely bearing capacity failure mode for soft soil at top and stiffened soil at bottom would be lateral flow. Planar flow should the trench slope and bottom fail, some granule sand will be lost laterally. The pipeable will be covered by river sediment instead of sand backfill.

Filter cloth to line the trench was selected and installed. Analysis indicated that the filter cloth could protect the thermal sand, increase the bearing capacity of the sediment and increase the stability of the overall system.

Settlement analysis for the combined pipe-backfill system was performed. The maximum total settlement consisted of 47cm of consolidation settlement and 25.4cm of secondary settlement (creep). The differential settlement between two points 30.5m apart along the cable alignment could then be estimated to be less than 30.5cm. The maximum amount of settlement was less than expected for the cables. The stress in the pipe induced by these total and differential settlements was verified by conventional analysis using beam on elastic foundation approach and was negligible.

INSTALLATION

A woven polyester (Mirafi's 2300 HP fabric) with excellent dimensional stability was selected. It was favored over polyethylene because of its heavy weight (1kg per square meter), and a fact that it could be designed to 40 percent of its ultimate tensile strength instead of 25 percent for polyethylene. Other critical properties of the 2300 HP fabric are: grab tensile strength of 6.8 MN/m²; wide strip tensile strength of 6 MN/m²; burst strength of 10.2MN/m²; soil to fabric friction of 28°; puncture strength of 159 kg; grab elongation of 15%; and equivalent opening size of 0.42mm.

In order not to disturb a fish spawning season in the Hudson River, the dredging operation, using a barge-mounted crane with watertight clamshell bucket and fabric placement, had to be completed between July 15 and October 15, 1986. Approximately 36,810 square meters of fabric were produced for the project and shipped in fabricated panels of 21.3 by 30.5m.

To get the fabric in position, a lead roller was run along the river bottom in front of the roll containing the fabric in order to push down the bottom mud in the trench. 6.1m of fabric overlapped at the end of each roll to provide a continuous stretch of geotextile across the river. As each roll was installed, divers inspected the fabric to make sure it was correctly positioned. Because of cross currents of as much as four feet per second, the fabric was unrolled at a slight angle and a 0.45m layer of the thermal sand was placed on top of the fabric for every 6.1m that was unrolled. The edges of each fabric at some locations were also held down to the bottom with 2m long by 2.2cm diameter pins at 1.5m spacing. The thermal sand was placed through a combination of direct clamshelling and tremie hopper system. Six 30cm OD conduits were assembled on the barge in the river and lowered with a winch across the river. The conduit was kept as a neutral buoyancy, which let it float a slight distance above the layer of thermal sand over the geotextile. A special sled device at the nose of the conduit kept them from plowing down into the sand and the filter fabric. The conduit was evacuated to a high vacuum and the conductor cable was then pulled through the conduit from the east side to the west.

During installation, the contractor provided an offshore surveying and monitoring crew to confirm all the work he performed. The crew was equipped with a Cubic Autotape model DM-40 Two-Range Precise Navigation system, which was capable of 0.5m accuracy in range measurement. For initial field work, the crew was equipped with a Raytheon DE-719 Survey Depth Sounder and a Klein model 400 Side Scan Sonar. Prior to the dredging operation and after the final work, bathymetric surveys at an interval of 6.1m and a minimum width of 6m along the whole cable alignment were performed.

An underwater sediment profile using a Bottom/Subbottom Video Profiler with remote sensing capability was also recorded by Video Recorder during dredging operations to confirm sediment condition.

CONCLUSION

Use of the geotextile enabled the owner to successfully place the pipe-cables underwater despite the unstable river bottom. The decision to use the geotextile resulted in approximately a third less dredging and a considerable savings in time and labor.

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REFERENCES


