

Heavy-Load Traffic Tests for Minimum Pipe Cover

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Twelve sections of culvert pipe were installed under soil cover ranging from 15 to 27 in. and trafficked with a single-tandem gear load cart. The average wheel load was 62,875 lb on an average measured contact area of 777 in². In addition, several sections of reinforced concrete pipe (RCP) were subjected to laboratory load testing to determine actual three-edge bearing strengths. The field test specimens were corrugated steel pipe (CSP) and RCP in 12-, 18-, and 24-in. diameters. Surface rutting progressed to about 1 in. at the end of trafficking. Surface stiffness, as measured by falling weight deflectometer, showed that the backfill around the pipes was less stiff than the undisturbed areas of the test section between pipe trenches. The RCP was stiffer than the CSP, except for the cracked RCP, which had a stiffness similar to the adjacent CSP. Permanent deformations (set) in the pipes increased only gradually beyond 326 passes of the load cart, even though the static and dynamic deformations caused by both the stationary and moving load cart, respectively, continued to increase. On the basis of these test results, minimum cover requirements are presented. They represent minor deviations above and below typical published values for minimum pipe cover under similar loading conditions.

This paper documents a previously unpublished part of a larger study concluded by the Waterways Experiment Station (WES) during 1977–1981 to develop design criteria for an MX roadway system. The pavement structural data have been previously reported by Alexander (*1*). This part of the investigation was conducted to develop criteria for minimum cover over drainage pipes installed beneath an MX roadway.

The depth of cover must be adequate to prevent both failure of the buried pipe and differential settlement of the overlying roadway under both moving (dynamic) and static loads. The tests described here were directed particularly at shallow-buried corrugated steel pipe (CSP) reinforced concrete pipe (RCP) subjected to heavy wheel loads similar to those of an MX transporter.

TEST SPECIFICATIONS

Pipe

Twelve sections of culvert pipe were installed, consisting of CSP and RCP in diameters of 12, 18, and 24 in.

The CSP met the requirements of Federal Specification

WW-P-405B (2) and was of full circular cross section having annular corrugations. This pipe was constructed of plain, galvanized, 16-gauge (0.064 in.) sheet, using riveted, lapped joints. Corrugations were 2 $\frac{2}{3}$ -in. by $\frac{1}{2}$ -in. deep; 15-foot pipe sections were used in Lane 1, and 10-ft sections were used in Lane 2.

The RCP conformed to standards (ASTM C-76-78, Class IV), with wall thicknesses of 2, 2 $\frac{1}{2}$, and 3 in. for the 12-, 18-, and 24-in. pipes, respectively. Three 4-ft sections with bell and spigot joints were used for the 12-in. installations and single 8-ft sections were used for 18- and 24-inch installations.

Instrumentation

Two Collins linear variable differential transformer (LVDT) displacement gauges were installed in each CSP section to measure vertical and horizontal deflection (or diameter change). These gauges had a range of ± 0.75 in. They were installed in mounts bolted to the outside surface of the pipe and adjusted off zero, so that pipe deflections up to 1.5 in. in one direction could be recorded. The four-conductor instrumentation cable was waterproofed with sealant and heat-shrink tubing and then routed to an instrumentation trailer.

Collins LVDT's with a range of +0.05 in. were installed in mounts epoxied to the inside walls of the RCP. Because less than 0.05 in. of deflection was anticipated for the RCP, these gauges were mounted at mechanical zero. The instrumentation cable was waterproofed and routed as for the CSP installations.

Crack detectors were also installed in the RCP specimens. The crack detectors for each RCP consisted of four $\frac{1}{2}$ -in.-wide traces of conductive paint of the type used to repair printed circuit boards. These traces were applied to the top and bottom quadrants of pipe circumference, 1 ft on either side of the single, vertical deflection gauge. A two-conductor instrumentation cable was run for each crack detector to the instrumentation trailer, where the resistance of each detector was continuously monitored. Increased resistance was used as an indicator of incipient RCP cracking.

A Z80 microprocessor-based system was used for automated data acquisition and processing.

Test Section

Pipe was installed only in Item 2 of Lanes 1 and 2 of the five-item MX Road Test Section (Figures 1 and 2). All pipe was installed in trenches excavated in the previously constructed subgrades. Average trench widths for CSP were 33, 43, and

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45 in. and for the RCP, 36, 47, and 51 in., for pipe sizes 12, 18, and 24 in., respectively.

The subgrade of both Lanes 1 and 2 of Item 2 consisted of material designated as Blend II, (≤ 4 -percent moisture, design CBR 15). Blend II is a sand-gravel combination blended to represent the typical gradation of the material encountered 2 to 20 ft below the potential MX siting area.

Lane 1 was surfaced with crushed limestone; Lane 2, with

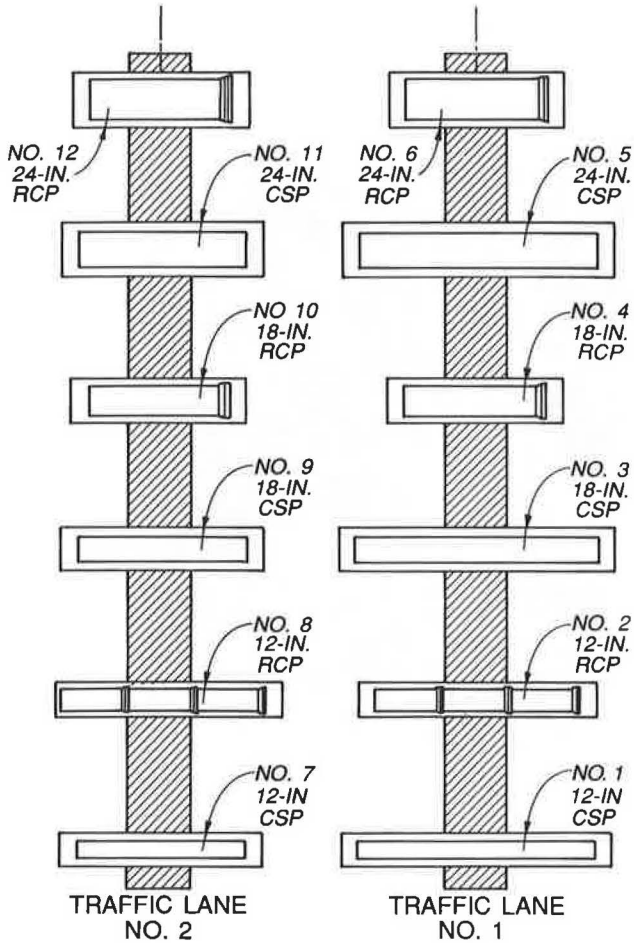


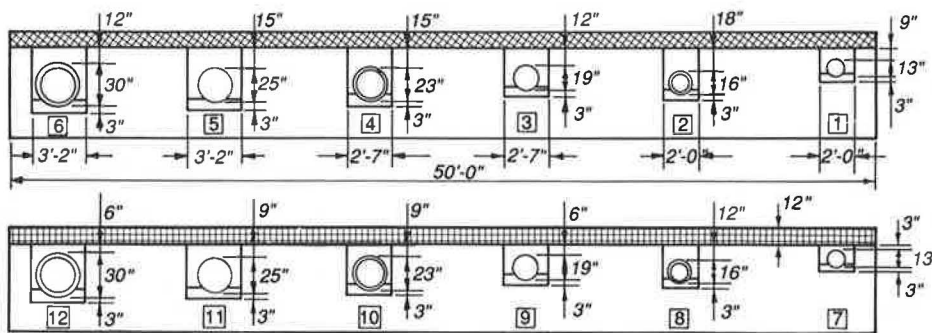
FIGURE 1 Test section plan.

cement-treated Blend I (design cement content of 7 percent). Blend I sand-gravel material was representative of that encountered in the top 2 ft of the potential MX siting area.

Item 2 was constructed to grade with the Blend II material, and trenches were excavated with a backhoe. The pipes were then placed on a layer of crushed gravel (in lieu of shaping the bedding), and 2 to 5 in. of crushed gravel were hand tamped around the pipes. The remainder of the trench was backfilled with Blend II material in 6- to 9-in. layers. The Blend II material was hand tamped to the top of the pipes, and a mechanical tamper was used for backfill above the pipes. Nuclear moisture and density measurements were performed in the bottom of each trench, on the first layer of crushed gravel (bottom of pipe), on the layers of crushed gravel around the pipes (each 2 to 5 in.), and on each lift of Blend II backfill material. Oven-dry moisture contents were also obtained. The final results of these tests are shown in Table 1. Cross-sections (profiles) were taken along the top of each pipe after each layer of backfill was completed. All instrumentation leads were trenched to a common exit point and then run to the instrumentation trailer.

Item 2 was completed by constructing the surfacing in two lifts. The pipe instrumentation was monitored during this phase of construction. The first lift of crushed limestone (Lane 1) and cement-stabilized Blend II (Lane 2) were rolled with a 25-ton self-propelled rubber-tired roller. The second (final) lift of crushed limestone was placed in Lane 1, and a 50-ton roller (100,000 lb) with small, high-pressure tires (100 psi) was used for compaction. On the first pass across the pipes with the 50-ton roller, the cover over the pipe being about 24 in., the crack detectors in Pipes 4 and 6 indicated that cracking had occurred under the load. Rolling with the 50-ton roller was halted, and the 25-ton self-propelled rubber-tired roller was used to complete the compaction of Lane 1 and was also used in Lane 2.

A 4-ft by 4-ft observation pit was excavated at the end of Pipe 6 (24-in. RCP). Hairline cracks were observed along the length of the pipe at both the top and bottom. Deflection gauges were reset, and the crack detectors were repaired (across the cracks). The pit was backfilled and compacted with a mechanical tamper. Pipe 4 (18-in. RCP) was not uncovered at this time because the crack detectors and deflection gauges were still operating.



PROFILE OF ITEM 2, LANE 2

 CEMENT STABILIZED BLEND II
 CRUSHED LIMESTONE

FIGURE 2 Test section profile.

TABLE 1 PRETRAFFIC SURFACE MEASUREMENTS OF CBR, MOISTURE CONTENT, AND DENSITY

Lane	Test	Upper Layer		Lower Layer		CBR	Dry Density (Nuclear) lb/ft ³	CE-55 %	Moisture Content (Nuclear) %
		Material	Thickness in.	Material	Thickness in.				
1	1	Crushed limestone	9	Blend II	63	144	147	100	0.8
	2		9		63	152	147	100	0.8
2	1	Blend II (cement stabilized)	17	Blend II	60	150	142	103	3.4
	2		12		60	150	141	103	3.9

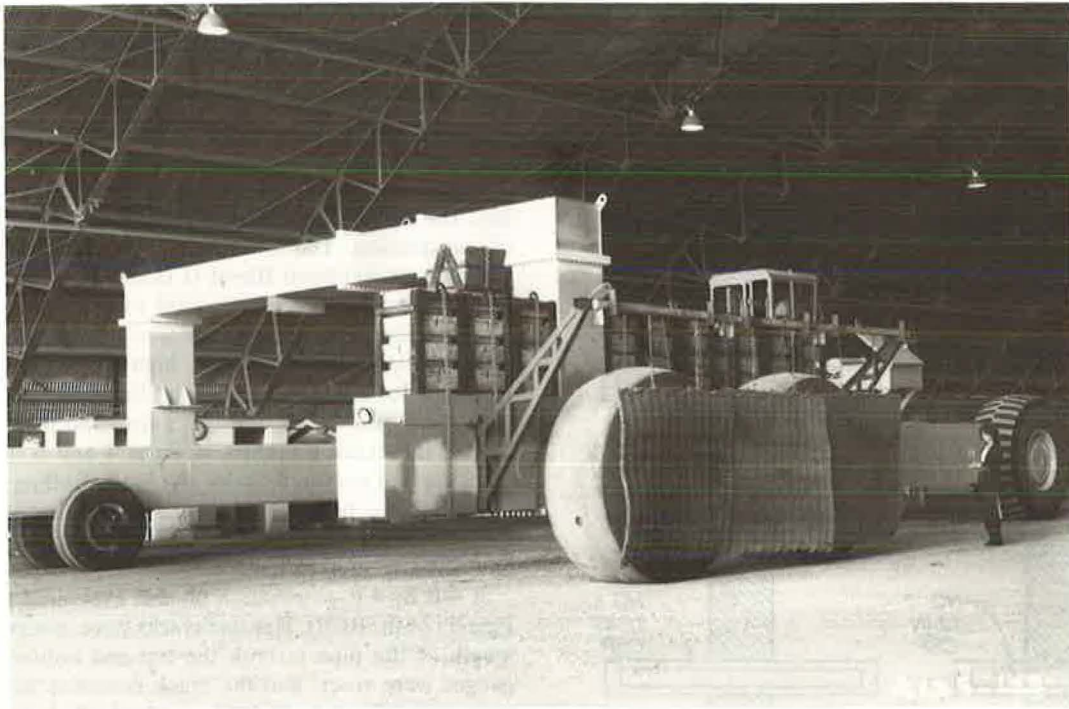


FIGURE 3 MX test vehicle.

LOAD CART AND TEST TRAFFIC

The load cart used to traffic and pipe test items is shown in Figure 3. The wheels were aligned in a single tandem arrangement 108 in. center to center and were equipped with smooth tires that measured 98 in. high by 40 in. wide. Both wheels were powered. The tires were loaded as follows:

	Front	Rear	Average
Load (lb)	68,750	57,000	62,875
Measured hard-surface contact area (in. ²)	758	796	777
Tire pressure (measured) (psi)	65	65	65
Average contact pressure (psi)	91	72	81

All traffic was applied to the test pipe in a single line, thus each pass of the load cart applied two coverages.

MEASUREMENTS

During the test, the following data were obtained:

1. Rutting of the surface in Lane 1, Item 2; and rutting and cracking in Lane 2, Item 2,
2. Permanent (nonrecovering) deformation of the pipe,
3. Deflection of the pipe resulting from one load wheel standing (statically) directly over the deflection gauges,
4. Deflection of the pipe resulting from the load cart passing or moving (dynamically) over the deflection gauges,
5. Cracking in RCP,
6. Nondestructive tests using the falling weight deflectometer (FWD) in Item 2 of both Lanes 1 and 2, and
7. Laboratory three-edge bearing strength tests of the RCP.

Photographs and rod-and-level profiles were obtained along the centerline of the wheel path (traffic lane) of Item 2, Lanes 1 and 2, at 0, 40, 130, 326, 650, 1,350, and 2,600 passes of the load cart. Readings were taken at 1-ft intervals. Cracking in Lane 2, Item 2, was mapped and photographed at the same load cart pass levels indicated above.

The deflection gauges used to record pipe diameter changes were read initially with the pipe in place in the trench prior to backfill. With this as a zero reading, the gauges were read periodically throughout the installation of the pipe and application of traffic, and the changes in diameter recorded. The measurements at zero coverages represented deflections due to the pipe installation, backfill, compaction, and weight of overburden.

Before and periodically during test traffic, the lead wheel of the load cart was placed directly over a pipe. The change in pipe diameter caused by this load placement is the static-load deflection. The change in pipe diameter resulting from passes of the load cart over the pipe gauges is the dynamic-load deflection. The permanent deformation (set) is the portion of the static-load deflection that remained after the load was removed. These values are summarized in Tables 2 and 3 for CSP and RCP, respectively.

The FWD had a mass of 440.92 lb (200 kg) dropped on a set of rubber cushions. The resulting force and deflection were measured by load cells and velocity transducers. The drop height was varied from 0 to 15.7 in. to produce a force from 0 to 16,000 lb. The device is trailer mounted and weighs a

TABLE 2 TOTAL CSP PIPE DEFLECTION, LANES 1 AND 2, ITEM 2

Pipe and Gage	Load Cart Passes	Lane 1					Percent of Diameter	
		Change in Pipe Diameter, Inches					(a+b)	(a+c)
		Perm. Deform. (a)	Static Load Defl. (b)	Dynamic Load Defl. (c)	(a+b)	(a+c)		
1V	326	-0.030	-0.042	-0.046	-0.072	-0.076	0.60	0.63
	2,600	-0.042	-0.047	-0.047	-0.089	-0.094	0.74	0.78
1H	326	0.022	0.042	0.043	0.064	0.065	0.53	0.54
	2,600	0.023	0.048	0.045	0.071	0.068	0.59	0.57
3V	326	-0.156	-0.066	-0.065	-0.222	-0.221	1.23	1.17
	2,600	-0.211	-0.089	-0.088	-0.300	-0.299	1.67	1.66
3H	326	0.142	0.060	0.060	0.202	0.202	1.12	1.12
	2,600	0.180	0.088	0.087	0.268	0.267	1.49	1.48
5V	326	-0.340	-0.086	-0.086	-0.426	-0.426	1.78	1.78
	2,600	-0.363	-0.096	-0.094	-0.459	-0.457	1.91	1.90
5H	326	0.317	0.092	0.091	0.409	0.408	1.70	1.70
	2,600	0.334	0.098	0.097	0.432	0.431	1.80	1.80
		Lane 2						
7V	330	-0.021	-0.043	-0.050	-0.064	-0.071	0.53	0.59
	2,600	-0.066	-0.076	-0.083	-0.142	-0.149	1.18	1.24
7H	330	0.001	0.036	0.046	0.037	0.047	0.31	0.39
	2,600	0.028	0.067	0.074	0.095	0.102	0.79	0.85
9V	330	-0.144	-0.128	-0.112	-0.272	-0.256	1.51	1.42
	2,600	-0.139	-0.151	-0.144	-0.290	-0.283	1.61	1.57
9H	330	0.127	0.128	0.117	0.255	0.244	1.42	1.36
	2,600	0.112	*	*	*	*	*	*
11V	330	-0.232	-0.128	-0.119	-0.360	-0.351	1.50	1.46
	2,600	-0.292	-0.182	-0.169	-0.475	-0.462	1.98	1.93
11H	330	0.210	0.125	0.115	0.335	0.325	1.40	1.35
	2,600	0.263	0.162	0.150	0.425	0.413	1.77	1.72

* Gage inoperative.

TABLE 3 TOTAL REINFORCED CONCRETE PIPE DEFLECTION, LANE 1, ITEM 2

Pipe and Gage	Load Cart Passes	Change in Pipe Diameter, Inches					Percent Internal Diameter	
		Perm. Deform. (a)	Static Load Defl. (b)	Dynamic Load Defl. (c)	(a+b)	(a+c)	(a+b)	(a+c)
2V	326	-0.006	-0.002	-0.002	-0.008	-0.008	0.07	0.07
	2,600	-0.006	-0.003	-0.003	-0.009	-0.009	0.08	0.08
4V	326	-0.008	-0.011	-0.012	-0.019	-0.020	0.10	0.11
	2,600	-0.012	-0.015	-0.015	-0.027	-0.027	0.15	0.15
6V	326	-0.118	-0.052	-0.051	-0.170	-0.169	0.71	0.70
	2,600	-0.140	-0.050	-0.049	-0.190	-0.189	0.79	0.79
Lane 2, Item 2								
8V	330	0.0	-0.002	-0.002	-0.002	-0.002	0.02	0.02
	2,600	0.0	-0.002	-0.002	-0.002	-0.002	0.02	0.02
10V	330	-0.001	-0.005	-0.005	-0.006	-0.006	0.03	0.03
	2,600	-0.001	-0.007	-0.008	-0.008	-0.009	0.04	0.05
12V	330	-0.002	-0.005	-0.006	-0.007	-0.008	0.03	0.03
	2,600	-0.002	-0.010	-0.010	-0.012	-0.012	0.05	0.05

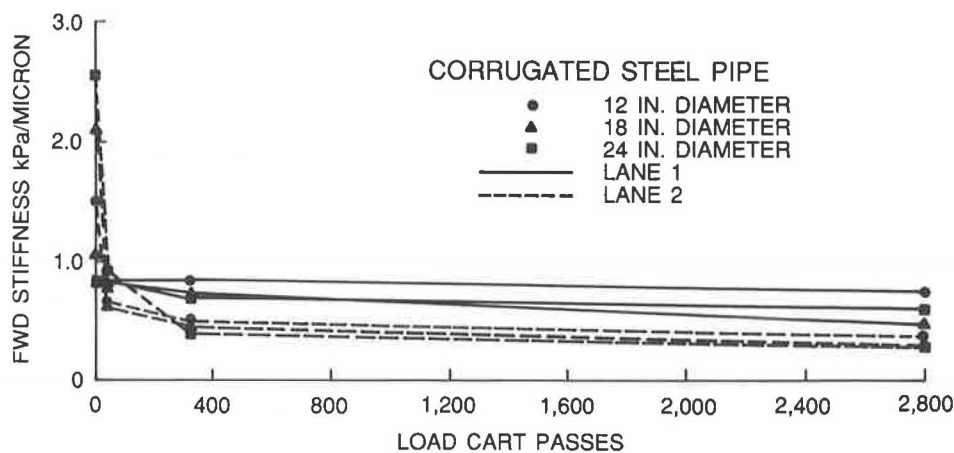


FIGURE 4 CSP stiffness data.

total of 1,500 lb. The load is transmitted to the surface through an 11.8-in. (30 cm) aluminum plate. The signal conditioning equipment displays the resulting pressure in kilopascals and the maximum peak displacement in micrometers. As many as three displacement sensors may be recorded. Tests were performed on the final two lifts during construction. Drop heights of 1.44, 3.44, 6.50, and 14.94 in. were used. Deflections were measured at the center of the load plate and at distances of 18 and 36 in. from the center. Nondestructive tests with the FWD were performed at traffic levels of 0, 40, 130, 326, 1,300, and 2,600 passes of the load cart. Tests were run directly over each pipe and at several points between each pipe. Data consisted of deflection basin measurements at the two force levels obtained by dropping the mass from heights of 3.44 and 14.94 in. FWD stiffness data, obtained directly above the pipes, for CSP and RCP, respectively, are presented in Figures 4 and 5; stiffness data for the entire test section

along Lanes 1 and 2, respectively, are presented in Figures 6 and 7.

Several RCP sections were subjected to three-edge bearing strength tests in accordance with ASTM requirements (ASTM C-497-78). The 24-in. pipe was about 10 percent stronger than ASTM requirements; the 18-in., about one-third stronger; and the 12-in., about twice as strong.

Posttraffic tests included one test pit in each lane, for post-test moisture, density, and CBR; and observation pits at the end of Pipes 4 and 6 in Lane 1. The posttraffic test pit data are shown in Table 4.

The observation pits revealed that additional cracks had formed on each side of Pipe 6 (24-in. RCP) and some spalling had occurred along the crack at the top of the pipe. The top and bottom cracks had also widened under traffic. Pipe 4 (18-in. RCP) had a barely visible crack at the top of the pipe.

Surface rutting was about 1 in. at the end of traffic.

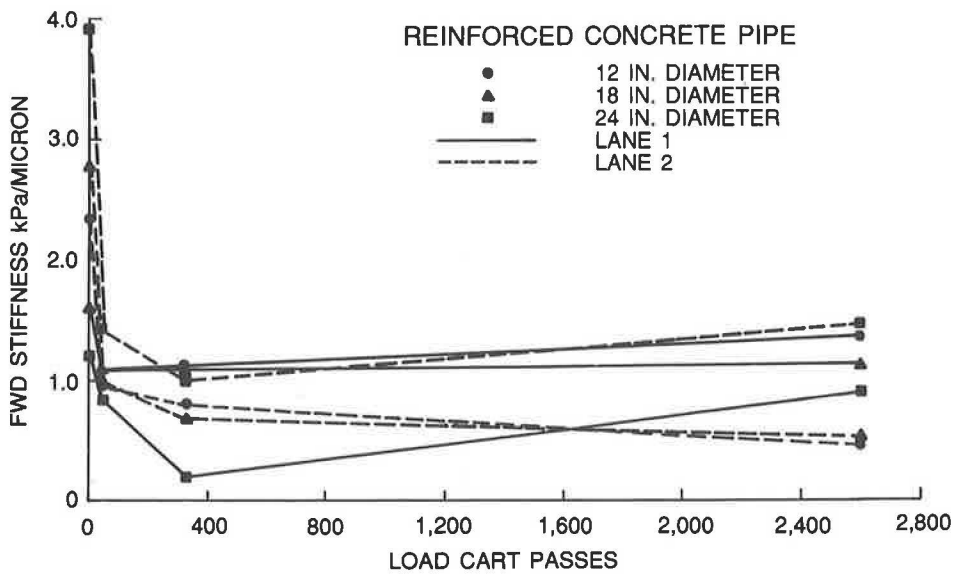


FIGURE 5 RCP stiffness data.

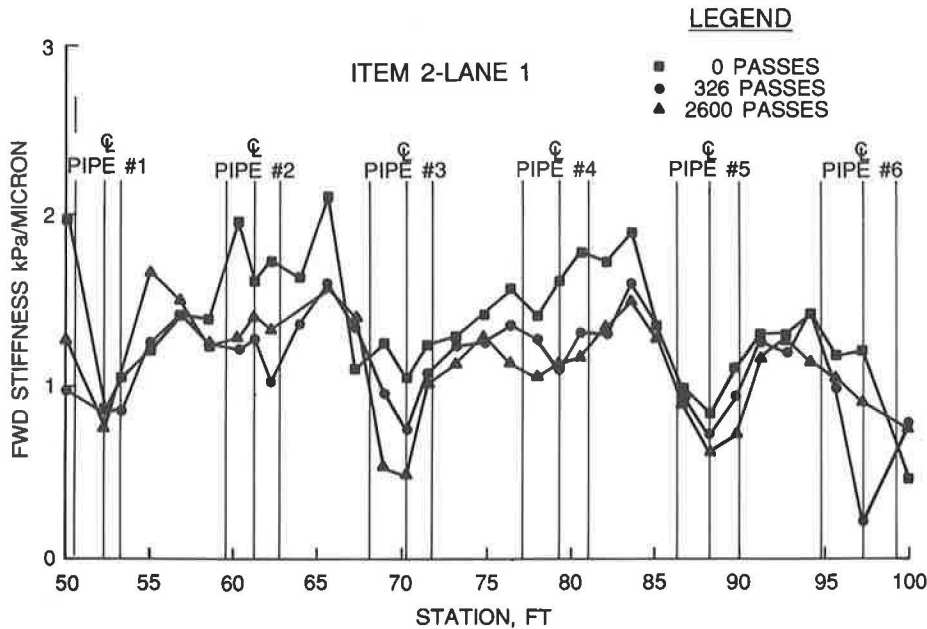


FIGURE 6 Lane 1 stiffness data.

RESULTS

Permanent Pipe Deformation

The permanent deformations of the pipe installed in Lane 1, Item 2, are shown in Figures 8 and 9; and for Lane 2, Item 2, in Figures 10 and 11. A consistent data pattern of vertical and horizontal pipe deformations is obtained. The data indicate that as the number of traffic applications increases, the vertical pipe diameter decreases and the horizontal diameter increases. In general, the data plots show relatively large successive increases in pipe deformation during early passes of the load cart, then a consistent gradual increase in defor-

mations until the end of test. This pattern is more pronounced in the CSP than the RCP. Other observations garnered from the permanent pipe deformation data are as follows:

1. For both lanes, vertical and horizontal pipe deformation increase in magnitude with increasing pipe diameter. CSP vertical deformations were much larger than RCP deformations.
2. In Lane 1, the horizontal CSP deformations were about 90 percent of the vertical deformation. Results were less consistent in Lane 2, possibly due to the randomness of cracking (and attendant loss of bridging) in the cement-stabilized surfacing of Lane 2.
3. In Lane 2, only very small deformations were measured

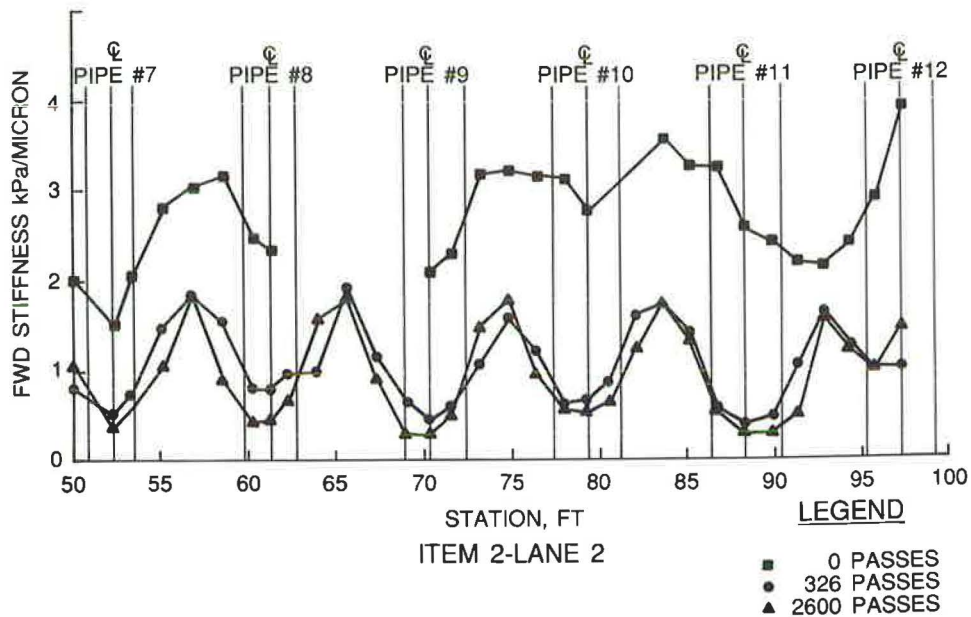


FIGURE 7 Lane 2 stiffness data.

TABLE 4 POSTTRAFFIC TEST PIT DATA—CBR, MOISTURE CONTENT, AND DENSITY DETERMINATIONS

Lane	Material	Depth in.	CBR	Dry Density Nuclear lbs/ft ³	CE-55 %	Moisture Content Nuclear %	Moisture Content Oven Dry %
<u>In Traffic Lane</u>							
1	Crushed limestone	0	150+	145	99	0.9	0.1
		6	99	139	95	1.4	0.4
	Blend II	12	45	130	94	3.0	2.9
		18	26	125	91	3.4	3.2
		24	21	120	87	3.6	2.6
		36	34	126	91	5.1	3.7
		48	21	123	89	4.3	3.4
		60	9	118	86	6.5	4.5
72	54	131	95	8.1	5.6		
2	Cement stabilized	0	150+	118	--	4.0	--
		6	--	112	--	4.0	--
	Blend II	12	8	124	90	2.5	1.9
		18	19	119	86	3.2	2.6
		24	11	119	86	3.2	2.4
		36	29	122	88	4.5	3.3
<u>Out of Traffic</u>							
1	Crushed limestone	0	150+	142	97	1.1	0.2
		6	94	136	92	1.6	0.4
	Blend II	12	51	129	93	3.0	2.7
		18	32	124	90	3.3	3.0
		24	20	120	87	2.9	2.3
		36	27	125	91	5.0	3.4
		48	22	123	89	4.2	3.3
		60	15	122	88	6.4	4.5
72	31	127	92	8.4	5.7		
2	Cement stabilized	0	150+	119	--	3.9	--
		6	--	114	--	4.8	--
	Blend II	12	11	125	91	2.5	2.0
		18	24	119	86	3.3	2.8
		24	17	118	85	3.4	2.5
		36	25	118	85	4.6	3.5

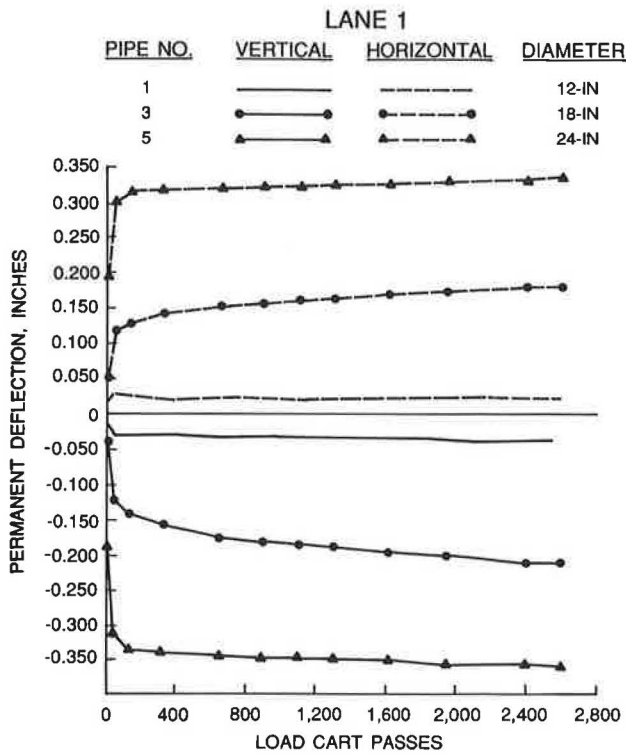


FIGURE 8 Lane 1 CSP permanent deflection.

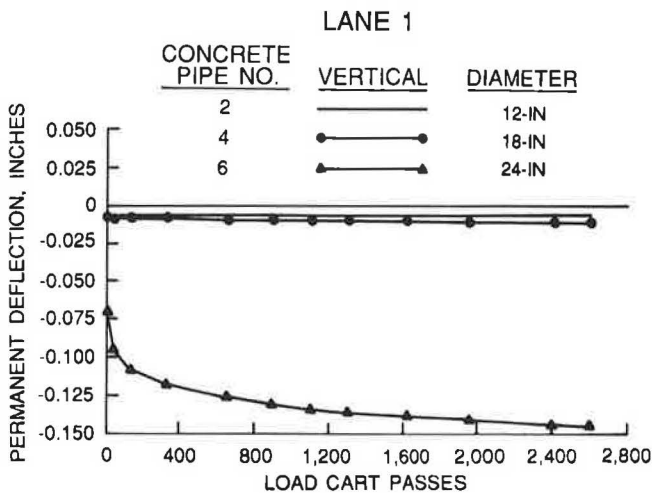


FIGURE 9 Lane 1 RCP permanent deflection.

in the RCP. RCP permanent deformations in Lane 1 were much larger than those in Lane 2, probably due to lack of bridging that might be expected from the stabilized surfacing of Lane 2.

4. Except for the 12-in. CSP, permanent CSP deformations are larger in Lane 1 than in Lane 2. Again, bridging by the stabilized surfacing of Lane 2 should reduce the vertical load and deformations in that lane.

5. The 24-in. RCP (Pipe 6) in Lane 1 had much larger deformations than any other RCP pipe. Pipe 6 had a deformation pattern similar to CSP—a rapid increase in deformation during early passes of the load cart, then a steady but

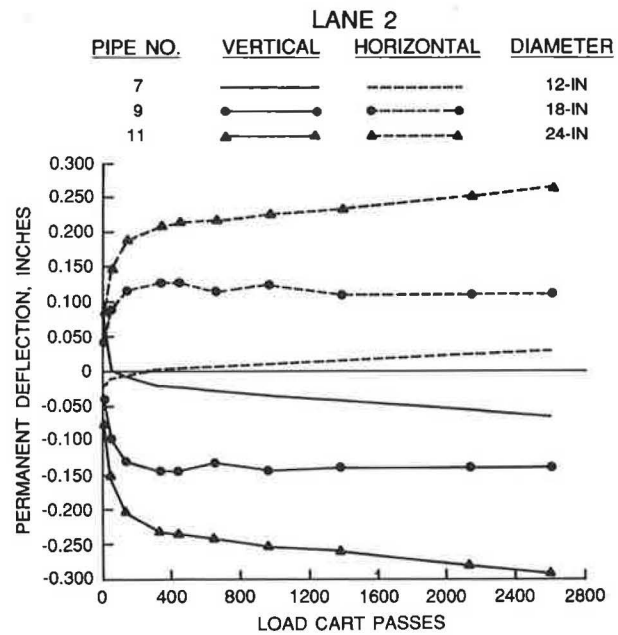


FIGURE 10 Lane 2 CSP permanent deflection.

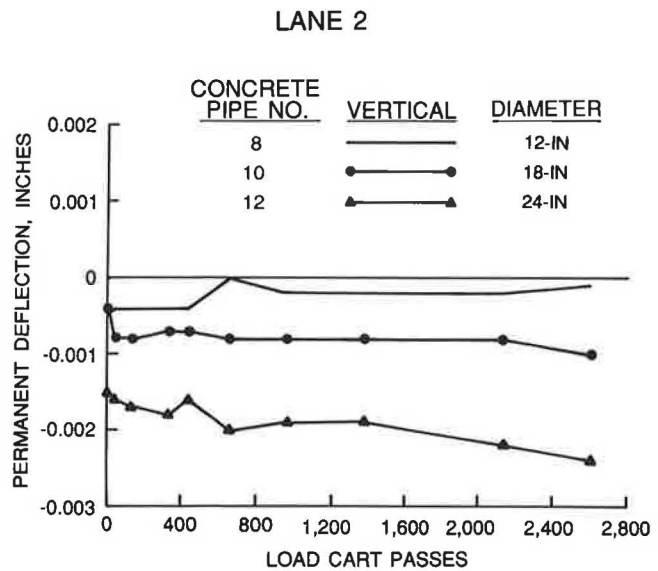


FIGURE 11 Lane 2 RCP permanent deflection.

small increase during the remainder of traffic. This pattern was probably caused by the cracking of the pipe during installation.

Static-Load Pipe Deflection

Deflections under the load cart, while stationary over each pipe and gauge, are plotted in Figures 12 and 13 for Lane 1 and in Figures 14 and 15 for Lane 2. A regular and consistent pattern can be observed. Very small readings are obtained from loading the RCP. In the case of the CSP, during early

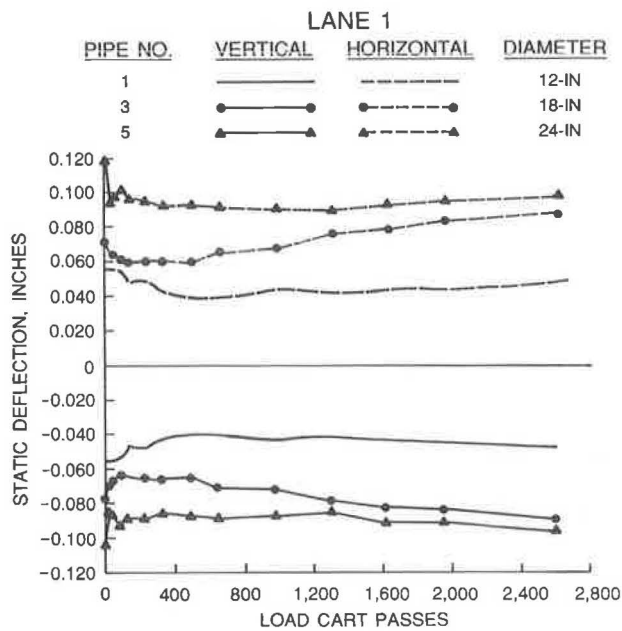


FIGURE 12 Lane 1 CSP static deflection.

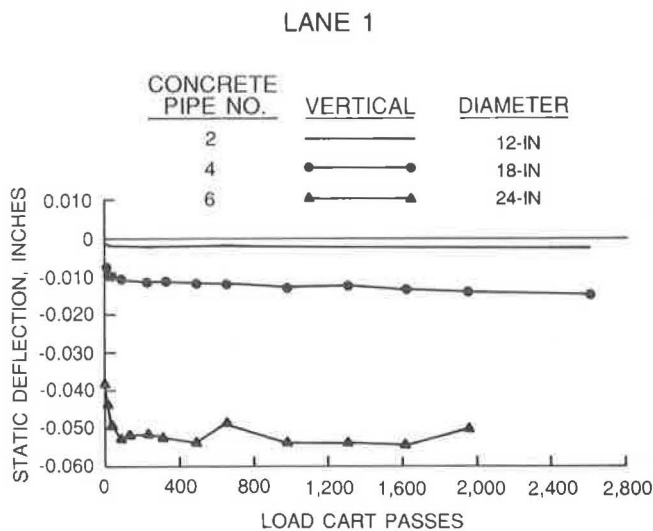


FIGURE 13 Lane 1 RCP static deflection.

loadings (Table 1) a large portion of the static-load pipe deflection was nonrecoverable, (i.e., permanent set or deformation). The following observations are also noted:

1. After the early static test loadings, both vertical and horizontal pipe deflections gradually increased until the end of test. These increases are attributed to the load (tire) being closer to the pipe (gauge) because of surface rutting and, additionally in Lane 2, because of the gradual cracking of the test item.

2. For CSP, Lane 2 static-load deflections were greater than Lane 1. The reverse was found for RCP.

3. Static-load deflections increase with increasing pipe diameter.

4. Except for Pipe 6, CSP pipe deflections were much larger than those of RCP.

5. CSP static-load horizontal deflections are about 90 percent of the vertical deflections.

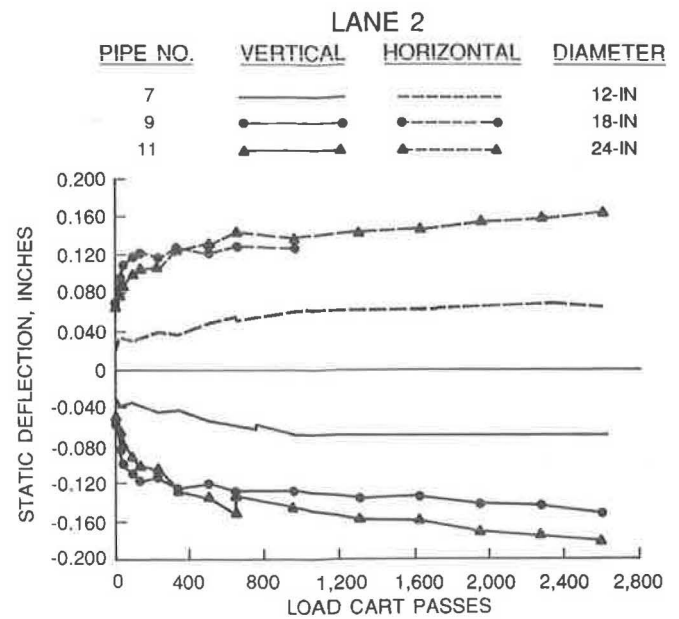


FIGURE 14 Lane 2 CSP static deflection.

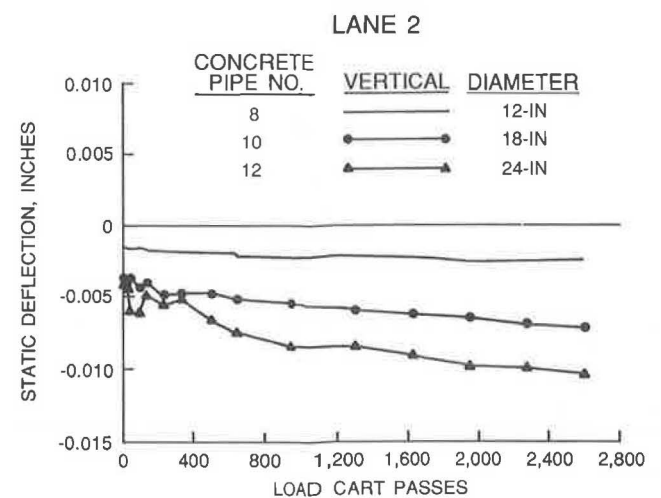


FIGURE 15 Lane 2 RCP static deflection.

Dynamic-Load Pipe Deflection

Deflections measured under the moving load are shown in Figures 16 and 17 for Lane 1 and in Figures 18 and 19 for Lane 2. As with the permanent and static deflection measurements, the greatest deviation from a regular pattern occurs in measurements made during early application of load cart passes. This irregularity is expected and reflects seating of the pipe and normal consolidation effects of the backfill material around the pipe. Other trends noted in the data are the same as those listed previously for static-load pipe deflections.

Nondestructive Testing

As would be expected, the FWD tests (Figures 5 and 6) conducted before the start of traffic (0 passes) show that Item 2 of Lane 2 was much stiffer than Item 2 of Lane 1. The FWD

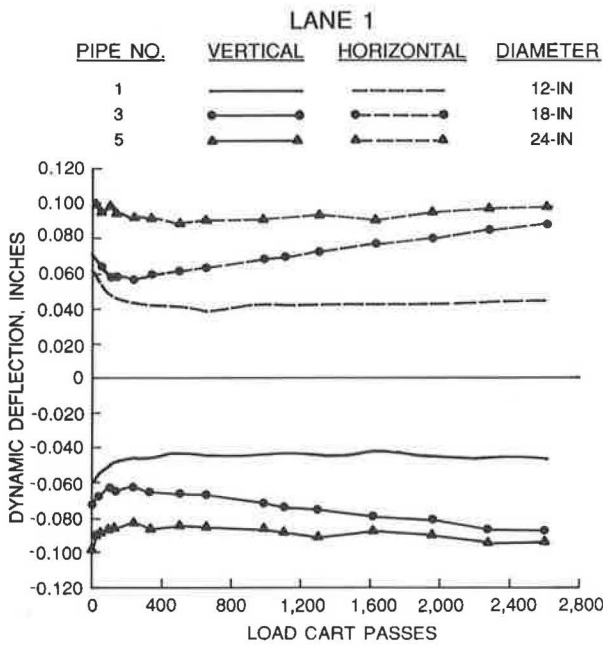


FIGURE 16 Lane 1 CSP dynamic deflection.

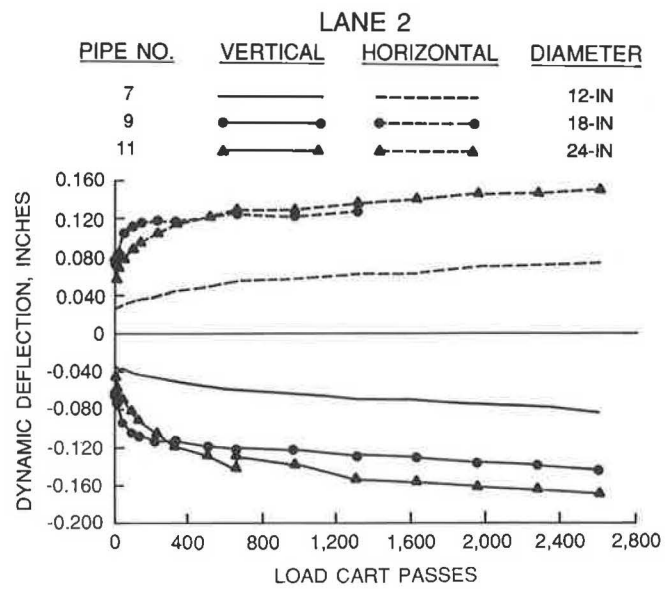


FIGURE 18 Lane 2 CSP dynamic deflection.

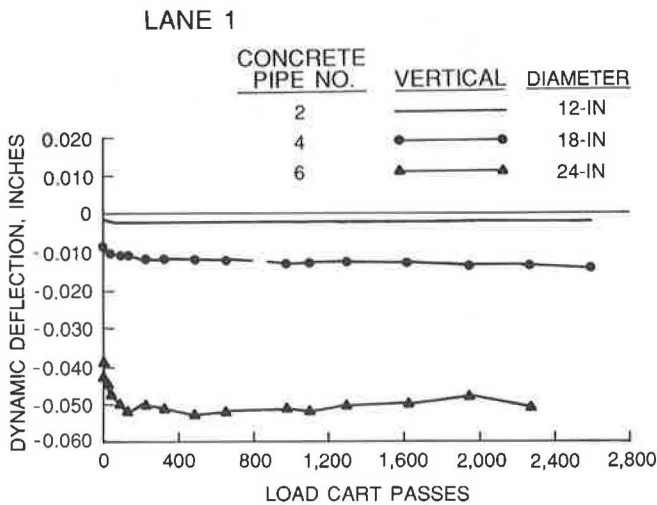


FIGURE 17 Lane 1 RCP dynamic deflection.

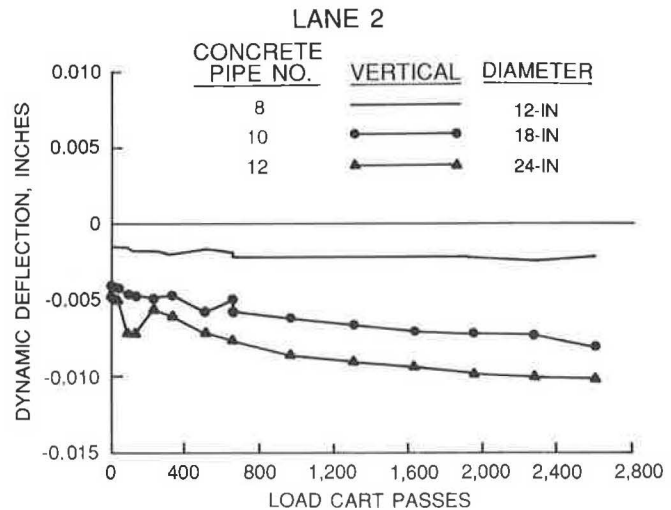


FIGURE 19 Lane 2 RCP dynamic deflection.

test data indicate, however, that cracking occurred in Lane 2, Item 2, with early test cart traffic (between 0 and 40 passes) with a resulting loss of stiffness. By the end of test traffic (2,600 passes), the FWD stiffness over the pipe centerlines gave less stiffness in Lane 2 than in Lane 1. This trend is very evident in tests conducted over the CSP. Some irregularity occurred in tests over the RCP, but in general, Lane 1 stiffnesses are greater than those in Lane 2.

ANALYSIS

A comparison of plots of permanent deformation and static-load deflection data shows the two sets of curves have similar trends. The permanent deformation and static-load deflections show rapid changes in the first 326 passes of the load cart and a more gradual and regular increase thereafter. This

trend is more pronounced with increased pipe diameter. The rapid initial changes in each of these cases probably reflect seating of the pipe and normal consolidation effects on the soil surrounding the pipe.

Comparison of the static- and dynamic-load deflection plots shows a very close similarity beyond 326 passes of the load cart; the deflection values for static and dynamic loads are approximately the same in this pass level range.

TOTAL PIPE DEFLECTIONS

The total deflection to which the pipe was subjected during the test is a combination of the permanent deformation and the deflection resulting from application of either the static or dynamic load. From the data presented previously, it can be seen that for all practical purposes a straight line can be

drawn through the data from approximately 326 passes of the load cart to 2,600 passes at the end of test. These two data points are tabulated in Tables 2 and 3 for permanent deformation, static load, and dynamic load. Also, shown on these tables are the total deflections in inches and in percent of pipe diameter.

As stated previously, there is little difference in static- and dynamic-load deflections. Although permanent deformations and static- and dynamic-load deflections generally show a gradual increase between 326 and 2,600 passes, the total diameter changes between 326 passes and 2,600 passes are relatively small. Thus, significant changes in total deflection can be expected only during early passes of the load cart and need not be expected beyond about 326 passes.

Vertical deflections in the CSP are greater than horizontal deflections in every case, as theory would predict.

MINIMUM COVER CRITERIA

Existing specific criteria for the minimum cover of pipe beneath the MX transporter are not available. However, criteria for aircraft loadings can be used to estimate the required cover. Criteria for the Air Force are found in TM 5-820-3 (3), where the MX transporter would be similar to a 100-kip twin-wheel load. The Federal Aviation Authority (FAA) also has criteria that would be helpful in estimating cover depths for the MX transporter. These criteria are found in AC 150/5320-5B (4) where the MX transporter falls between the 30-kip single-wheel and the 110-kip dual-wheel loadings. These criteria and

the comparison to the tests conducted are summarized in Tables 5 and 6.

SUMMARY AND CONCLUSIONS

Permanent pipe deformations increase gradually beyond 326 passes of the load cart, and even though static- and dynamic-load deflections also increase in the same pass range, the increases in total deflections are relatively small beyond about the first 326 passes.

A comparison of test results with airfield pipe cover requirements used by the Air Force and FAA revealed that the cover depths tested and the resulting performance of the pipe fall around the current criteria for similar aircraft loads.

Based on the test results, the minimum cover requirements shown on Table 7 are proposed. For CSP, the cover requirements are the same thicknesses as used in the actual test. One widely accepted failure criteria for CSP is that vertical deflection not exceed 5 percent of the pipe diameter. The CSP used in these tests sustained deflections less than 2 percent and were at no time in any structural distress.

Cracking is the accepted criteria for failure of RCP. Pipes 4 and 6 (Lane 1) cracked during installation, and Pipe 6 (24-in.) showed a working of this crack under repeated passes of the load cart. Pipe 2 (12-in.) did not crack. There was no cracking of the RCP in Lane 2. One complicating feature of the RCP tests is that the laboratory three-edge tests on RCP (from the same lot as those used in the traffic tests) showed that all exceeded ASTM requirements, especially for the smaller

TABLE 5 CSP MINIMUM COVER DEPTHS

Pipe No.	Pipe Diam. in.	Cover Test Depth in.	Cover Depth Existing Criteria (inches)	
			Air Force	FAA
<u>Lane 1</u>				
1	12	18	12	12 to 18
2	18	21	12	12 to 18
5	24	24	12	12 to 24
<u>Lane 2</u>				
7	12	15	24	30
9	18	18	24	30
11	24	21	24	30

NOTES:

- Cover depths are measured from the ground surface.
- Air Force criteria are for average bedding and backfill conditions and for a 100 kip twin wheel gear.
- FAA criteria is for excellent backfill and for a range of loadings from 30 kips single wheel to 110 kips dual wheel.
- CSP = corrugated steel pipe, 16 gage (2-2/3 in. by 1/2 in.) annular corrugations.
- Lane 2 is considered to be rigid pavement, requiring a minimum of 12 inches between the top of the pipe and the bottom of the slab.

TABLE 6 RCP MINIMUM COVER DEPTHS

Pipe No.	Pipe Diam. in.	Cover Test Depth in.	Cover Depth	
			Current Criteria (inches) Air Force	FAA
<u>Lane 1</u>				
2	12	27	54	12 to 30
4	18	24	50	12 to 30
6	24	21	48	12 to 30
<u>Lane 2</u>				
8	12	24	54	30
10	18	21	50	30
12	24	18	48	30

NOTES:

- Cover depths are measured from the ground surface.
- Air Force criteria are for average bedding and backfill conditions and for a 100 kip twin wheel gear.
- FAA criteria is for excellent backfill and for a range of loadings from 30 kips single wheel to 110 kips dual wheel.
- RCP = reinforced concrete pipe, ASTM C76, Class IV, Wall B.
- Lane 2 is considered to be rigid pavement, requiring a minimum of 12 inches between the top of the pipe and the bottom of the slab.

TABLE 7 RECOMMENDED MINIMUM COVER DEPTHS

Pipe Dia. In.	Cover Depth - in.	
	Lane 1	Lane 2
16 Gage CSP		
12	18	15
18	21	18
24	24	21
Class IV RCP		
12	36	33
18	30	27
24	24	21

NOTE: Cover depths are measured from the ground surface.

diameters. Thus, minimum cover requirements based on testing to failure of these RCP would be inconservative for RCP just meeting ASTM requirements. Design requirements and contract specifications can be based only on a known and specified standard, which in this case is a Class IV (2000 D-load) pipe. Thus, by testing a stronger pipe, the test results have to be adjusted (by adding required cover) back for the standard strength. For RCP, the proposed cover requirements are the test section thicknesses, plus an adjustment. Because

the pipe tested exceeded the actual strength specified by ASTM or other specifications, an adjustment of 9, 6, and 3 in. was added to the test cover depths for 12-, 18-, and 24-in. pipe diameters, respectively. The adjustment was determined by using the pipe strength cover depth pattern employed in the current Air Force airfield criteria (Headquarters, Department of the Army, 1978). No adjustment for backfill conditions was applied, as every effort was made to ensure that these installations conformed to the minimum Corps of Engineers

criteria. It was presumed that the designer would specify back-fill requirements and tests sufficient to achieve the minimum required by the Corps of Engineers criteria.

ACKNOWLEDGMENT

The authors are grateful to the U.S. Army Engineer Waterways Experiment Station for administrative support and permission to publish this paper. The views of the authors do not purport to reflect the position of the Department of the Army or the Department of Defense. This paper is published with the permission of the Chief of Engineers.

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DISCUSSION

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The authors' efforts in determining minimum fill height requirements for CSP and RCP under heavy wheel loads were flawed because the testing procedure, instrumentation, and theory utilized in the project contained serious defects.

The testing procedures and instrumentation used do not account for all possible actions and reactions of the pipe products. The use of only two displacement gauges in each CSP section will not register unsymmetric shape changes. If the CSP installations deform uniformly, as the authors suggest, than the horizontal and vertical displacement gauges will register accurate results. If the CSP installations, however, deform unsymmetrically (Figure 20), the two gauges will not indicate the excessive deflection. Additional displacement gauges would be necessary to detect all deflection variations. Unsymmetrical deflections are very significant because they may lead to cracking at the seams, thus affecting the ring compressive capacity and watertightness or soiltightness of the pipe.

The crack detectors used in the RCP are useful for determining when the where the first microcrack occurs, but have no benefit in assessing the structural capacity. The authors erroneously assumed cracking was an accepted criterion for failure of RCP. This error was further compounded by using 1/2-in.-wide strips of conductive paint for detecting cracks. The paint detectors were activated by hairline cracks and became inoperable after the first crack. The detectors could not identify the depth, width, and length of cracks. Cracking is essential for the proper performance of RCP and merely means

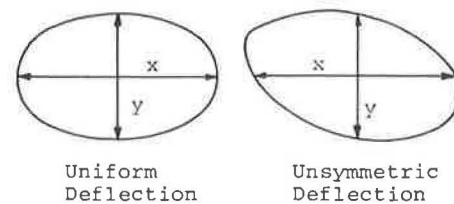


FIGURE 20 CSP instrumentation.

the steel has accepted the design tensile stresses. RCP that does not crack needs no reinforcement. According to the ASTM specifications on RCP, a 0.01-in. crack is a quality control test criterion for pipe tested in the three-edge bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions. In the test condition, RCP is designed for an ultimate strength of 1.25 to 1.5 times the 0.01-in. crack strength. In the buried condition, the ultimate strength of RCP is virtually unlimited, because if the pipe could be sufficiently overloaded, it would simply crack at the crown, invert, and springline and continue to function as a four-hinged arch flexible pipe transferring loads into the surrounding soil. Cracking, therefore, is not the accepted criterion for failure of RCP as the authors assumed.

If the authors' concerns with cracking were motivated by concerns of leakage, then the leakage performance of the research pipe barrels and joints should have been measured, both for the RCP and the CSP. Such measurements should have been made of the pipe before installation, after installation, and at intervals during the loading sequence.

The testing of CSP and RCP was done with an apparatus that simulated an MX missile transporter load and produced a maximum wheel load intensity of 91 psi, with the average estimated as 81 psi. Due to the fill heights, small pipe diameters, class of pipe, and type of installation used in the testing, however, the MX pipe loading will not produce any effects visibly different than those experienced by an AASHTO HS-20 wheel loading, which exerts a wheel load intensity of 80 psi. Although the AASHTO and MX loadings are both below those recommended for the pipe's strength class, the authors' minimum recommended fill heights differ dramatically from those recommended by AASHTO. It is also interesting to note that a previous Army Corps of Engineers report (1) on the subject found that with aircraft loadings or tire pressure intensities of approximately 250 to 300 psi there were no signs of distress on Class III RCP under 3 ft of fill. These loadings were more severe and the pipe was a strength class less than that used by the authors. The results of the previous Corps report appear to conflict with the authors' recommendations, especially for Lane 2, which is considered to be a rigid pavement.

The authors recommend increasing the cover requirements for RCP by an adjustment factor based on the fact the pipe tested exceeded the actual strength specified by ASTM. Several facts negate this recommendation. First and most significant, the pipe did not fail. Without a failure to provide a distinct reference point, the selection of any minimum fill height other than that tested would be simply a wild guess. The test sections were not instrumented correctly to predict a point of failure, and based on the authors' comments and previous studies on the subject, it is obvious that no failure took place under these test loadings.

Second, ASTM specifications on RCP are not installed performance specifications. The specifications are manufacturing standards intended to insure the pipe meets a uniform set of requirements regarding its material, manufacture, chemical and physical composition, and finish. Performance specifications (such as the AASHTO Standard Specifications for Highway Bridges—Section 17) define how a product, specifically reinforced concrete pipe, will react in an installed condition. The authors have obviously confused the two types of specifications. If the RCP was properly instrumented, the authors would have found that the moments, thrusts, and shears were well within the design limits for the cross-sectional parameters specified in the ASTM RCP specifications (ASTM C-76-88). The three-edge bearing test the authors relied on for predicting the D-load for the 0.01-in. crack cannot predict the complex relationships between moments, thrusts, and shears in an installed pipe. ASTM standards insure only that a pipe was made as specified. Performance specifications predict how a pipe product will react in a given installation but are applicable only for that specific installation. Arbitrary fill height adjustment factors cannot be made for a general installation or strength of pipe due to the wide variations with soils and installation properties. The authors' adjustment factors, therefore, have no validity.

REFERENCE

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DISCUSSION

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The paper reports the permanent, static, and dynamic deflections measured for various passes of a load cart with a front wheel load of 68,700 lb and a rear wheel load of 57,000 lb over pipes of three different diameters: 12, 18, and 24 in.; two different materials: corrugated metal and reinforced concrete (Class 4); two different soil cover materials: crushed lime stone and cement stabilized soil and arbitrary depths of soil cover over the pipe:

	Depth of Soil Cover (in.)	
	Lane 1 (crushed stone)	Lane 2 (soil cement)
12-in. pipe		
CSP	18	15
RCP	27	24
18-in. pipe		
CSP	21	18
RCP	24	21
24-in. pipe		
CSP	24	21
RCP	21	18

The final conclusion of the paper is that the test cover depths used in the tests are adequate for the CSP pipe, but that the minimum cover depths should be increased for the RCP pipe to the following values:

	Depth of Soil Cover (in.)	
	Lane 1 (crushed stone)	Lane 2 (soil cement)
12-in. pipe	36	33
18-in. pipe	30	27
24-in. pipe	24	21

The reasoning used as a basis for recommending the increased cover depth for the RCP pipe is extremely vague, but apparently is based on the fact that companion pipe to the test pipe developed substantially higher three-edge bearing strength than the minimum specified three-edge bearing strengths.

The above conclusions are not supported by the actual test results from the application of the specified wheel loads above the pipe at the shallower burial depths used in the test program. The RCP test pipe in Lane 1 was actually subjected to loads substantially higher than the test loads during installation of earth cover when a 100-ton roller was used to compact the top layer in a two-layer application of the specified crushed stone cover material. This excessive roller load produced hairline cracking (that was detected by traces of conductive paint) in the 18- and 24-in. RCP pipe test specimens. The authors erroneously refer to the occurrence of this cracking as "failure." They state that the RCP pipe has failed when it cracks.

The statement in the paper that cracking constitutes failure is inconsistent with the basis used for the design of nearly all reinforced concrete structures, as well as that used for the design of pipe in such widely used standards as ASTM C76 and Section 17.4 of Part 1 of the AASHTO *Bridge Specification*. The authors do not state the width of the observed cracks, but their statement that hairline cracks were observed implies that the width was much less than 0.01 in., the commonly accepted limit level of crack width in concrete pipe design practice.

The authors' conclusion that the RCP pipe requires a greater depth of special earth cover than that used in the test is totally without a basis. The test results demonstrate that this pipe safely withstands the much greater load of the 100-ton roller without failure and with acceptable crack control. The fact that their three-edge bearing strength was higher than the minimum specified value provides no basis for the recommendation to increase the minimum earth cover; it merely indicates that the tests did not provide enough information to provide conclusive evidence of the adequacy of pipe having the minimum levels of three-edge bearing strength. Furthermore, this recommendation flies in the face of the excellent performance of the RCP test pipe under the test loads, including its satisfactory resistance to the 100-ton roller load for the Lane 1 earth cover.

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