Effects of Heavy-Load Traffic on a Shallow-Buried Flexible Pipe

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A 12-ft long, 12-in. diameter, 16-gage corrugated metal pipe was installed in a trench, covered with 16 in. of material (1-in. layer of cold-mix asphalt, 5 in. of crushed limestone base course, and 10 in. of lean clay), and subjected to 350 coverages of a 50,000-lb single-wheel load to determine the effects of this simulated aircraft traffic on a shallow drainage-pipe installation. Two sets of deflection gages were placed in the test pipe, one at the midpoint the other near one end of the pipe. Each set consisted of two gages, one for measuring vertical deflection of the pipe, the other for measuring horizontal deflections.

During the tests, four types of deflection data were obtained: (a) deflection of the pavement over the pipe; (b) permanent deformation of the pipe resulting from application of traffic; (c) deflection of the pipe resulting from stationing the load wheel (statically) directly over the deflection gages; and (d) deflections of the pipe resulting from the load wheel passing (dynamically) over the deflection gages.

• THE TESTS reported herein are part of a general study of pipe action under load being conducted for the Corps of Engineers by the U. S. Army Engineer Waterways Experiment Station. The study includes model analysis of the many variables and conditions pertaining to the problem, and prototype testing to help translate results from the model studies to full-scale design criteria for drainage-pipe installations beneath airfield facilities and roads. The tests were directed particularly toward assessing the effect on a shallow-buried, flexible pipe of repeated passage of a heavy wheel load simulating an aircraft landing gear.

TEST EQUIPMENT

A 12-ft-long, 16-gage, standard corrugated metal pipe of nominal 12-in. inside diameter was buried beneath 16 in. of material (above the top of the pipe) and subjected to 350 coverages of a 50,000-lb, 200-psi tire pressure, single-wheel load. A coverage consists of sufficient passes of the load vehicle to cover completely the width of the lane being trafficked.

Two sets of deflection gages were placed in the test pipe, one at the midpoint and the other near one end. Each set consisted of two gages, one for measuring vertical deflection (or diameter change) of the pipe and the other for measuring horizontal deflection. (Pipe-diameter change will be referred to as pipe deflection throughout this paper.) The gages were made from electrical linear potentiometers (Bourns), and were connected to equipment (Brush) which yielded ink-trace records of deflections under dynamic conditions. Deflections under static conditions were read directly using electrical resistance-indicator equipment. In general, an increase in diameter is taken as positive deflection or deformation while a decrease in diameter is considered negative.

Figure 1 shows one end of the test pipe with gages installed; Figure 2 shows the test pipe in position before the trench was backfilled. The test rig used to load

Figure 1. End of test pipe with deflection gages installed.

Figure 2. Test pipe in position before backfilling of trench.

the pipe is shown in Figure 3. The rig consists of a load wheel supporting a load box, which is balanced by an unloaded yoke and pulled by a Super C Tournapull. The test tire has a gross contact area of 270 sq in., a 14-in. width, and a 24.5-in. length. This gives an average contact pressure of 185 psi.

The test pipe was offset with respect to the test section so that the gages in the pipe were well within the lane being trafficked. Figure 4 shows the position of the pipe and deflection gages with respect to the traffic lane. Standard corrugations of metal pipe are ½ in. in depth and are spaced 2⅔ in. center-to-center. Gages were mounted to measure between the crests of corrugations internally.

TEST SECTION

The test section, constructed in a hangar on a clay-silt subgrade, consisted of a 5-in. crushed-stone base and a 1-in. cold-mix asphaltic surfacing. Table 1 summarizes soil conditions in the test section just prior to application of traffic.

The pipe was installed in a 20-in.-wide trench that extended 25 in. into the subgrade. A 3-in. layer of sand was placed

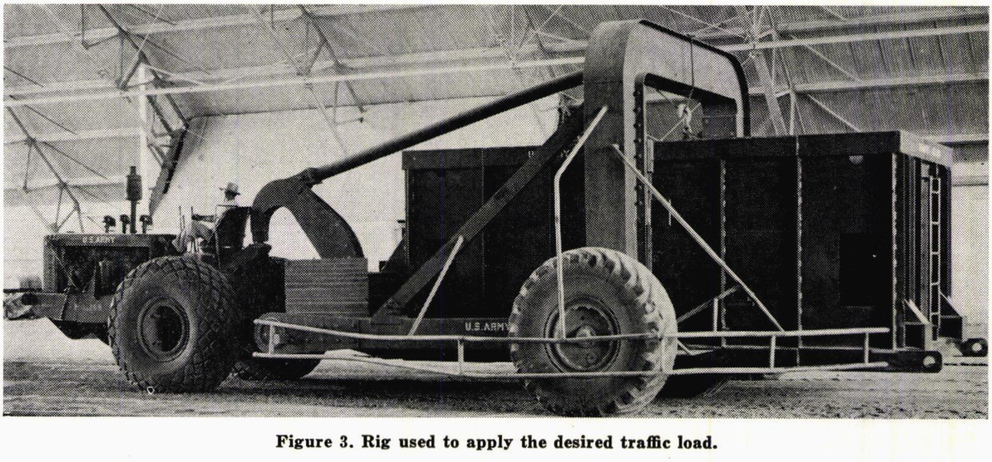

Figure 3. Rig used to apply the desired traffic load.

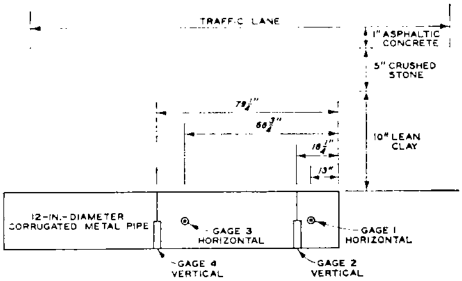

Figure 4. Cross-section of traffic lane, showing location of gages and test pipe.

in the bottom of the trench, and the pipe was placed on this sand layer. An additional 4-in. depth of sand was placed beneath the haunches of the pipe, and the remainder of the ditch was backfilled with lean clay subgrade material compacted to 89 percent AASHO maximum density. A 5-in. crushed-stone base and a 1-in. cold-mix pavement were placed over the backfilled ditch at the same time they were applied to the rest of the test area. Figure 5 shows a cross-section of the installation.

Although the test section was under a hangar, the end of the maneuver area was near an open end of the hangar, and a blowing rain that occurred prior to final paving wet the area and resulted in a reduction in the strength of the section of the traffic lane between the pipe and the end of the traffic area. This zone, which extended to within 1 to 2 ft of the pipe, required heavy maintenance and ultimately was covered with metal landing mat. Although this did not appear to affect the test, whether or not it caused adverse effects is not definitely known. Rutting occurred in the backfill over the pipe and was remedied by filling the ruts with crushed stone and covering the area with a thin membrane material.

DATA OBTAINED

During the tests, four types of deflection data were obtained, as follows.

1. Deflection of the pavement over the pipe.
2. Permanent (nonrecovering) defor-

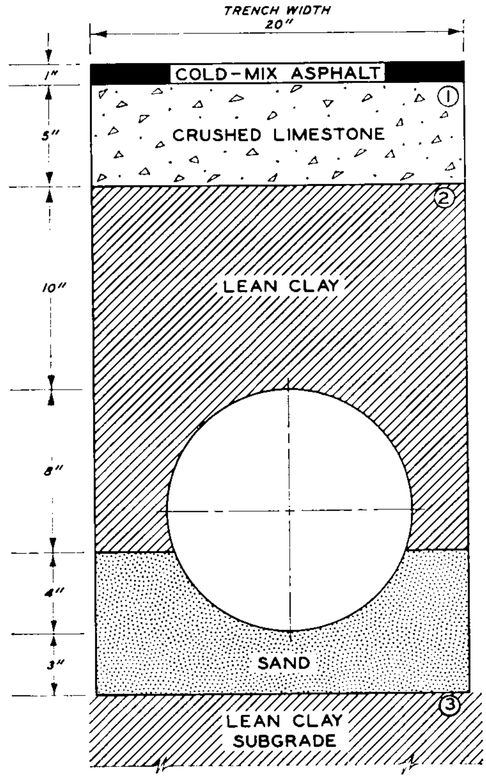

Figure 5. Cross-section of pipe installation. Samples to determine in-place CBR, water content, and density of the base, backfill, and subgrade taken at points 1, 2, and 3, respectively.

TABLE 1

SOIL CONDITIONS BEFORE TRAFFIC APPLICATIONS

Sample[1]	Material	CBR	Water Content (%)	Dry Density (pcf)	Dry Density % Mod. AASHO
Base	Crushed limestone	78	1.8	143.8	97.8
Top of backfill	Lean clay	31	12.2	103.6	89.0
Subgrade beneath pipe	Lean clay	13	15.6	87.2	75.0

[1] Sample taken from top of each element (see Fig. 5).

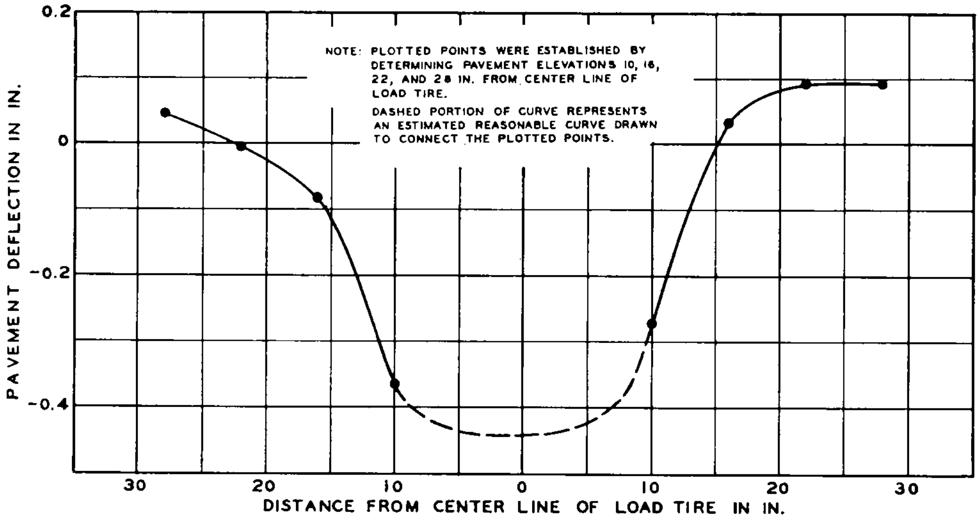

Figure 6. Deflection of pavement under stationary load.

mation of the pipe resulting from application of traffic.

3. Deflection of the pipe resulting from the load wheel standing (statically) directly over the deflection gages.

4. Deflection of the pipe resulting from the load wheel passing (dynamically) over the deflection gages.

Pavement Deflection

To measure pavement deflection over the test pipe, the wheel of the load rig was placed directly over the pipe. Pavement elevations were then determined at a point as near to the load tire as possible, which was 10 in. from its centerline, and 6, 12, and 18 in. out from this point perpendicular to the tire path and opposite the midpoint in the direction of travel. Standard surveying methods were used except that a special short level rod and level tripod were used to gain a line-of-sight beneath the load box of the test vehicle. Next the load rig was rolled away, and elevations were again read at the same points. The difference in the two elevations, at each point, is the pavement deflection.

These pavement deflections are the maximum static-load deflections for the various offset positions at which measurements were made. Since no measurements were possible directly under the wheel, it is of interest to plot deflection versus offset position and connect the points with a reasonable curve to obtain an indication of the greatest deflection that occurred (Fig. 6).

Since surface disturbance of the test section began with the first application of traffic and became severe rather quickly, pavement deflections were obtained only prior to application of regular test traffic.

Permanent Pipe Deformation

The deflection gages used to record pipe-diameter changes were read initially with the pipe in place in the trench prior to backfilling. With this as a zero reading, the gages were read periodically throughout the application of traffic, and the changes in diameter were recorded. This procedure gave a record of the effect of traffic of the load vehicle on the installation but did not directly reflect the effect (deflection) of the load. Table 2 gives the permanent deformation measurements. The measurements at 0 coverages represent deflections due to the weight of overburden.

TABLE 2

SUMMARY OF PERMANENT DEFORMATIONS RECORDED

Coverages	Change in Pipe Diameter, in.							
	Gage 1, Horiz.		Gage 2, Vert.		Gage 3, Horiz.		Gage 4, Vert.	
	Incremental	Total	Incremental	Total	Incremental	Total	Incremental	Total
0[1]	+0.020	+0.020	−0.028	−0.028	−0.039	−0.039	−0.019	−0.019
12	+0.088	+0.108	−0.085	−0.113	+0.004	−0.035	−0.104	−0.123
40	+0.049	+0.157	−0.047	−0.160	+0.004	−0.031	−0.010	−0.133
44	+0.014	+0.171	−0.019	−0.179	−0.005	−0.036	−0.007	−0.140
88	+0.002	+0.173	−0.005	−0.184	+0.002	−0.034	−0.012	−0.152
142	+0.008	+0.181	−0.008	−0.192	−0.007	−0.041	−0.002	−0.154
176	+0.006	+0.187	−0.014	−0.206	−0.003	−0.044	−0.008	−0.162
218	+0.007	+0.194	−0.001	−0.207	−0.011	−0.055	−0.005	−0.167
270	+0.003	+0.197	−0.010	−0.217	−0.008	−0.063	+0.004	−0.163
322	+0.002	+0.199	−0.005	−0.222	−0.004	−0.067	−0.009	−0.172
350	+0.002	+0.201	−0.014	−0.236	−0.003	−0.070	−0.004	−0.176

[1] Deformation due to weight of overburden.

Static-Load Pipe Deflection

Prior to and periodically during test traffic, the load cart was placed with the load tire directly over a point midway between each pair of gages (Fig. 7). The change in pipe diameter caused by this load being placed over the gages is given in Table 3, which also gives the portion of this deflection which remained as permanent deformation after the load was removed.

Dynamic-Load Pipe Deflection

Automatic recording equipment was used with the deflection gages to indicate the change in pipe diameter resulting from passage of the load over the gages. Figure 8 shows typical traces produced by the recording equipment.

Deflections were recorded for the first four to six coverages at the start of traffic each day. The traces were analyzed, and the average recorded deflections determined (Table 4).

Pipe Movement

Elevations were taken on the top of the test pipe at the times of placement and of removal of the pipe after testing. These measurements showed the top of the pipe moved downward about 1 in. during testing. Since permanent vertical deformations (as shown in Table 2) are

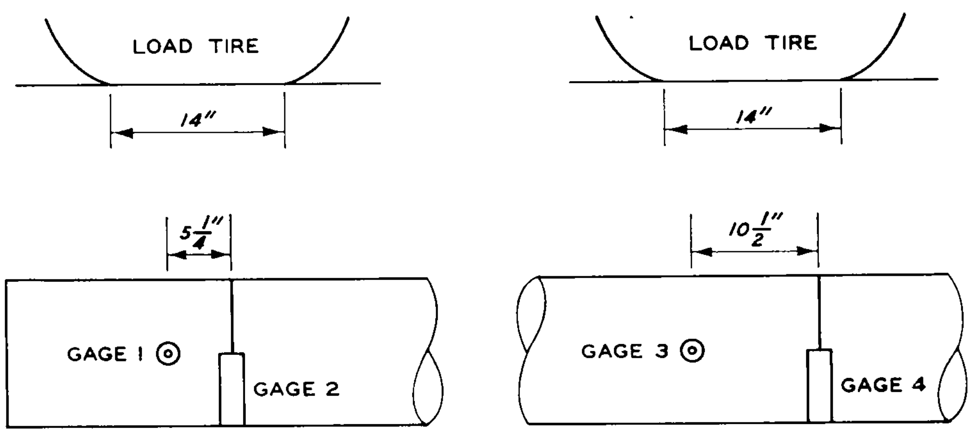

Figure 7. Position of static load over gages.

TABLE 3

SUMMARY OF STATIC-LOAD DEFLECTIONS[1]

Coverages	Change in Pipe Diameter, in.							
	Gage 1, Horiz.		Gage 2, Vert.		Gage 3, Horiz.		Gage 4, Vert.	
	Defl.	Perm. Set	Defl.	Perm. Set	Defl.	Perm. Set	Defl.	Perm. Set
0	+0.304	+0.123	−0.253	−0.098	+0.188	+0.048	−0.163	−0.028
40	+0.187	+0.026	−0.203	−0.022	+0.117	+0.003	−0.236	−0.037
175	+0.163	+0.003	−0.191	−0.003	+0.135	+0.016	−0.177	−0.020
270	+0.162	+0.023	−0.184	−0.013	+0.127	+0.001	−0.157	−0.001
350	+0.157	+0.003	−0.188	−0.013	+0.154	+0.002	−0.175	−0.014

[1] See Fig. 7 for position of static load over gages.

less than ¼ in., most of the measured movement must have resulted from pipe embedment.

GENERAL STRENGTH OF THE INSTALLATION

The pipe installation tested was purposely made less conservative than current design criteria require in order to approach more nearly (or possibly to obtain) a pipe failure condition. Present pipe-cover requirements, as given in Corps of Engineers EM 1110-345-283, Drainage and Erosion Control Structures for Airfields, are for 27 in. of material over the top of a 12-in.-diameter, 16-gage metal pipe that will be subjected to a 50,000-lb wheel load. Present requirements published in the ARMCO Handbook of Drainage and Construction Products for this type of pipe and load are for 26 in. of material covering the pipe. The installation tested had only 16 in. of material above the pipe, and this was reduced somewhat by surface rutting.

TABLE 4

SUMMARY OF DYNAMIC-LOAD DEFLECTIONS

Coverages	Change in Pipe Diameter, in.			
	Gage 1 Horiz. Defl.	Gage 2 Vert. Defl.	Gage 3 Horiz. Defl.	Gage 4 Vert. Defl.
1 to 6	+0.16	−0.23	+0.14	−0.14
13 to 16	+0.18	−0.22	+0.16	−0.21
41 to 44	+0.09	−0.13	+0.11	−0.14
47 to 52	+0.15	−0.21	+0.12	−0.20
91 to 96	+0.08	−0.15	+0.14	−0.18
143 to 148	+0.17	−0.20	+0.13	−0.17
177 to 182	+0.15	−0.18	+0.12	−0.20
219 to 224	+0.15	−0.18	+0.14	−0.17
271 to 276	+0.14	−0.18	+0.13	−0.16
323 to 328	+0.13	−0.17	+0.12	−0.15
347 to 350	+0.11	−0.13	+0.13	−0.16

Since the test pipe was at no time in distress from overloading, it can be concluded that, from the standpoint of protection of a pipe from structural failure, the tests indicate that current design criteria are conservative.

On the other hand, the surfacing over the pipe was considerably disturbed by the test traffic. Although wetting of part of the test section may have aggravated the surface failure, the pavement deflection over the pipe prior to application of traffic (Fig. 6) was of such magnitude as to indicate the likelihood of pavement failure. Part of this surface deflection reflects the embedment of the test pipe into its bedding an amount between ¾ in. and 1 in., as indicated previously. Another part reflects the surface deflection to be expected from a load of this magnitude on a pavement structure which does not include a buried pipe. However, since deflection of the pipe probably accounts for part of this surface deflection, it appears that, from the standpoint of protection of the pavement above the pipe from failure, the 16 in. of cover over the pipe may have been inadequate.

Pavement Deflection

The data in Figure 6 indicate a maximum pavement deflection of 0.44 in. This value can only be accepted as approximate since the dashed portion of the curve could have been drawn in such a way as to give a somewhat higher or lower value. As already mentioned, however, this magnitude of pavement deflection can usually be considered to result in a pavement failure.

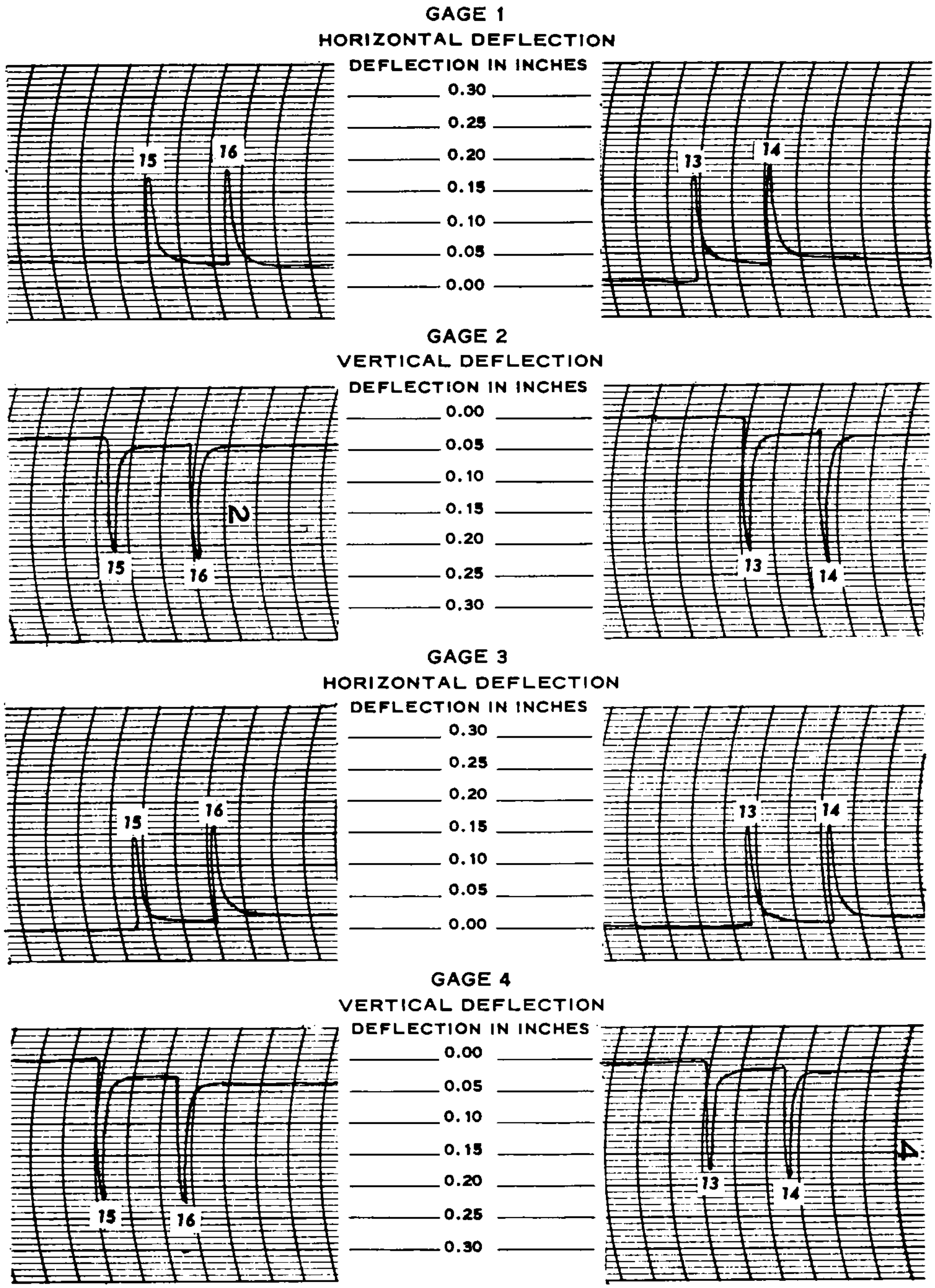

Figure 8. Typical dynamic-load deflections.

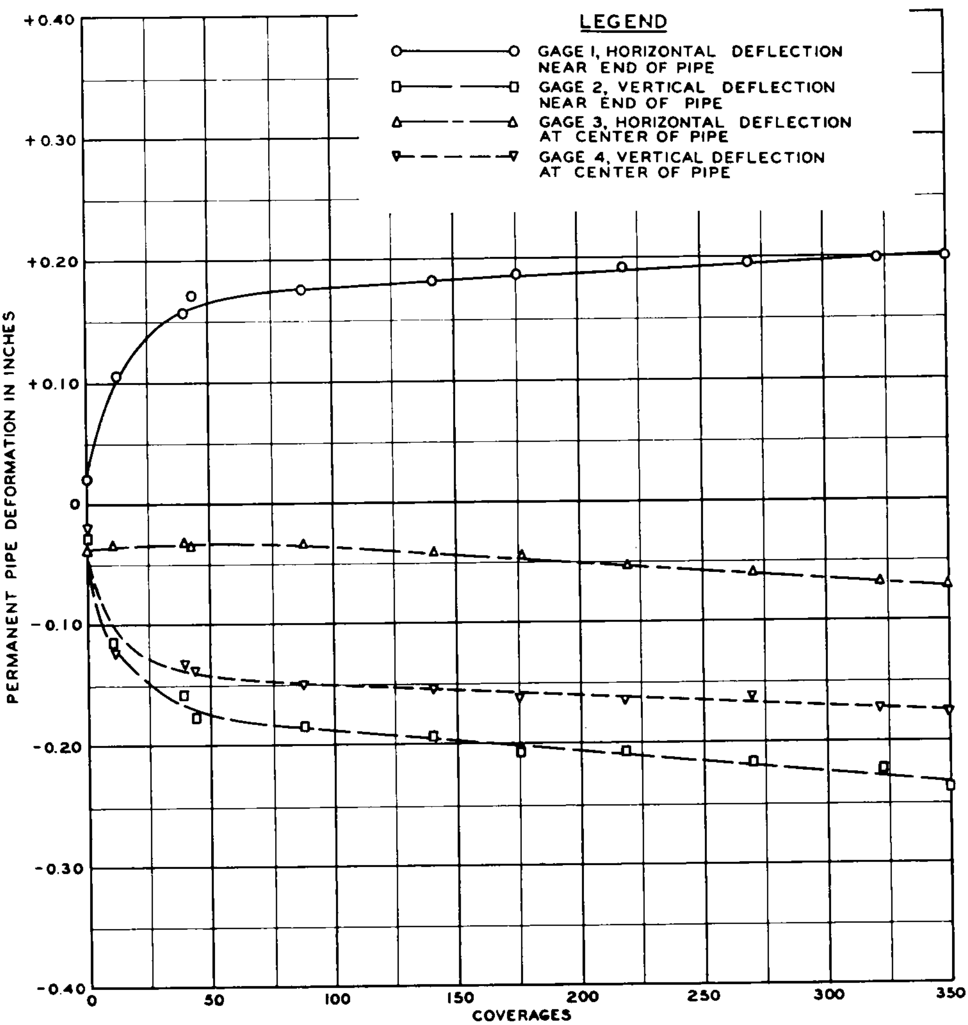

Figure 9. Permanent pipe deformation.

Permanent Pipe Deformation

The permanent deformations of the pipe as recorded at the four gage positions (Table 2) are shown in Figure 9. The pattern is consistent for gages 1, 2, and 4, which define the horizontal and vertical diameter changes near the end of the pipe and the vertical diameter change at the center of the pipe, respectively. The data obtained at these three gages indicate that as the number of traffic coverages increased, the vertical diameters of the pipe decreased and the horizontal diameters increased. However, gage 3, which measured the horizontal diameter at the center of the pipe, gave data that were inconsistent with other results and with expected action of the pipe. These data indicated a shortening of the horizontal diameter at the same time the vertical diameter was shortening. This could occur only if the pipe was being deformed toward a square-shaped cross-section, which is possible but quite unlikely. Subsequent re-examination of

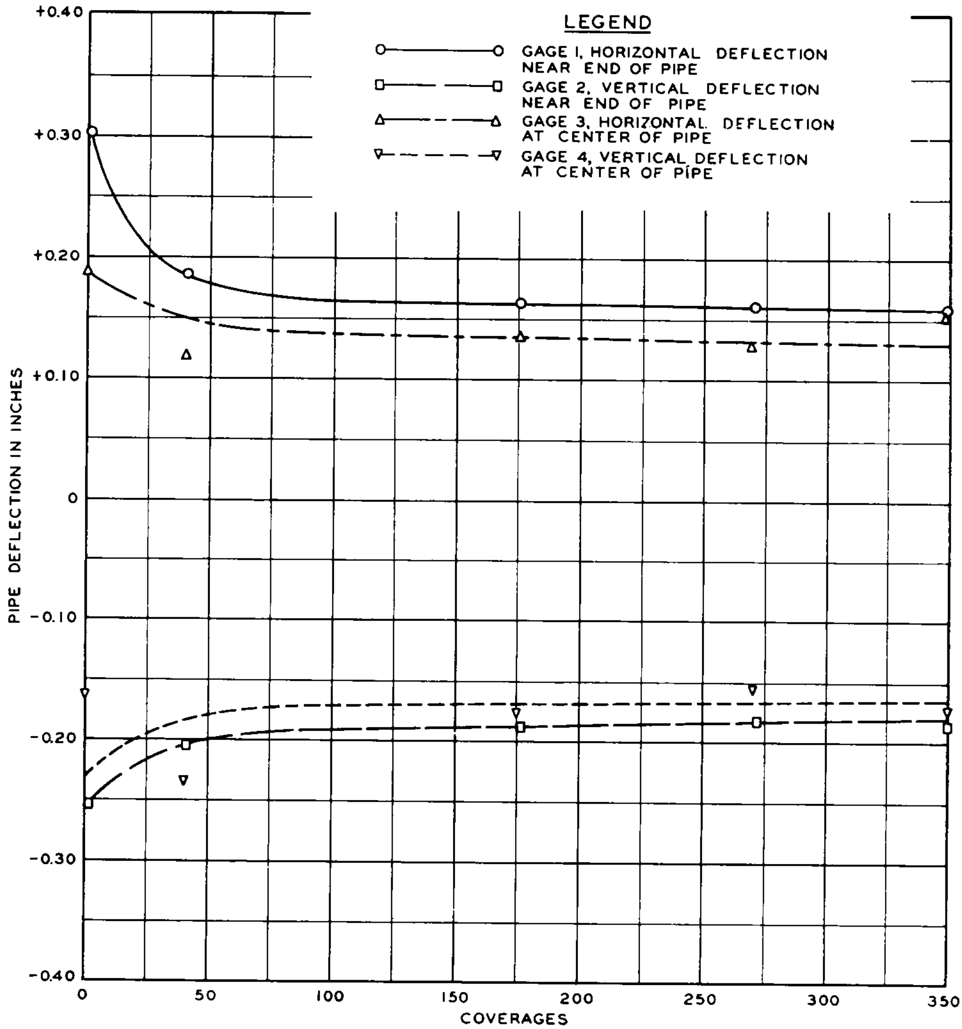

Figure 10. Static-load pipe deflection.

the data disclosed no error in the handling of these data; nevertheless they remain suspect.

In general, the plots in Figure 9 show relatively large successive increases in deformation during application of the early coverages and then a consistent gradual increase to the end of the tests.

Static-Load Pipe Deflection

Deflections under the stationary load positioned over the gages (Table 3) are plotted in Figure 10. They show a regular and consistent pattern. During the application of the early coverages, a large portion of the total deflection was nonrecoverable, permanent set or deformation. This agrees closely with the pattern of permanent deformation shown by Figure 9, and in this range some irregularity of the pattern is to be expected and is found (Table 3). It was also during application of the early coverages that heavy maintenance of the surface was required. This no doubt also contributed to

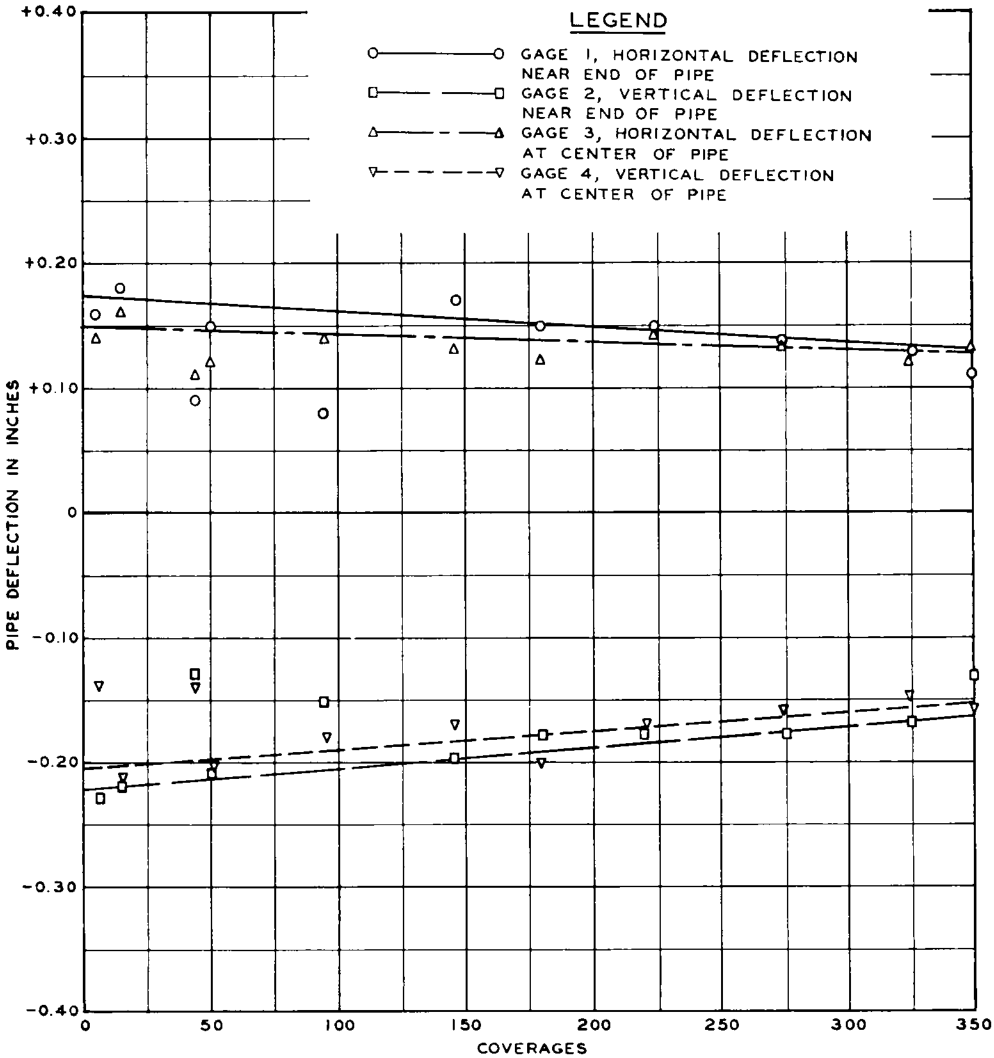

Figure 11. Dynamic-load pipe deflection.

irregularity in the deflection pattern. For the remainder of the test, total deflections gradually decreased in a regular pattern with increase in coverages. In these tests the data from gage 3 are entirely consistent with that from gages 1, 2, and 4.

Dynamic-Load Pipe Deflection

Deflections measured under the moving load (Table 4) are shown in Figure 11. The plots reflect an effect of the way in which the load was applied. The movement of the load wheel along successive parallel wheel paths to obtain complete coverage of the test section was controlled only by guidelines and the skill of the load rig operator. It was not possible to insure that, for each coverage during which a measurement was taken, the pass of the load was directly over the gage as intended. Accordingly, maximum gage readings for the load applied are not necessarily the maximum readings that would have resulted had the load been directly over the gage. The curves through the plotted data have therefore been drawn to reflect a visual average of the maximum points. As in Figures 9 and 10, the greatest deviations from a regular pattern occurred during the early coverages. In these tests, also, the gage 3 data appear to be consistent with the rest of the data.

The largest vertical deflections experienced were of the order of 0.22 in. It was previously noted that static-load deflection of the pavement over the pipe prior to initiation of traffic was 0.44 in.

COMPARISON OF DEFORMATION AND DEFLECTION DATA

Plots of the curves from Figures 9-11 are grouped in Figure 12 for comparison of the individual curves and sets of curves. Also, the individual curves are plotted together with respect to magnitude of deflection without regard to whether an increasing or decreasing pipe diameter is represented.

This treatment makes all curves in each group follow generally parallel paths except the gage 3 curve defining permanent pipe deformation which is not completely consistent with the other curves, as mentioned previously. In the two lower plots (Fig. 12) vertical deflection near the end of the pipe is the greatest, vertical deflection at the center of the pipe is second largest in magnitude, horizontal deflection near the end of the pipe is third, and horizontal deflection at the center of the pipe least in magnitude. In the top plot, that for permanent pipe deformation, the horizontal deflection near the end of the pipe is greater than the vertical deflection at the center.

A comparison of the plots of permanent deformation and static-load deflection data (Fig. 12) shows the two sets of curves to have opposite trends. The permanent deformation shows a rapid increase in the first 50 coverages and a more gradual and regular increase thereafter. The static-load deflection shows a rapid decrease in the first 50 coverages and a more gradual and regular decrease thereafter. 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 remarkable similarity beyond about 50 coverages. It may be concluded that for practical purposes the static- and dynamic-load deflections are the same in this coverage range. In the low coverage range (less than 50), however, the static-load deflection shows high initial values and then gradually decreasing values until the curve settles into the pattern that is apparent beyond 50 coverages. The dynamic-load deflections show a consistent pattern throughout the entire coverage range. Table 3 shows that for the initial range in which values of the static-load deflection are high, values of the nonrecoverable deflection (permanent set) are also high. This suggests that the initial rapid adjustments of the static-load deflection (and perhaps also the permanent deformation) may be time-dependent adjustments not reflected in the dynamic-load measurements.

TOTAL PIPE DEFLECTIONS

The total deflection to which the pipe in these tests was subjected is a combination of the permanent deformation, as indicated in the upper plot in Figure 12, and the deflection resulting from application of either a static or a dynamic load, as indicated in the two lower plots. In each plot, the curves drawn through the data points are straight lines between about 100 and 350 coverages (the end of the test). Because these curves are all straight lines in this coverage range and because total deflections at lesser coverages are in no case greater than those for 100 coverages, it was not considered necessary to develop plots of the total deflections.

Deflections or deformations have therefore been read from the plots in Figure 12 at 100 and 350 coverages and combined to indicate total pipe deflections. The results are given in Table 5. As stated previously, there is no significant

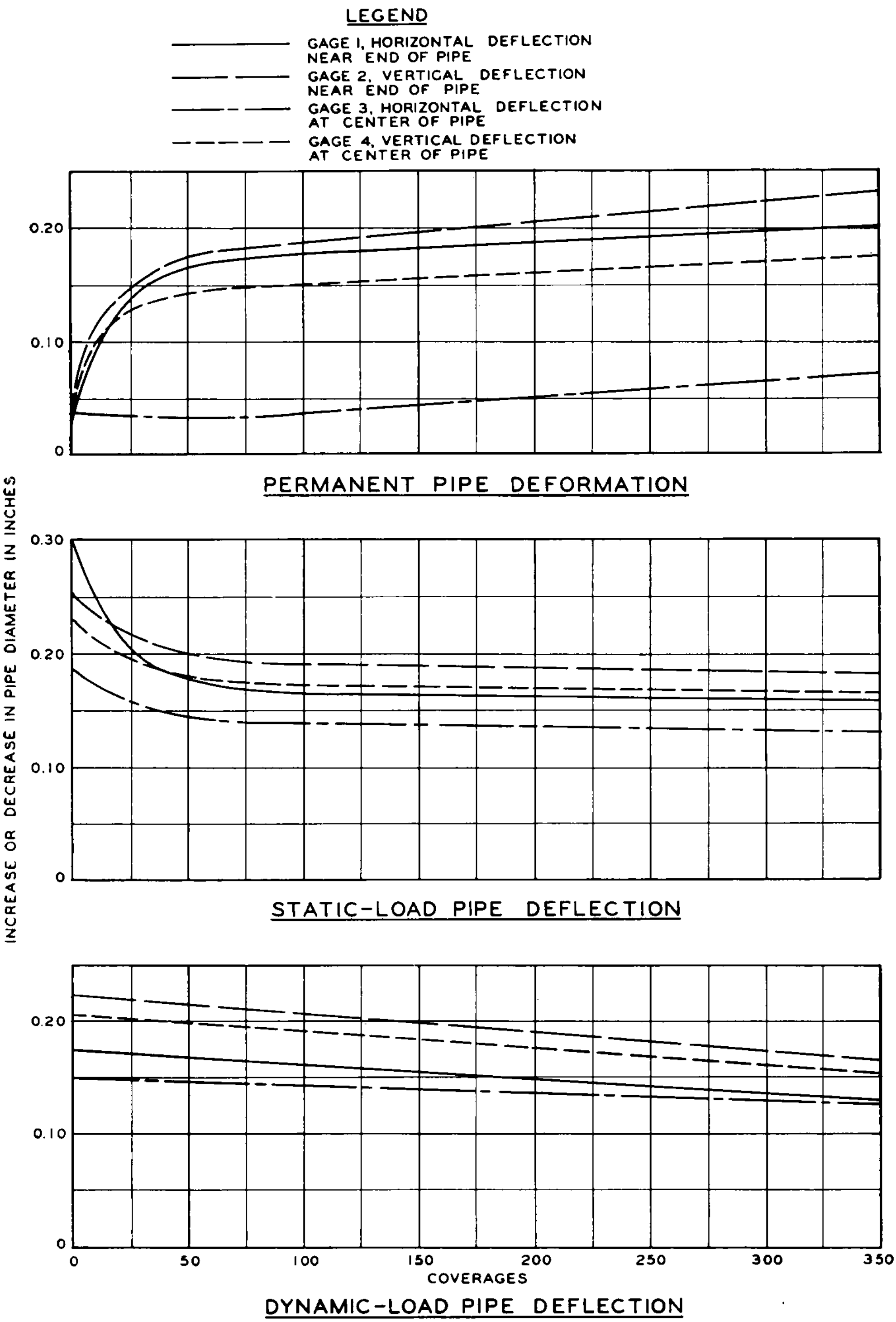

Figure 12. Comparison of pipe deformation and deflection.

TABLE 5

TOTAL PIPE DEFLECTIONS

Gage	Coverages	Change in Pipe Diameter (in.)				
		Perm. Deform., a	Static-hood Defl., b	Dynamic-hood Defl., c	$a + b$	$a + c$
1	100	0.179	0.164	0.161	0.343	0.340
	350	0.202	0.158	0.130	0.360	0.332
2	100	0.188	0.190	0.206	0.378	0.394
	350	0.231	0.180	0.164	0.411	0.395
3	100	−0.039[1]	0.138	0.142	0.099	0.103
	350	−0.070[1]	0.130	0.127	0.060	0.057
4	100	0.151	0.171	0.190	0.322	0.341
	350	0.174	0.165	0.153	0.339	0.327

[1] Deformation opposite to pattern reflected by all other readings.

difference between the deflections for static and dynamic loads, and comparison of the bottom two lines in Table 5 verifies this. The inconsistency of the permanent deformations recorded at gage 3 is again reflected here. Excepting the gage 3 data, the total deflection experienced by the pipe is between 0.322 in. and 0.411 in., which are 2.7 and 3.4 percent, respectively, of the nominal pipe diameter.

The total diameter changes are not significantly different at 350 coverages than at 100 coverages. While permanent deformation is increasing between 100 and 350 coverages, both static and dynamic load deflections show a compensating decrease between 100 and 350 coverages. Thus, it is concluded that significant changes in total deflection need not be expected beyond 50 to 100 coverages.

The relative magnitudes of deflections measured by the various gages can be compared in Figure 12. Deflections are greatest near the end of the pipe, where the added support of adjacent parts of the pipe is effective on only one side, and least at the center where added support is effective on both sides. Also, vertical deflections are generally greater than horizontal, as theoretical treatments indicate they should be.

CONCLUSIONS

The 12-in.-diameter, 16-gage, corrugated metal pipe used in these tests sustained deflections of generally less than 3.4 percent and was at no time in any distress structurally. Since this pipe was protected by only 16 in. of cover whereas current, generally accepted criteria require 26 or 27 in. of protective cover to sustain a 50-kip load, and since up to 5 percent deflection of a pipe is generally accepted as tolerable, it may be concluded that present requirements (for the conditions tested in this study) are conservative in regard to protection of the pipe itself. It must be realized, however, that the surface deflection that accompanied and may have been contributed to by the 0.3- to 0.4-in. pipe deflections sustained in these tests are probably too great to be tolerated in a pavement. The tests conducted did not permit a good evaluation of the surface-deflection factor.

Other observations that may be made, based on the results of this study using a 12-in.-diameter, 16-gage, corrugated metal pipe, are as follows:

1. The application of static and of very slowly moving loads on shallow-buried pipe gave essentially the same values of measured deflections.
2. Permanent deformations increase somewhat beyond 50 coverages but live-load deflections decrease in the same range and compensate; consequently, total deflections did not significantly increase with application of traffic beyond about the first 50 coverages.