Use of dilatometer testing for design of a large diameter steel water main

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ABSTRACT: Large diameter steel water mains rely on the soil's support to maintain their shape and allow them to perform as intended. Dilatometer tests were used to evaluate the soil's stiffness for a finite element design. During the evaluation of an existing water main, we discovered that the natural soil, which had a lower dry unit weight than the compacted backfill, had constrained deformation moduli that were about four times higher than the backfill.

1 INTRODUCTION

To meet the water needs in the Maryland suburbs of Washington, D.C., the Washington Suburban Sanitary Commission (WSSC) sends large quantities of water through 72 to 120 inch (1.83 to 3.05 m) diameter water mains that parallel the capital beltway (Interstate I-495). A section of 84-inch (2.13 m) diameter water main near Central Avenue was not performing as intended, and a flexible steel pipe was designed to replace the existing prestressed concrete pipe. The geotechnical investigation included evaluating the existing water main and designing the replacement water main.

2 COMPACTION

Compaction specifications require the contractor to compact structural fill to a specified effort based on either standard or modified Proctor tests. While these specifications make it relatively easy for a trained technician to monitor the placement of fill, they do not assess the deformation characteristics of the fill. Soil type is usually more important to the soil's performance than the compactive effort, but it is often overlooked in compaction specifications. For example, sands will usually be stiffer than clays with similar compactive efforts. Dilatometer tests should be used to evaluate the deformation properties of compacted fills that are significantly thick and do not contain much gravel.

3 TEST PIT EXCAVATION

A large test pit was excavated along the existing prestressed concrete water main. Soil samples were collected and used for laboratory standard Proctor and soil classification tests. The soil was classified as a light brown, medium to fine sand with some silt. The pipe backfill was the same soil type as the adjacent natural soil.

In-place density tests were performed in the backfill and adjacent natural soil and are summarized on Table 1. As shown on that table, the pipeline backfill was compacted to higher unit weights and to lower void ratios than the natural soil.

Parameter	Number of Data Points	Average	Standard Deviation	Range
BACKFILL:				
Total Unit Weight (pcf)	10	118.6	4.9	111.0 to 128.6
(kN/m^3)		18.63	0.77	17.4 to 20.2
Dry Unit Weight (pcf)	10	96.8	4.8	91.4 to 108.3
(kN/m^3)		15.21	0.75	14.4 to 17.0
Moisture Content (%)	10	22.5	1.8	18.7 to 25.7
Void Ratio*	10	0.75	0.08	0.56 to 0.84
Percent Compaction (%)	10	90.1	4.4	85.2 to 100.5
NATURAL SOIL:				
Total Unit Weight (pcf)	7	111.9	4.9	107.2 to 120.0
(kN/m^3)		17.58	0.77	16.8 to 18.9
Dry Unit Weight (pcf)	7	91.7	3.9	88.0 to 98.5
(kN/m^3)		14.41	0.61	13.8 to 15.5
Moisture Content (%)	7	22.2	7.3	14.8 to 32.1
Void Ratio*	7	0.84	0.08	0.71 to 0.91

*Void ratio computed using an assumed specific gravity equal to 2.7

Table 1: Statistical summary of field density test data

4 DILATOMETER TESTS IN PIPE BACKFILL

During our testing the pipe was in service and had an internal water pressure of 180 psi (1241 kPa). Based on the drawings for the existing concrete pipeline, we staked out the approximate locations of the pipe's centerline and springline from the state highway fence line. However, we needed to precisely locate the springline. We attached a ¾-inch (19 mm) schedule 40 PVC pipe to the discharge of our drill rig pump and jetted vertical holes at locations perpendicular to the pipe's centerline. Jetting refusal occurred when the concrete pipe was encountered. The horizontal distances from our reference centerline stake and the jetting refusal depths were recorded. When the probing hole was just beyond the springline, however, we lost the return water at 14.0 feet (4.3 m). We believe at this depth the water went into the gravel bedding of the pipe, and we were confident that we were within the backfill of the pipe.

We performed a dilatometer sounding 4.0 feet (1.2 m) north of that probe hole and parallel to the state highway fence. Dilatometer tests were performed at approximately 0.5 meter intervals within the backfill. The dilatometer membrane faced the pipe.

5 DILATOMETER TESTS IN NATURAL SOIL

Eleven (11) dilatometer test soundings were performed along the pipeline alignment in the natural soil. Tests were done at 0.5 meter intervals with the membrane facing the pipe. The constrained deformation moduli from the tests in both the backfill and natural soil are shown on Figure 1.

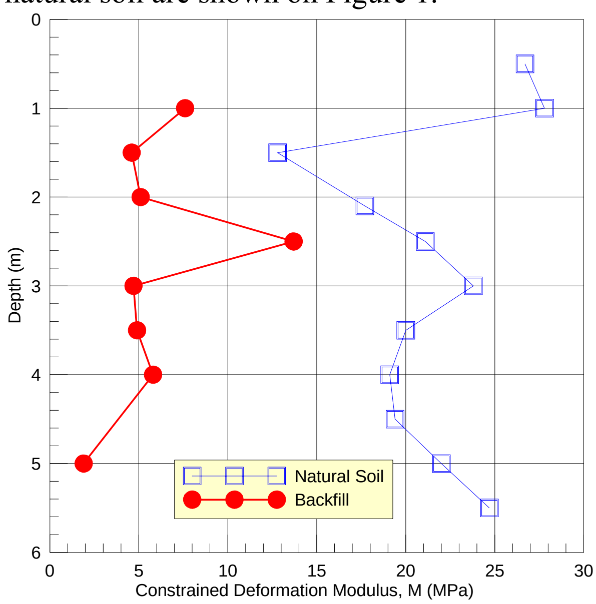

Figure 1: Comparison of constrained deformation moduli in natural soil and backfill

As shown in Figure 1, the constrained deformation moduli values were up to 4 times higher for the natural soil than the backfill. However, as shown in Table 1 the void ratios for the backfill were significantly lower than the natural soil. We believe that the better deformation moduli in the natural soil are due to its aging, stress history and cementation.

6 STEEL PIPE FINITE ELEMENT METHOD FOR DESIGN

Steel pipe is a flexible system that relies on the surrounding soil for support. Without adequate lateral support, the pipe will become egg-shaped and not perform as intended. The structural engineers used the constrained deformation modulus of the soil in their finite element analyses for this soil-structure interaction design. They determined that the soil needed to have a constrained modulus of at least 10 MPa to provide adequate support.

Based on the first phase explorations with dilatometer tests, we identified two areas where the soil was inadequate. A second phase of dilatometer tests was conducted to delineate those areas better. In the inadequate zones, the design recommended that the natural soil be excavated one pipe diameter on each side of the springline and replaced with compacted backfill. The specifications required that existing soil not be reused as backfill, but that concrete sand (ASTM C-33 gradation) be used and be compacted to 95% of the maximum dry unit weight determined from a standard Proctor test.

7 CONCLUSIONS

1. The dilatometer is needed to evaluate the constrained deformation modulus for the finite element method of design for flexible steel pipelines.
2. The percentage of compaction is not a good indicator of the soil's deformation properties.
3. Natural soils through their aging, stress history and cementation can have higher deformation moduli than fills consisting of the same soil type that are compacted to higher dry unit weights.

8 REFERENCES

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