Progress Report

for

HR-332

"Design Methodology for Corrugated Metal Pipe Tiedowns"

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The Goal and Objectives

The goal of this research is to develop a rational method for the design of tiedowns for corrugated metal pipe (CMP) and to provide standard designs. Because of the formidable scope of this project, the study is divided into two phases with specific objectives in each phase. The objectives of Phase 1 are: a) synthesize design standards from state DOTs around the nation, b) determine longitudinal stiffness of corrugated metal pipe and c) begin to obtain experimental data on soil-CMP interaction. This report addresses the objectives of Phase 1.

The objectives of Phase 2 are: a) complete collection of data on soil-structure interaction, b) incorporate the water depth computations of Austin et al (1990) into an integrated program, c) synthesize all of the data into a rational design procedure and develop software for use on microcomputers and d) develop design standards for corrugated metal pipe tiedowns. These objectives will be addressed at a later date.

Generalizations from Literature Review

Although considerable attention has been given to the ring strength of CMP and to forces associated with overburden pressures and live loads, very few studies have addressed longitudinal stiffness and uplift forces. More specifically, only the analytical work of Poulos (1974), the model studies of Trautmann et al (1985), and the laboratory testing of Lane (1965) provide some insight into the longitudinal response of CMP.

Overview of survey of transportation agencies

In order to synthesize design standards for CMP culvert inlet restraints used by various transportation agencies, Iowa DOT and ISU sent questionnaires to each of the 50 states, Washington D.C., Puerto Rico and eight provinces of Canada, requesting information on the use of restraints and any uplift problems that may have been encountered in the last five years.

In general, uplift failures of CMP throughout North America and Puerto Rico are fairly rare with only 17% of the agencies reporting failures within the last five years. Of those reporting failures, only one agency had used end restraint standards. Twenty six of 52 agencies have standards and three other agencies do not use CMP. Of those agencies that provided data to compare end restraint force as a function of CMP diameter, five have lower resisting forces than those computed by Austin et al (1990) and three have forces approximately equal or slightly greater. The large range in these standards and the continuation of uplift failures suggest that experimental work including the determination of pipe longitudinal stiffness and soil-pipe interaction is appropriate to develop a rational set of standards for end restraint.

Overview of Testing Program

Because no longitudinal stiffness data for large diameter CMP are available in the literature, a program of flexural tests on larger diameter CMP was initiated. Three specimens of 4 ft., 6 ft., and 8 ft. in diameter were selected for testing.

Scope of Reported Results

Results from the tests performed on specimens 1, 2, and 3 are presented in this section. Applied moments, mid-span vertical deflections and steel surface strains, on the compression sides of the pipes were recorded. Strains on the tension side of the specimens were generally smaller than strains measured at corresponding corrugation positions on the compression side.

Deflection data used for calculation of the CMP flexural EI factors were obtained from the location on the CMP where the load was not placed during the test. Longitudinal moment capacity, stiffness, and mid-span deflections measured or calculated from test measurements have been obtained.

Stiffness values were calculated from the service load tests assuming that the simple-span CMP is a small beam subjected to uniform distributed loads. It is recognized that this approach is a broad extension of the original intent. Secondary effects in the behavior of large diameter CMP, including a shift in the neutral axis, may make these equations subject to question; however, a similar approach was employed by Lane (1965), so these equations may be viewed as a first approximation solution to the problem of determining EI for CMP.

Longitudinal Moment Capacity

The measurements of longitudnal moment capacity were limited to three large diameter pipes by budget constraints; however for this study to have broad applications, an equation is needed to relate the influence of pipe diameter, steel gage, and corrugation geometry to CMP longitudinal moment capacity. To meet this need a general equation to calculate longituinal moment capacity for any CMP has been developed based on the principles of mechanics and on observations from the flexural tests.

Comparison of Experimental and Theoretical Results

Good agreement exists between the yield moment formula values and the laboratory results for specimens 1 and 3; however, the theoretical formula provides a higher (less conservative) moment capacity for specimen 2 than the test results. Two characteristics of specimen 2 may have contributed to the poor agreement between the experimental and theoretical results. Specimen 2 was the only specimen in which the applied load was only water. Also, the corrugation collapse locations were some distance from the mid-span which had already yielded.

The theoretical ultimate moment formula results are not compared with the laboratory results because they are partly dependent on the empirical parameter θ_{EP} which is back-calculated from the laboratory test results.

The EI factor equation provides good agreement with the test data for specimens 1 and 2. This formula does not agree as well with the laboratory results for specimen 3; this may result from relatively low length to diameter ratio of the test specimen. All EI factors calculated with the theoretical formula are conservative with respect to the actual test results.

Description of Field Test Specimen

The CMP used for the field test was galvanized steel, 10 ft in diameter, 53 ft long with 3 by 1 helical corrugations. The pipe was 10 gage with the exception of a 5 ft long section at the downstream end that was 8 gage. The pipe was in two sections with a 27 ft long section upstream and a 25 ft section downstream. The sections were joined with a 1.5 ft wide connection band.

The pipe was placed in a 12 ft deep trench excavated in undisturbed glacial till at the Spangler Geotechnical Laboratory site on the ISU campus. The sides of the trench were sloped at 1 horizontal to 2 vertical. A Class B bedding was obtained by shaping the underlying till to fit the lower part of the conduit. The backfill was placed at a slope of 2 horizontal to 1 vertical from the upstream end of the CMP to a maximum depth of cover of 2 ft. to simulate a highway embankment with minimum cover and typical side slope.

The uplift loads will be applied by pulling the pipe up with two 15 inch wide steel slings that pass under the CMP. Uplift force will be applied to the slings through a system of steel tendons, hydraulic jacks and transverse cross beams. Measurements for this test include longitudinal and transverse corrugation strains, changes in pipe diameter, vertical deflections of the CMP, and soil pressures. Six instrument locations were established. Strain gages (total of 48 applied) to measure the longitudinal and transverse strains in the corrugations were placed on the top, bottom, and at both ends of the horizontal diameter at all 6 locations.

Steel rods with DCDT's were attached to the inside walls of the CMP at all six locations to measure vertical and horizontal changes in diameter. This instrumentation is essentially the same as was used in the laboratory tests. In addition, at two locations, additional rods and DCDT's were placed at 45° to horizontal and vertical, because theoretically the maximum moments during uplift should occur at these locations.

Vertical deflection measurements will be made using vertical steel rods attached to the top of the CMP and extending above the fill at all six instrument locations. Scales will be placed on the rods so that their movements can be monitored with a transit.

Soil pressure cells will be installed within the backfill adjacent to the pipe's horizontal diameter, directly above the CMP and in the soil outside the prism of soil defined by the pipe diameter.

All instrumentation has been installed on the CMP. Loading frames have been fabricated and installed. Weather permitting, it is anticipated backfilling will be completed within the next two weeks and testing will take place in early October.