MnDOT Overload Field Tests of Standard and SIDD RCP Installations

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ABSTRACT

The design, manufacture and installation of concrete pipe have changed significantly under the new Standard Installation Direct Design (SIDD) beddings. The Minnesota Department of Transportation (MnDOT) initiated a research project to evaluate the benefits of these new installations in conjunction with use of state-of-the-art means for determining soil stiffness, and thereby, its effect on concrete pipe performance. This paper describes the methodology used in developing the test installations, how the pipes were instrumented, the significance of soil stiffness relative to soil density, the performance of concrete pipe under both the SIDD and MnDOT Standard installations, the resulting variability found with specific soils, and recommendations for concrete pipe design and installation.

INTRODUCTION

The American Concrete Pipe Association undertook a long-range research program in the 1970's to provide pipe designers a better understanding of the behavior and interaction of buried concrete pipe and the surrounding soil. The results of the research concluded with a new method of concrete pipe design and installation which was named Standard Installation Direct Design (SIDD). The new installations were developed through actual field performance evaluations of soils and finite element soil-structure modeling with the Soil-Pipe Interaction Design and Analysis (SPIDA) program. The new installations are detailed for ease of construction as well as providing haunch support that reduces flexure moments in the invert of the pipe. The supporting stiffness of bedding material is based on objective, but indirect criteria such as soil classification, placement, and measured density.

Advancements in testing procedures and apparatus for obtaining information on soil densities and stiffness have enabled the field inspectors and designers to essentially have instantaneous data on the integrity of compaction efforts. The technology now exists to ensure field construction techniques correspond to engineering structural and soil design.

The Minnesota Department of Transportation initiated a research project to combine these recent technological developments on pipe and soil installation to reevaluate and change their traditional methods used to design and install concrete pipe. Economic issues are forcing the need for change. New pipe installations must be reliable, less labor intensive, safer during construction and use native soil materials as much as possible for support of the pipe. At the same time, there has been a shift of the responsibility for the quality of construction from the owner to the contractor. Certification of conformance to specifications will become more common as on-site inspection becomes less common. This idea recognizes that when the owner sets performance criteria, it is more efficient for the contractor to determine how to meet these criteria. The new methods of soil-structure analysis, installation details and the ability to directly measure soil properties with modern methods have made this advancement practical.

TEST INSTALLATIONS

In the spring of 1997, the Minnesota Department of Transportation entered into an agreement with CNA Consulting Engineers to analyze the effectiveness and constructability of the SIDD pipe installation. The performance of the SIDD installations was to be compared to the traditional Marston-Spangler installations using native soils for the bedding and haunch material.

The comparison of the two types of concrete pipe installations were a part of a larger geotechnical study that involved evaluation of advanced instruments used to measure soil properties. In current engineering practice, the desired material property, the stiffness of soil, is indirectly specified by the combination of the Proctor Density and the soil classification. A recently developed electromechanical instrument directly measures the elastic modulus of the soil. The soil stiffness, as expressed by elastic modulus, provides the key soil parameter required for soil-pipe design methods and may be directly measured and specified in the future.

The test installation included two lines of pipe as a special provision on a MnDOT contract for the reconstruction of Minnesota State Highway 610 in Brooklyn Center. The 1200 mm round and 1485 mm arch reinforced concrete pipe were installed in a subtrench with a surcharge load of 7 meters of fill.

These two pipelines were laid in parallel with two pipe diameters (4.4-meters) separating them to minimize any effects of soil arching between the two structures. Figure 1 illustrates the geometry of the installation and the configuration of its surcharge loading. The test installation consisted of five standard bedding conditions. Each of these installations had three 1.2-meter long butt end pipe installed with a specified bedding. Use of these multiple installation details was intended to provide data in which to evaluate the performance of the new SIDD beddings as compared to the existing MnDOT beddings.

The dimensions of the various bedding types were chosen based upon soil measurements taken during the installation of the project's storm sewer mainline. This data was used to estimate the stiffnesses that would be obtained using different soils and bedding types during the overload test. Figure 2 illustrates the bedding thickness, trench widths, bedding angle, compaction requirements and respective stiffness estimates necessary for one of the SIDD clay installations.

TEST MEASUREMENTS AND PIPE INSTRUMENTATION

Pressure Cell Instrumentation

Geokon 4800E earth pressure cells were placed in 21 key locations around the pipe (see Figure 3) to determine the soil pressure and thereby the distribution of the soil loads to the surrounding soil envelope.

An initial reading of each cell was obtained just prior to its installation. Each cell was then read as the overload soil was placed and removed. Pressure was recorded when the overload was 1 meter above the pipe crown, 3.7 meters above the crown, and when the full overload of 7 meters was in place. The load was left on for 6 days, and the cells were measured again. Additionally, they were measured when the load was back down to 3.7 meters and at 1 meter. The cell temperature was also recorded at these times, and the pressure results presented in Table 1 have been corrected for temperature fluctuation.

Diameter Measurements

Measurements were also taken in the pipe to determine the vertical and horizontal deflections. Deflections were correlated to the soil pressures to estimate the effects of the soil loading and were examined in conjunction with soil stiffness and density taken during the pipe's backfill and excavation.

Pipe deflection was monitored by measuring the pipe diameters. Metal points were anchored into the concrete pipe prior to pipe installation. An initial measurement was taken when the pipe had been backfilled to the springline. Additional measurements were taken at soil levels of 3.7 meters (above pipe crown), 7 meters, and six days later at 7 meters, 3.7 meters, and again at springline (unloaded condition).

All diameter measurements were obtained through the use of a micrometer and are presented in the Table 2. The first arch pipe in the test (pipe 0) did not have the metal points installed, and as a result does not have any diameter measurements.

Crack Measurement

Cracking was monitored in the pipe sections by using a crack comparator card. Crack measurements were taken at the same time as the deformation measurements. The results are not included in this report.

Density and Moisture

A Humboldt H–4140 nuclear density gauge was used to collect soil density and moisture data. Over 500 measurements were made along the 30 sections of 1.2 meter long arch and round pipe. Meaurement locations were similar to those illustrated in Figure 4.

Stiffness

Soil stiffness was measured with a Humboldt soil stiffness gauge. Test locations were the same as the nuclear density gauge tests (see Figure 4). The soil modulus may be obtained (in kPa) by multiplying the stiffness results by 8,668 .

Excavation

The overload was placed from November 19, 1997 through November 22, 1997 and remained in place until its removal from December 1, 1997 through December 2, 1997. The overload was removed to the top of the trench, at which time there was approximately 1 meter of soil remaining above the crown of the pipe.

Excavation of the pipe sections took place from December 3, 1997 through December 12, 1997. Three 1.2 meter sections of pipe were excavated at each time, with soil data collected at various elevations as the excavation progressed. In general, measurements were taken: at the top of the trench, top of pipe, in between the crown and the springline, springline, quarter point, invert, and 0.3 m below the invert..

PIPE PERFORMANCE

The pipe for this research project were placed in specified soil and installation conditions to determine their performance relative to field and soil variations. Five installation conditions were modeled: SIDD Clay, MnDOT Standard Clay, SIDD Sand, MnDOT Standard Sand and Flowable Fill. This analysis is limited to the effects of the observed pipe deflections relative to the installation types, construction procedures and soil properties. Detail information on the structural design of the pipe can be obtained by reviewing the ASCE paper, "Evaluation of New Installations for Concrete Pipe."

The pipe sections were installed in groups of three for each installation and soil type (see Figure Y). The pipe sections were butted, with no bell or spigot joint, to prevent the transfer of shear forces to adjacent sections. This made the deformation of each section of pipe unique unto itself. Three pipes were used in line to assure at least one, the middle section, would have minimal effects from the adjoining installations, or be disrupted by the construction of these adjoining installations.

DEFLECTION DATA

A review of the vertical deflection data for both circular and arch pipe (see Figures 5 and 6) demonstrated the center pipe acted independently of the two adjacent sections in the same installation. The border pipe sections or those adjoining different installations did demonstrate deflection results which closely approximated the pipe sections in the adjacent installation. These results supported the initial assumption that the adjoining installations would effect pipe performance in the border areas.

The horizontal and vertical deflection values for the center circular pipe had a greater difference at design fill heights, 3.7 meters, but were nearly identical at overload, 7.0-meters. Under the lower fill depths the pipe was experiencing elastic shortening, resulting in vertical deflections greater than horizontal. As the pipe was overloaded, the pipe began to perform as a four-hinged arch with hinged points at the crown, invert and springlines. The deflections due to plastic hinge rotation then dominated and the elastic shortening between hinge points became less noticeable. At this point, the side soil support became a larger influence in the pipe performance, more load was transferred to the side fill and the two deflections equalized (see Figures 5 and 6).

The pipe installed with the low strength flowable fill bedding showed the greatest deflection, but this was due to incorrect construction procedures rather than any bedding performance problems. The pipe in this area had hay bales placed over the flowable fill after installation to insure proper curing in the sub-freezing ambient temperatures. The pipe was mistakenly backfilled with the hay bales left in place between the springline and crown of the pipe. The results for these pipe, however, did demonstrate the ultimate strength of this type of bedding.

The deflections on the flowable fill beddings were largest on the pipe sections adjoining the previous installation. Pipe 13 showed concrete compression strength failure at the springline (see Figure 7). This type of failure seldom occurs in underreinforced concrete sections since the reinforcing steel must first exceed the ultimate strength at the outside springline of the pipe. However, even after reinforcing failure there was enough redistribution of load to the soil and flowable fill that the pipe remained stable and even rebounded with load removal.

A review of the deflections in Pipe 14 demonstrated the strength of flowable fill beddings. Even with no side support above the pipe springline, the vertical and horizontal deflections, 6 mm and

6 mm, were similar to those obtained with well-installed sand and clay bedding and backfill at the overload condition.

The histograms of the clay and sand soil stiffness and densities for native, compacted, uncompacted and backfilled soils (see Figures 8–10) demonstrate the variability of these materials relative to MnDOT Standard and SIDD beddings. A key component of this information was the low correlation between density and stiffness as well as variability in density for sand and clay soils.

For sand, the dry density was consistently between 1680 to 1760 kg/m^3 regardless of the level of compaction. The corresponding stiffness also was consistent, with median values of 4 to 5 MN/m. These values would indicate a SIDD or MnDOT Standard sand installation should have similar performance results regardless of the level of compaction. This analogy is supported by the deflection data, where at the overload condition each had the same horizontal deflection and vertical deflections within six percent. Additional creep separated these values further, with the SIDD installations creeping less than the MnDOT Standard, but there was still very tight correlation in comparison to clay soil installations.

The values for clay dry density, like sand, were consistent with median values ranging from 1600 to 1760 kg/m^3 for native, compacted and backfilled material. The stiffness, however, varied considerably. Native clay material had a stiffness range of 3 to 20(+) MN/m, whereas, the compacted and backfilled clays had median values of 3 MN/m. The deflection data indicated the clay installations performed extremely well for MnDOT Standard installations for circular pipe and all arch pipe, and not as well for SIDD installations for circular pipe.

These results suggest the clay installations are not as predictable as the sand installations. The soil densities did not directly correspond to pipe performance with clay soils, but show a high correlation with sand soils. This fact may be attributed to the narrow stiffness performance band in which sand soils operate. There are little performance differences between concrete pipe installed in compacted and uncompacted sand.

The performance of these installations was excellent at both the design, 3.7 meter, and 7 meter overload depths. All pipe remained serviceable to the crack criteria specified in the AASHTO Standard Specifications for Highway Bridges at these loading conditions. The lone exception was Pipe 13, which had hay bales inducing greater loads, as previously discussed.

For practical field installations both materials can be used, but the designer must expect to have more compaction effort and closer inspection required for a clay installation. On the other hand, a sand installation is essentially a low risk, least effort, consistent installation.

Arch Pipe Test

Background

The performance of fifteen 1200 mm equivalent sized or 1485 mm span concrete arch pipes was evaluated when installed with the same parameters as were used for the circular pipe. Standards for arch pipe are found in ASTM C-506 Reinforced Concrete Arch, and the Minnesota

Department of Transportation's standard design. Concrete arch pipes are frequently specified in the Upper Midwest, but rarely used in other areas of the United States. Arch shaped pipes are intended to be used where the available headwater elevation is low or there is little vertical earth cover over the pipeline.

Arch pipes are more complicated to manufacture and install because of their cross-sectional geometry. The arch cross-section is defined by three radii (see Figure 11), the longest defining a nearly flat invert. Because of the flat invert, it is difficult for installers to provide soil support in standard installations. Inadequate soil support causes overloaded inverts, particularly in shear near the outer edges or haunches.

In the late 1960's, engineers at MnDOT developed a direct design method for manufacturing and installing concrete arch pipe in response to several installation failures. Arch pipes could pass traditional three-edge bearing (TEB) tests adequately yet did not perform well in deep field installations. The engineers concluded that arch pipe, because of their unusual cross-sectional shape, did not behave the same as circular pipe in standard installations. The Minnesota Department of Transportation's arch pipe design is heavily reinforced with flexural steel and in many cases included stirrups, particularly across the invert.

Installation

Both the SPIDA finite element analysis and the SIDD design constants were based on circular shaped concrete pipe, but SIDD bedding principles may be adapted to arch shaped pipe. SIDD type 3 installations for circular pipe were used to model the SIDD arch pipe installation for this test. 50 to 100 mm of soil were loosened in the middle third of the bedding under the invert of the pipe. For the SIDD-sand installations, haunching material and side fill was placed up to the spring line in a single uncompacted layer. For the SIDD-clay installations, two compacted lifts were used to place the haunching material and side fill. The arch pipes were reinforced to support 3 meters of embankment at service load conditions. The final height of the embankment was chosen to find either the flexural or the shear strength limit of the pipe.

Test Results

Soil modulus and density measurements were made on the soil surrounding the test pipe after the embankment was removed. Soil modulus for SIDD installations in clay and sand are shown in Figure 4. Both materials provide good haunch support for the arch. Sand that was initially uncompacted had similar elastic modulus values to clay that was placed in layers and compacted.

Installation in Clay

Four soil pressure gauges were arrayed around test pipe number 7 which was installed with a standard installation in clay. Under service conditions, the invert pressure gauge recorded nearly 324 kPa stress. In contrast, a soil pressure gauge at the same location under pipe section 1, which was installed with SIDD installation in clay, recorded a pressure of about 55 kPa. Under service load conditions, the vertical deformation measurements on the internal rise, are nearly identical.

Installation in Sand

None of the installations of the arch pipes in sand included soil pressure gauges. Deflection measured on the vertical were nearly equal for both the standard and SIDD installations except for the initial measurement at the service load. At the initial loading, the SIDD installation had nearly three times as much deformation as the standard installation. The large initial deflection of the SIDD test pipe might be attributable to characteristics of the sand used for the bedding. The sand for the SIDD installations was not compacted. As the embankment was constructed over the pipe, the sand became stiffer and as the overload was completed, the uncompacted sand became structurally as effective as the compacted sand.

CONCLUSIONS

The performance on this MnDOT research project provided a unique insight to not only the soils used for pipeline installation but also the key performance issues for concrete pipe. Historically, designers and installers have been concerned exclusively with soil density. The results from this project indicated soil stiffness plays a more significant role in the performance of concrete pipe.

If this finding is collaborated by subsequent studies, the design and installation of underground pipeline structures will change dramatically.

The sensitivity of clay soils with regard to compaction, stiffness and density was also a significanr finding. Clay's performance as a bedding bridged the full spectrum from excellent to poor. If this materail is to be used as a SIDD bedding, it should be designed with this sensitivity in mind. A bedding using a native clay soil is extremely economical, but the design must either require high consolidation of this material or accommodate its use by requiring a minimum amount of compaction effort indicative of a SIDD Type 4 installation.

The performance of the sand soils demonstrated the benefit this material can have on concrete pipe installations. The level of compaction had little effect on the overall performance of the concrete pipe. These findings support the use of sand over any other material if consistent, high quality beddings are needed. The lack of sensitivity with regard to stiffness and density of this material with comparison to compaction efforts makes it the ideal concrete pipe bedding material.

These research findings support the use of both clay and sand soils for the new SIDD concrete pipe installations. The key to using these materials is specifying them in the right conditions. Clay should be used for native Type 4 beddings and sand for Type 2 and Type 3 installations.

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		1 m Soil Load (Above Crown)		3.7 m Soil Load (Above Crown)		7 m Soil Load (Above Crown) 11-22-97		7 m Soil Load (Above Crown) 11-28-97		3.7 m Soil Load (Above Crown) 12-1-97		1 m Soil Load (Above Crown) 12-2-97	
Bedding Type	**Location**	Cell Temperature (C)	Adjusted Stress (kPa)	Cell Temperature (C)	Adjusted Stress (kPa)	Cell Temperature (C)	Adjusted Stress (kPa)	Cell Temperature (C)	Adjusted Stress (kPa)	Cell Temperature (C)	Adjusted Stress (kPa)	Cell Temperature (C)	Adjusted Stress (kPa)
SIDD Clay	Section 1, Arch, Invert	6.0	32.6	5.5	54.7	5.5	57.5	7.0	50.8	5.0	46.0	5.0	5.2
SIDD Clay	Section 2, Round, Haunch, North	2.0	5.6	4.5	10.0	5.0	25.2	6.0	26.7	5.0	4.5	5.0	0.4
SIDD Clay	Section 2, Round, Invert	6.0	161.0	6.0	635.0	6.0	858.4	7.0	836.9	5.5	630.1	5.5	60.9
SIDD Clay	Section 2, Round, Springline, Lateral, South	0.0	4.5	4.0	10.6	4.0	28.5	5.0	32.4	4.5	8.1	4.5	0.9
SIDD Sand	Section 11, Round, Haunch, South	2.0	7.5	4.0	38.1	4.0	126.4	4.0	119.1	4.0	21.1	4.0	0.5
SIDD Sand	Section 11, Round, Invert	5.0	9.4	5.0	121.7	5.0	227.6	5.0	217.9	5.0	153.4	5.0	9.9
SIDD Sand	Section 11, Round, Springline, Lateral, South	0.0	11.6	2.0	37.9	2.5	83.9	3.0	74.4	3.0	30.1	3.0	1.9
SIDD Sand	Section 11, Round, Springline, Vertical, North	-0.5	15.6	2.0	41.5	2.0	78.5	3.0	71.6	3.0	30.6	3.0	1.8
Standard Clay	Section 5, Round, Haunch, South	3.5	12.0	5.0	28.0	5.5	47.7	5.0	47.2	5.0	7.6	5.0	0.4
Standard Clay	Section 5, Round, Invert	7.0	256.0	6.5	698.7	6.5	1035.4	6.5	994.0	6.0	697.8	6.0	62.4
Standard Clay	Section 5, Round, Springline, Lateral, South	-0.5	10.0	3.0	26.7	3.5	72.0	4.5	76.5	3.5	26.1	3.5	0.8
Standard Clay	Section 5, Round, Springline, Vertical, North	-0.5	14.2	2.5	23.6	3.0	48.5	3.5	55.0	3.0	26.2	3.0	1.4
Standard Clay	Section 7, Arch, Crown	2.5	3.8	0.0	172.5	1.0	263.3	2.5	239.7	2.0	157.9	2.0	2.3
Standard Clay	Section 7, Arch, Invert	6.0	61.5	6.0	320.7	6.0	556.8	6.5	539.3	5.5	463.5	5.5	42.9
Standard Clay	Section 7, Arch, Lower Radius, South	2.0	4.4	5.5	22.1	5.5	37.2	6.0	35.1	5.5	7.3	5.5	0.7
Standard Clay	Section 7, Arch, Springline, Lateral, South	0.0	7.5	4.5	25.2	4.5	47.0	5.5	41.2	4.5	18.5	4.5	1.9
Standard Sand	Section 8, Round, Crown	3.0	25.2	1.0	90.4	1.0	318.3	2.0	388.5	2.0	156.0	2.0	2.1
Standard Sand	Section 8, Round, Haunch, South	4.5	14.7	5.5	34.9	5.5	113.9	5.5	130.4	5.0	33.4	5.0	0.5
Standard Sand	Section 8, Round, Invert	6.0	57.2	6.5	151.8	6.5	391.4	6.0	422.2	6.0	266.1	6.0	15.3
Standard Sand	Section 8, Round, Springline, Lateral, South	0.0	15.1	4.0	36.3	4.0	108.6	5.0	129.4	4.0	29.3	4.0	1.1
Standard Sand	Section 8, Round, Springline, Vertical, North	-0.5	11.9	3.0	30.0	3.0	70.8	4.0	74.0	3.0	24.1	3.0	1.2

Table 1. Earth Pressure Cell Results

Round Pipe Vertical Measurements in Millimeters

Pipe Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bedding	SIDD Clay			Standard Clay			Standard Sand			SIDD Sand			Flowable Fill		
0 m	1202.33	1204.19	1205.84	1204.95	1206.93	1195.96	1197.61	1200.84	1201.12	1200.66	1200.94	1200.58	1206.12	1197.25	1199.74
3.7 m	1200.81	1202.41	1201.65	1203.78	1205.87	1195.81	1196.98	1200.07	1200.56	1199.26	1199.46	1199.16	1202.11	1196.77	1195.50
7 m	1190.47	1191.72	1194.36	1195.53	1199.97	1192.89	1194.87	1192.30	1192.89	1192.43	1192.86	1188.06	1170.74	1191.46	1181.07
7 m	1187.37	1189.36	1194.03	1195.12	1199.90	1192.50	1193.01	1189.28	1191.41	1190.85	1192.53	1187.50	1145.95	1191.46	1179.07
4 m	1188.59	1191.08	1195.76	1197.38	1201.14	1193.83	1194.10	1191.56	1192.50	1192.45	1194.05	1188.34	1145.31	1191.64	1178.94
0 m	1194.49	1197.76	1199.31	1200.96	1203.83	1194.38	1195.25	1195.63	1197.38	1196.57	1197.48	1194.08	1159.84	1194.74	1189.23

Round Pipe Vertical Deformations in Millimeters

Pipe Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bedding	SIDD Clay			Standard Clay			Standard Sand			SIDD Sand			Flowable Fill		
0 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.7 m	1.52	1.78	4.19	1.17	1.07	0.15	0.63	0.76	0.56	1.40	1.47	1.42	4.01	0.48	4.24
7 m	11.86	12.47	11.48	9.42	6.96	3.07	2.74	8.53	8.23	8.23	8.08	12.52	35.38	5.79	18.67
7 m	14.96	14.83	11.81	9.83	7.04	3.45	4.60	11.56	9.70	9.80	8.41	13.08	60.17	5.79	20.68
7 m	13.74	13.11	10.08	7.57	5.79	2.13	3.51	9.27	8.61	8.20	6.88	12.24	60.81	5.61	20.80
0 m	7.85	6.43	6.53	3.99	3.10	1.57	2.36	5.21	3.73	4.09	3.45	6.50	46.28	2.51	10.52

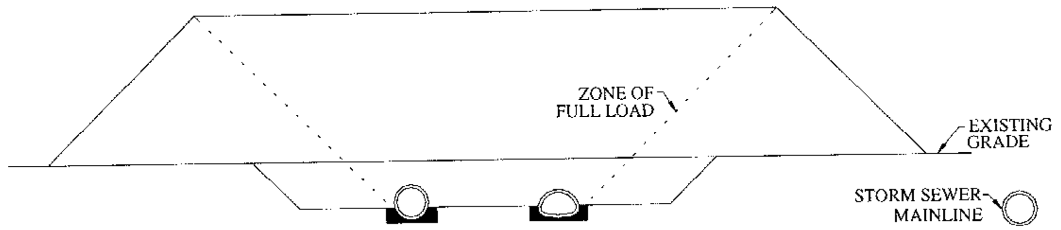
Round Pipe Horizontal Measurements in Millimeters

Pipe Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bedding	SIDD Clay			Standard Clay			Standard Sand			SIDD Sand			Flowable Fill		
0 m	1199.7182	1203.0456	1203.198	1201.7502	1202.3344	1215.009	1197.3052	1194.181	1205.484	1205.5602	1202.0042	1203.9092	1200.3786	1198.372	1205.738
3.7 m	1200.8612	1204.1632	1204.214	1202.4868	1202.9948	1215.1614	1197.6354	1194.5366	1205.7888	1206.5254	1203.1726	1205.2554	1204.2902	1198.7276	1209.6496
7 m	1211.453	1215.136	1212.2912	1210.7672	1208.4558	1217.3204	1199.9468	1202.4868	1213.3834	1213.2056	1210.31	1217.7522	1241.806	1203.8584	1224.7118
7 m	1214.5772	1217.6252	1212.9008	1211.1482	1208.5828	1217.7776	1201.42	1205.357	1216.279	1214.5518	1210.4878	1219.073	1267.968	1203.9854	1226.4644
4 m	1212.1896	1215.009	1210.3608	1208.151	1206.4492	1216.0758	1199.6928	1202.6392	1214.1962	1212.2404	1208.5066	1216.66	1268.0696	1202.7916	1225.423
0 m	1205.8904	1207.5414	1205.2554	1204.6204	1204.0108	1215.1614	1198.372	1197.8132	1209.548	1208.0748	1204.087	1209.548	1252.3978	1199.4642	1215.3646

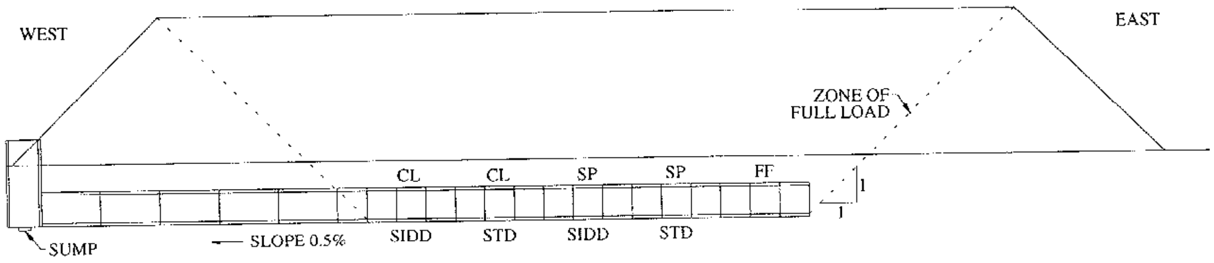
Round Pipe Horizontal Deformations in Millimeters

Pipe Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bedding	SIDD Clay			Standard Clay			Standard Sand			SIDD Sand			Flowable Fill		
0 m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.7 m	1.143	1.1176	1.016	0.7366	0.6604	0.1524	0.3302	0.3556	0.3048	0.9652	1.1684	1.3462	3.9116	0.3556	3.9116
7 m	11.7348	12.0904	9.0932	9.017	6.1214	2.3114	2.6416	8.3058	7.8994	7.6454	8.3058	13.843	41.4274	5.4864	18.9738
7 m	14.859	14.5796	9.7028	9.398	6.2484	2.7686	4.1148	11.176	10.795	8.9916	8.4836	15.1638	67.5894	5.6134	20.7264
4 m	12.4714	11.9634	7.1628	6.4008	4.1148	1.0668	2.3876	8.4582	8.7122	6.6802	6.5024	12.7508	67.691	4.4196	19.685
0 m	6.1722	4.4958	2.0574	2.8702	1.6764	0.1524	1.0668	3.6322	4.064	2.5146	2.0828	5.6388	52.0192	1.0922	9.6266

Table 2. Round Pipe Deflection Measurements



OVERLOAD CROSS SECTION



OVERLOAD LONGITUDINAL SECTION

Figure 1. Overload Test Schematic

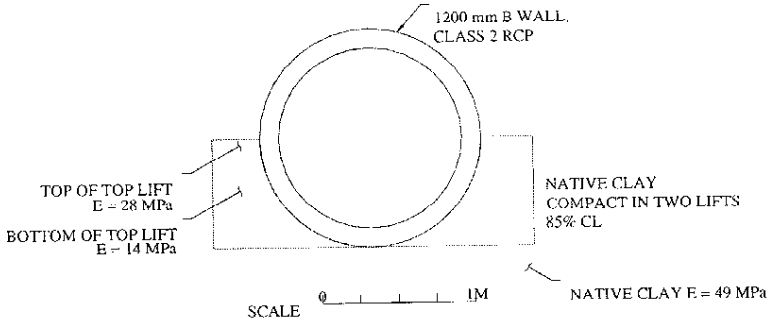


Figure 2.SIDD Clay Bedding Detail

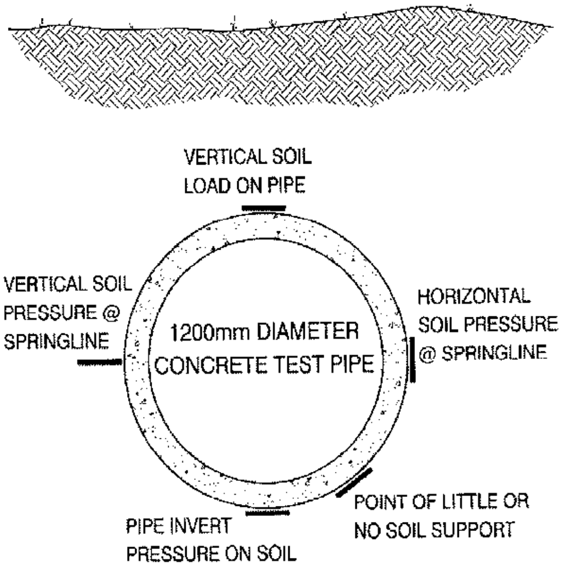


Figure 3. Soil Pressure Cell Locations

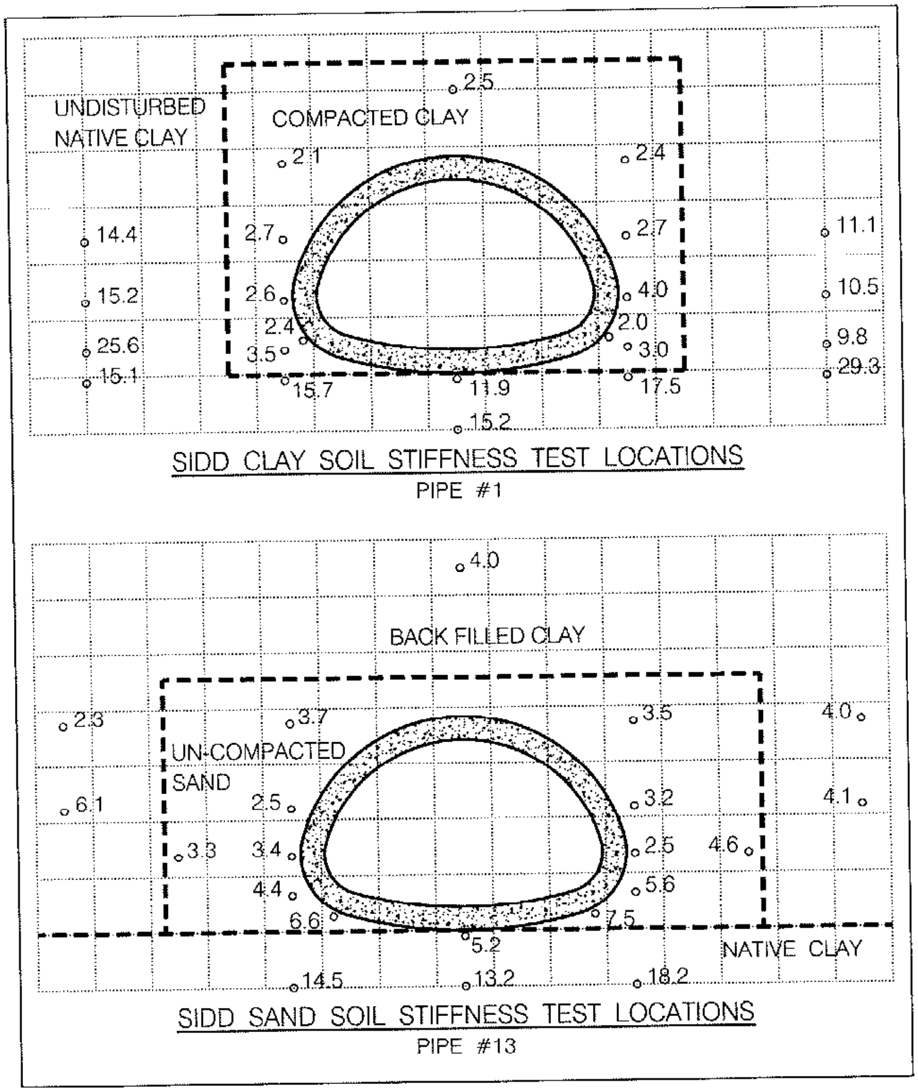


Figure 4. Typical Soil Test Locations and Stiffness Values

Figure 5.
Vertical and Horizontal Deflection of Circular Pipe
3.7 Meter Soil Load

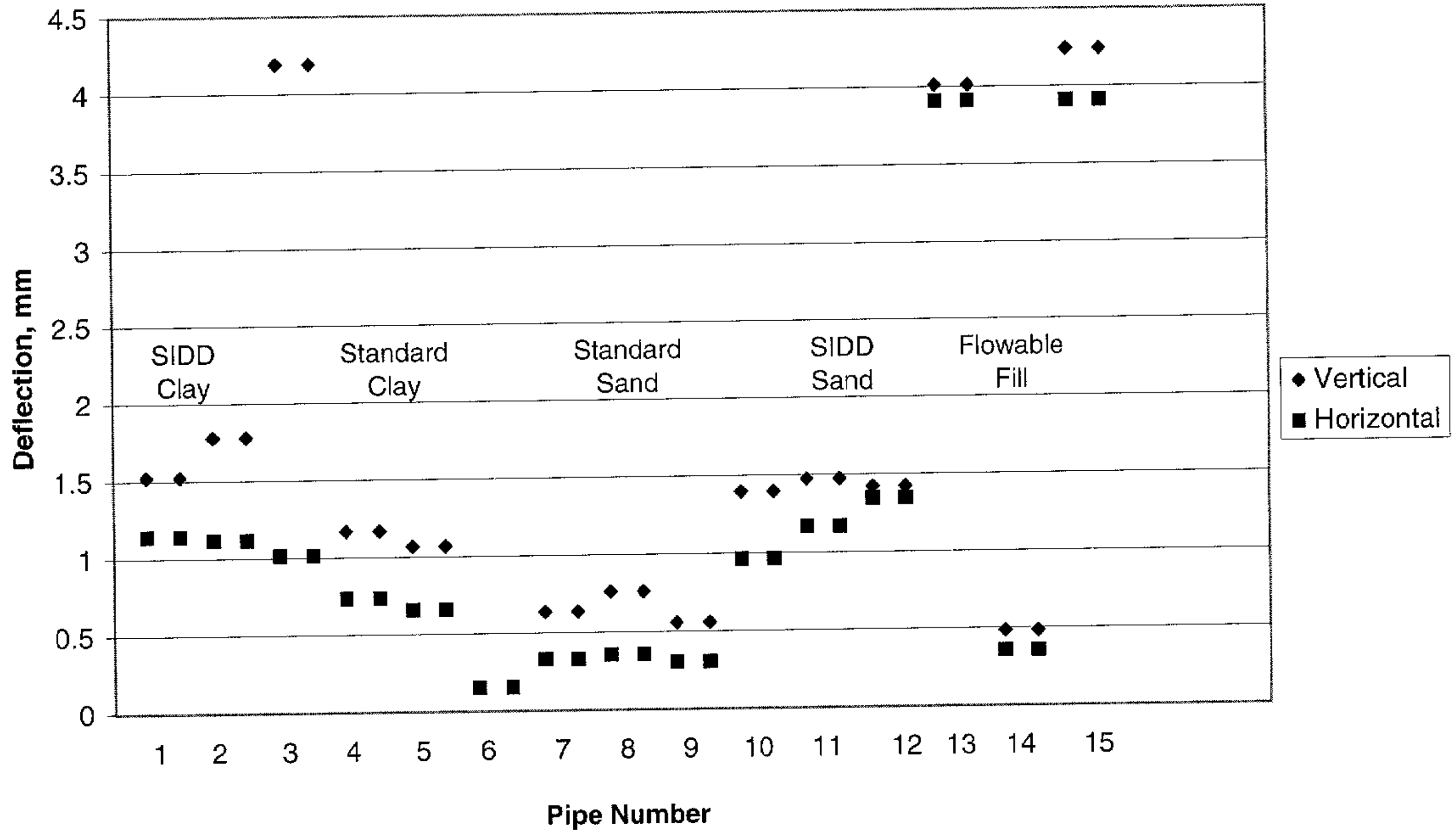


Figure 6.
Vertical and Horizontal Deflection of Circular Pipe
7 Meter Soil Load

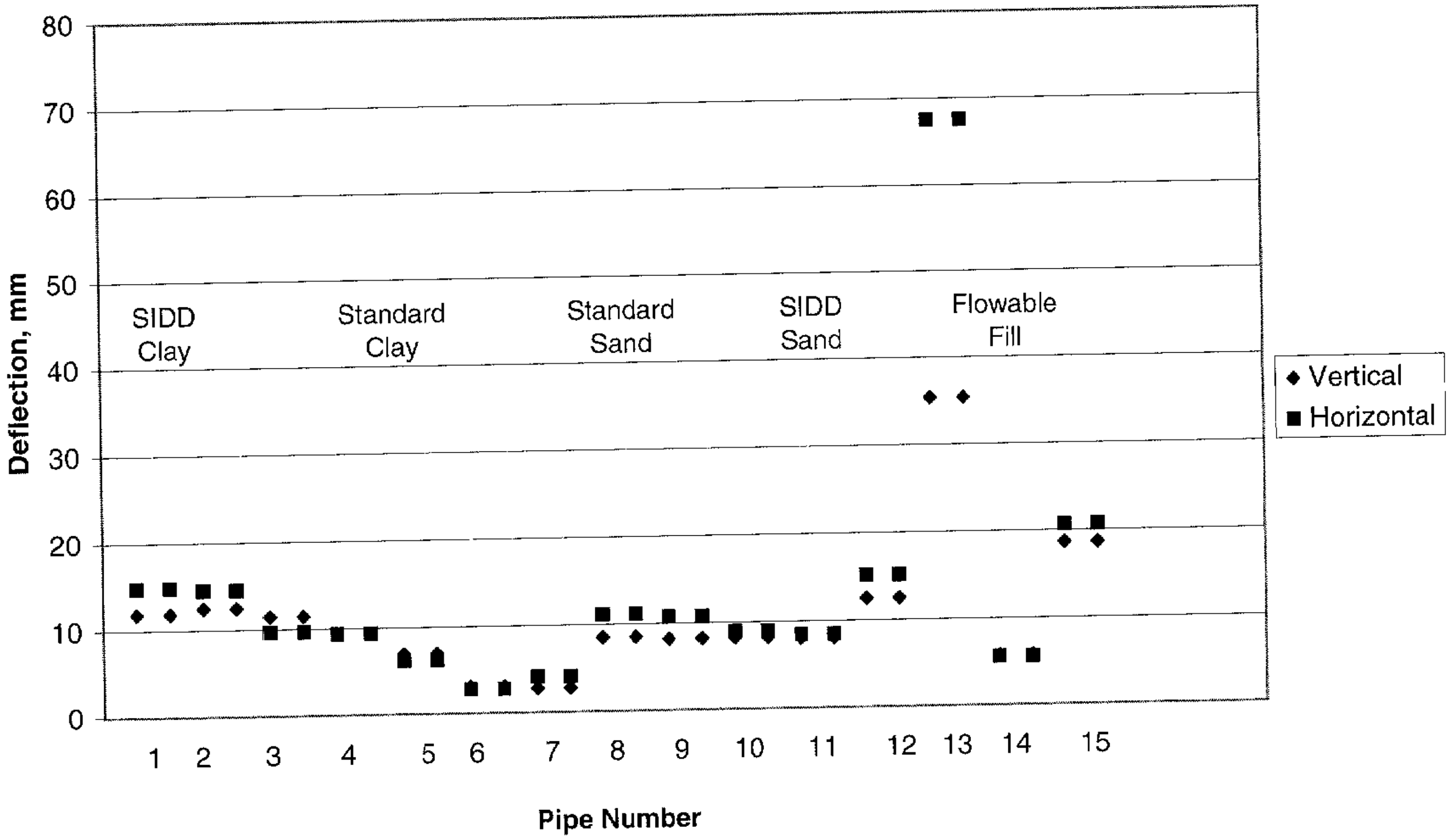


Figure 7. Photograph of Pipe 13 Springline

Figure 8.
Histogram of Native Clay Soil Stiffness

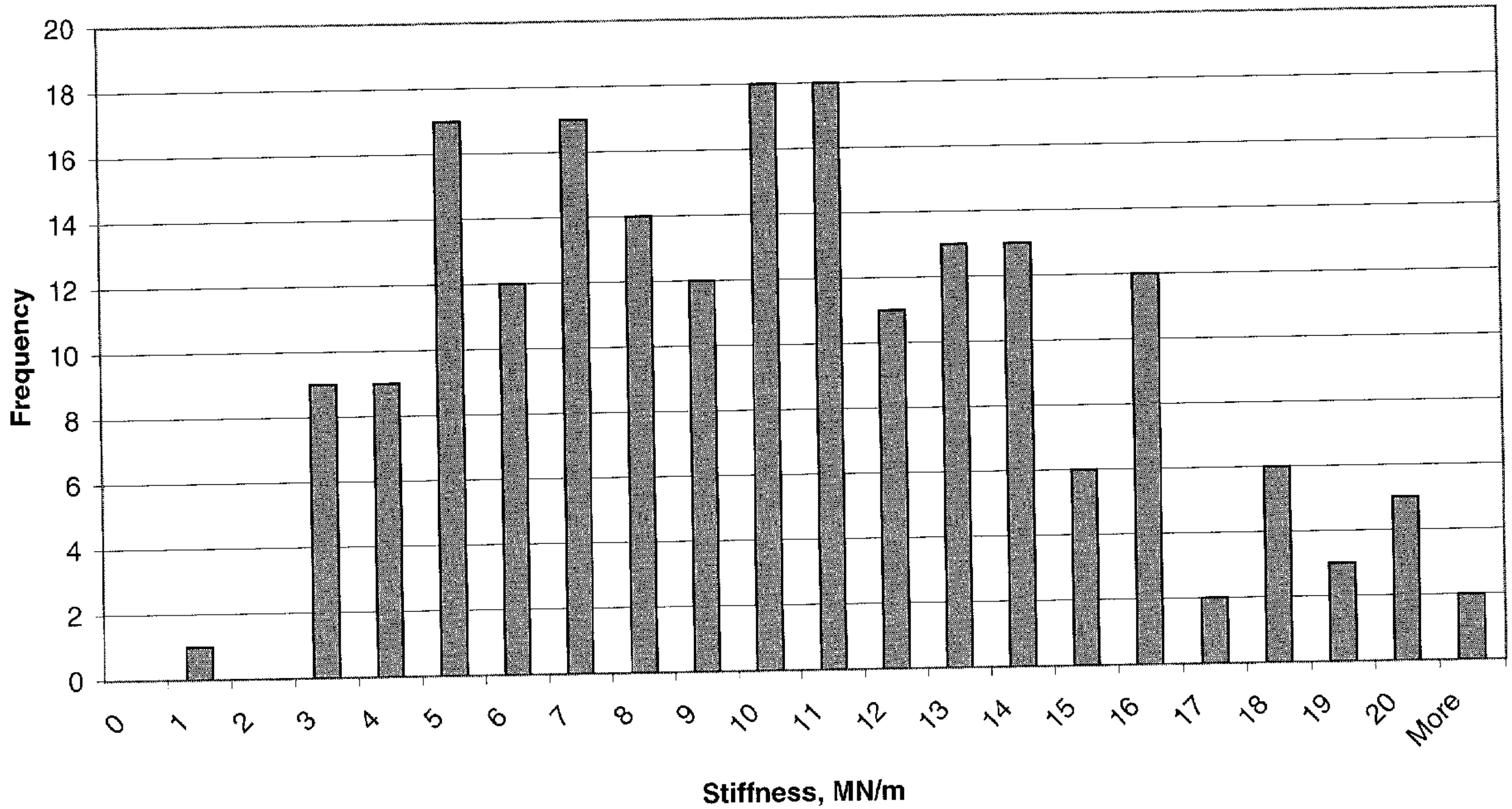


Figure 9.
Histogram of Bedding Soil Stiffness

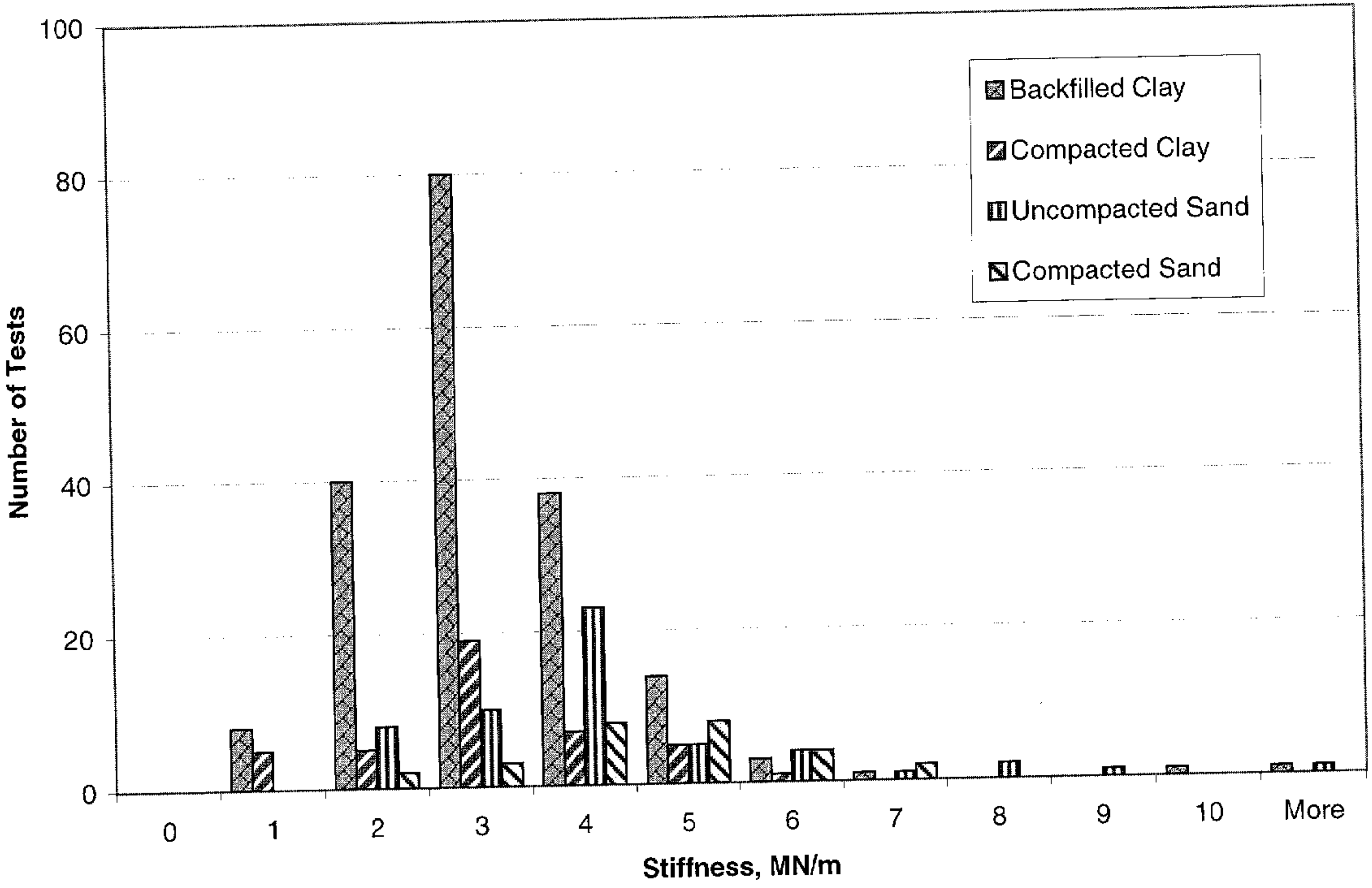
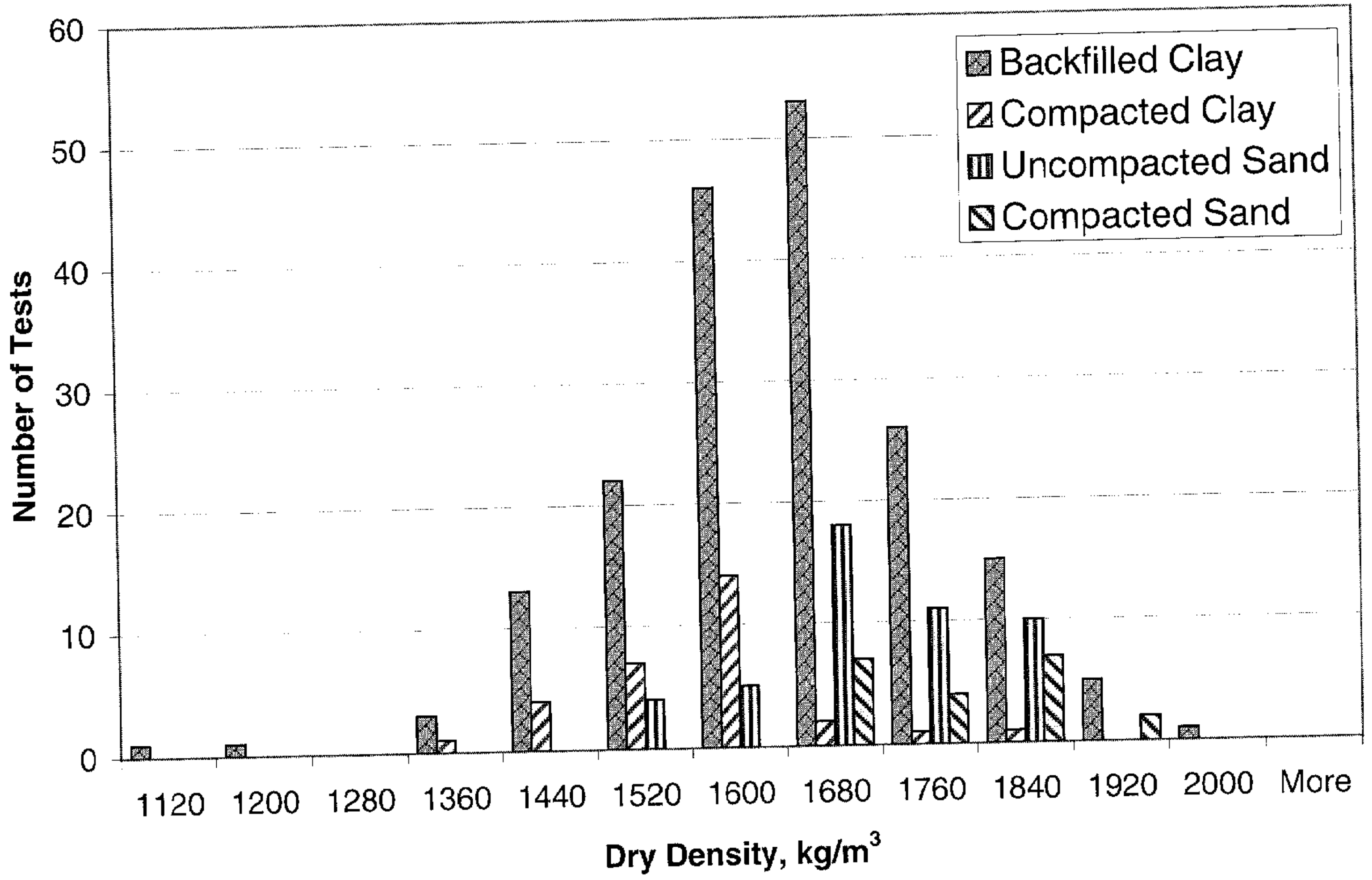


Figure 10.
Histogram of Bedding Soil Density



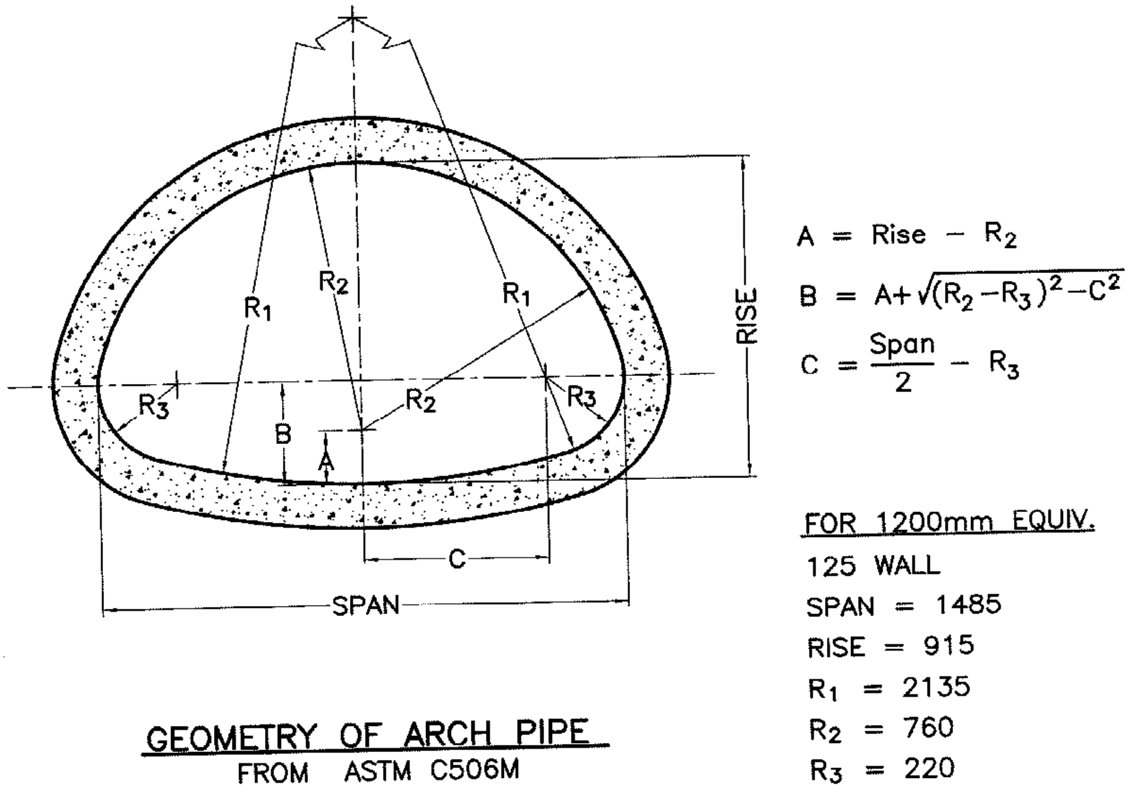


Figure 11. Geometry of Arch Pipe