Field Performance of Corrugated Polyethylene Pipe Culverts in Ohio

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A total of 172 corrugated polyethylene pipe culverts 12 through 24 in. in diameter and ranging in age from 0 to 4 years were inspected in Ohio in the summer of 1985. Data pertinent to structural performance and durability of the culverts were collected at each site. These data were pipe diameter, cover over the pipe, type of backfill, culvert age, average daily traffic, pipe deflection, flow depth and velocity, bed load depth and size, water pH, and pipe slope. No culvert showed any signs of wear even at sites with abrasive flow. One 4-year-old site had constant low pH dry weather flow with a bed load of large cobbles. The incidence of large maximum deflections or wall flattening and buckling, or both, was significantly greater for 12- and 15-in. pipes than for 18- and 24-in. pipes. The only instances of wall flattening or buckling were limited to the 12- and 15-in. culverts. Large deflections, flattening, and buckling were generally due to bending of the pipe wall in both the circumferential and longitudinal directions. The greater flexibility and thinner walls of the 12- and 15-in. culverts were the only apparent reasons for the difference in performance.

Because of recent concern of governmental agencies about the nation's deteriorating infrastructure *(1–3)* many highway agencies have placed increased emphasis on repairing or replacing deteriorating bridges and roadway culverts. This concern has been reflected by the numerous recent reports on culvert durability *(4–8)*.

Corrugated polyethylene pipe has been suggested as a feasible material for small culvert replacement because of its ease of handling and corrosion resistance to most normal stream flows. Current available culvert pipe sizes range to 24 in. in diameter. The pipe is normally provided in 20-ft lengths. The most common concern about the use of corrugated polyethylene pipe for culvert replacements is its structural performance under highway loadings.

Considerable laboratory testing of tubing and pipe, and field testing of pipe installed with controlled backfill procedures, has been carried out *(9–14)*. The results of this work have been used to establish a theoretical required ring stiffness ($53.77EI/D^3$, as defined in the Iowa deflection formula) for various pipe diameters based on an allowable deflection of 5 percent. Deflections in excess of 25 percent can occur without buckling (reversal of curvature); failure of the ring occurs if adequate sidewall support is available. However, there is still concern about the use of these design criteria for real-world culvert installations with less than optimal "uncontrolled" backfill procedures.

Several Ohio Department of Transportation (ODOT) districts and Ohio county engineers have been using corrugated polyethylene pipe for small culvert replacements on a provisional basis since 1981. Use of this material by ODOT and the county engineers contacted has been limited to 12- through 24-in. sizes. Most culvert installations have been on secondary highways with no more than 6 ft of shallow cover.

Because there was concern regarding the structural capability of corrugated polyethylene pipe installed under pavement with uncontrolled backfill procedures, seven of the early culvert installations in Ohio were measured shortly after construction to determine deflection. There were no structural problems observed in any of the culverts measured. Measured deflections ranged from negative (i.e., crowning of the pipe) to approximately 8 percent.

Because the few corrugated polyethylene pipe culverts previously evaluated were nearly new when measurements were taken, there was still some question regarding the longer-term effects of live loading on the structural performance of these culverts. Updated measurements on these culverts would be required to determine if there was any effect of long-term live loading. That these culverts were also the first of their type installed may also have led to "more careful" than normal installation procedures. Thus there was some question whether these installations were representative of true maintenance replacement procedures. A broader data base would be required to determine to what degree corrugated polyethylene pipe culverts were "installation proof." In addition to structural performance, the ability of the pipe material to withstand abrasive flows was of interest because of the questionable performance of polymeric coatings of metal pipe at abrasive flow sites *(5–8)*.

Therefore, as part of ODOT's continuing culvert performance evaluation program, the structural and durability performance of all existing known corrugated polyethylene pipe culverts installed in the state of Ohio was evaluated. This study was undertaken in February 1985 and completed in August 1985.

CULVERT INVENTORY

To provide a data base for the study, all ODOT district maintenance engineers and Ohio county engineers who had purchased corrugated polyethylene pipe from a local supplier were contacted and asked to provide a list of culvert locations. Culvert locations were obtained from five ODOT field districts and five county engineers.

A total of 172 culverts were inspected in 21 counties in Ohio. Twenty-eight 12-in., ninety-two 15-in., thirty-one 18-in., and twenty-one 24-in. culverts were inspected. The number of culverts of each specific size in each county is shown in Figures 1 and 2.

DATA COLLECTION

A total of 3 weeks of field work by a two-man team was required to collect field data for the 172 culverts inspected. In addition to the culvert site inspection several members of ODOT district and local

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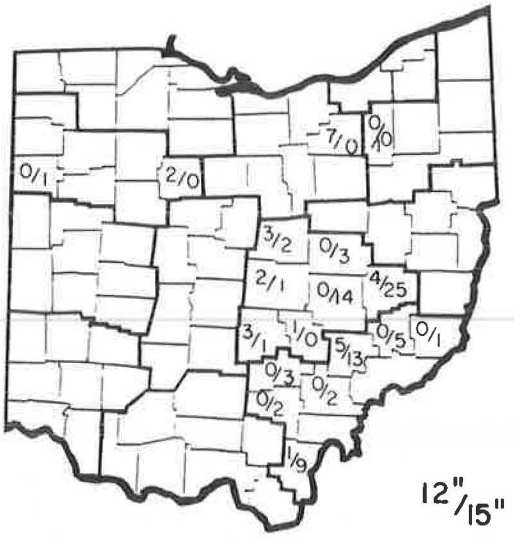

FIGURE 1 12- and 15-in. corrugated polyethylene pipe culverts in Ohio.

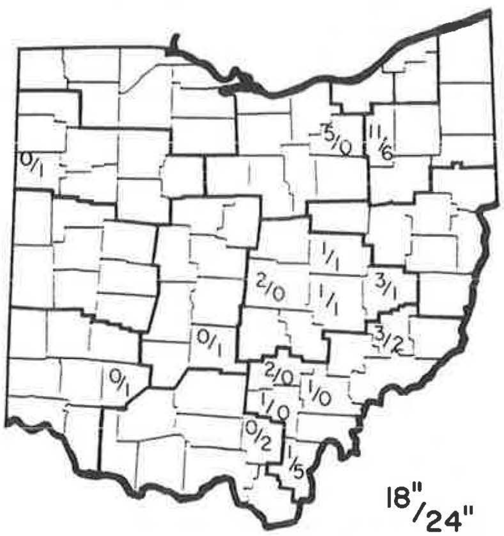

FIGURE 2 18- and 24-in. corrugated polyethylene pipe culverts in Ohio.

county engineers' staffs were contacted in person or by telephone to obtain traffic counts and other additional information regarding culvert installations. The following information, pertinent to the structural performance and durability of corrugated polyethylene pipe culverts, was obtained during the field data collection phase.

Pipe Diameter

The pipe diameter of each culvert provided on the culvert inventory was verified at the site. As previously indicated, pipe sizes were 12, 15, 18, and 24 in.

Cover over Pipe

The cover from crown to road surface over each culvert provided on the culvert inventory was visually verified at the site. If this information was not provided on the inventory or provided incorrectly, the cover was measured at the site. Pipe covers ranged from less than 6 in. to 6 ft. Various installation specifications require a minimum cover of from 12 to 18 in.

Type of Backfill

The type of culvert backfill or bedding material, or both, was obtained from ODOT or county personnel or visually determined at each site. Additional specific information related to bedding and backfill procedures at each site was not available because the culverts inspected were "real-world" maintenance installations. The installations are usually done hurriedly under maintained traffic. Conformance with ODOT construction specifications varies from site to site even within an individual county. Normally mechanically tamped backfill in shallow lifts is not used as often as large lifts "compacted" by saturation with water. A distinction was made among five different types of backfill material: crushed limestone, sand and gravel, a mixture of ash and stone, miscellaneous granular material, and native soil.

Age of Culvert

The installation dates of culverts were obtained from the culvert inventory. If the site inspection indicated a gross error in the inventory, the age was adjusted. New installations were considered to be installed in late spring of 1985. Ages ranged from 0 to 4 years.

Average Daily Traffic

The average daily traffic total of cars and trucks was obtained from ODOT published traffic counts for state highways and from county engineers for county highways. Average daily truck traffic ranged from 2 to 480 vehicles per day. Average daily car traffic ranged from 20 to 4,800 vehicles per day. One section of highway with several installations had frequent coal truck traffic. None of the culverts observed on this section of highway showed any sign of structural problems. Several culverts were inspected when coal trucks passed over them and no apparent movement was observed. Cover over these culverts ranged from less than 1 to 4 ft.

Culvert Alignment

Changes in vertical or horizontal alignment, or both, of the culverts were noted. Because of the longitudinal flexibility of corrugated polyethylene pipe, minor changes in culvert grade or direction can be accomplished by "bending the pipe." An increase in pipe deflection was not noticed with a gradual transition accomplished by a long bend. However, a slight increase in deflection was observed at quick changes in grade. Shear loading points such as soil settlement behind retaining walls or soil slip planes were also noted (Figure 3). Considerable increases in deflection were observed at these points. Buckling of the ring section was observed at a soil slip plane on one culvert, but the remainder of the pipe had no deflection. Alignment changes were observed much more often in 12- and 15-in. pipe than in 18- and 24-in. pipe. District and county personnel noted difficulties in maintaining alignment of the 12- and 15-in. pipes during backfill procedures.

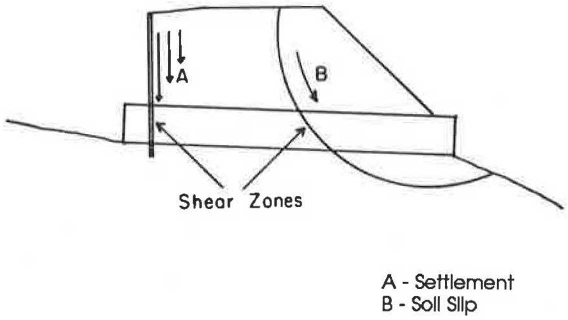

FIGURE 3 Schematic representation of shear loading.

County of Installation

The county of installation was used as representative of the installation crew. Alignment changes and deflection varied considerably among the various counties.

Deflection and Buckling

Three primary indices were used in the evaluation of the structural performance of corrugated polyethylene pipe culverts: average deflection, maximum deflection, and the presence of wall flattening or buckling. Average deflection is the average observed or measured deflection throughout the length of the culvert, excluding the ends. Average deflection is representative of culvert performance under "uniform" loadings and backfill conditions that are in general conformance with ring compression-deflection theory. Maximum deflection is the deflection at the point within the culvert where deflection is greatest, excluding the ends. Maximum deflection is more representative of culvert reaction to variable spot loadings and backfill conditions often encountered in actual installations. Flattening is the loss of curvature in the pipe wall, and buckling is the reversal of curvature in the pipe wall. Deflection, flattening, and buckling are shown schematically in Figure 4.

Because all the culverts were relatively short, the interiors could be easily observed from the ends with the aid of a high-intensity flashlight powered from an automobile cigarette lighter. Where no vertical deflection or slight vertical deflection was observed, it was so recorded. Where significant vertical deflection was observed and the interior of the pipe was accessible for measurement, the rise of the pipe was measured with a deflectometer developed by a local corrugated polyethylene pipe manufacturer. Where the pipe interior was not accessible vertical deflections were estimated. In general there was concurrent increase in the horizontal dimension with decrease in the vertical dimension. Deflectometers were available for 15-, 18-, and 24-in. culverts. The 24-in. deflectometer is shown in Figure 5. All seven culverts previously measured were remeasured even if no significant deflection was observed. There was no increase in pipe deflection in any of these seven culverts.

FIGURE 5 Direct-reading deflectometer for measuring deflection in 24-in. culverts.

Significant deflection to the point of wall flattening or buckling through a significant portion of the culvert length was observed in four culverts. Flattening occurred at deflections exceeding approximately 15 percent. Buckling occurred at deflections exceeding 25 percent. Where significant deflection occurred throughout the pipe length, it was not constant but occurred in waves as shown in Figure 6. Large deflections, flattening, and buckling appeared in general to be caused by bending of the pipe wall inward in both the circumferential and longitudinal directions. In three cases flattening of the wall was more prevalent in the invert than on the crown

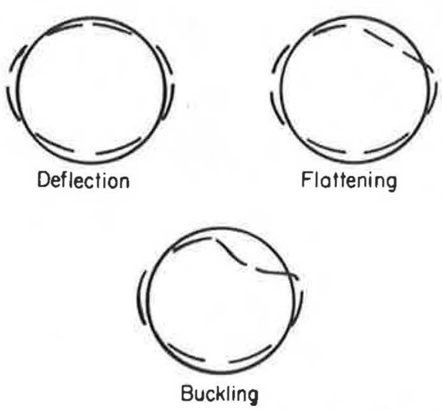

FIGURE 4 Schematic representation of flexible pipe deflection, flattening, and buckling.

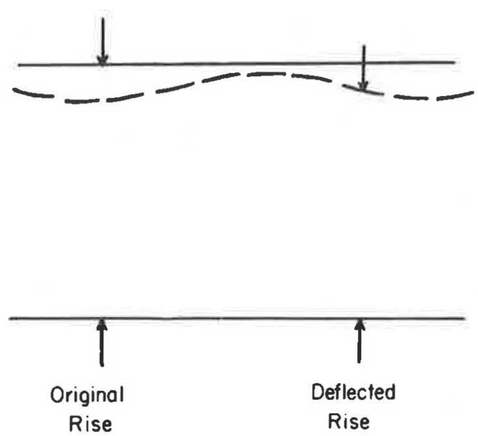

FIGURE 6 Varying deflection observed in corrugated polyethylene pipe culverts.

of the culvert, which suggests poor foundation. Two of the culverts had buckled to the point of being cracked and needing repair. Apparently the internal corrugation crests had been stressed by bending moment to the point of tearing apart.

Seven additional culverts had single flattened or buckled spots less than 1 ft long. These spots on three culverts were at shear points or severe vertical bends. Buckled spots on the other four culverts appeared to be just dents in the crown of the pipe, possibly caused by the dropping of a heavy object on the pipe.

All of these cases were limited to 12- and 15-in. culverts. Although the dented spots do not cause structural problems for the culvert as a whole, they produce a constriction within the barrel of the pipe and are not desirable hydraulically. Care should be taken to avoid denting the pipe.

Deflections in the rest of the culverts ranged from negative (i.e., crowning) to approximately 10 percent. The deflections at pipe joints were in general slightly larger than the deflections throughout the rest of the culvert.

On the basis of field observations only, it appears that pipe culvert performance is related only to pipe size and county of installation.

Condition of Pavement

The pavement surface above the culverts was observed at each site and any significant dips were noted. In general there was no concurrent dip in the roadway surface over culverts with larger deflections. This suggests that the deflections observed were built into the culverts rather than produced by live load on the pipe.

Durability Data

The condition of the culvert invert was observed at each site. It was planned to take coupons from pipes with noticeable wear. Because none of the culverts inspected showed any visible signs of loss of materials, no coupons were taken. Flow depth, observed flow velocity, sediment depth, and bed load size were recorded at each site as indicators of abrasiveness of flow. Water pH was taken at sites where there was significant flow. Pipe slopes were obtained from the inventory or estimated at the site for most of the culverts. Water pH ranged from 3.5 to 8.3 and flows ranged from nonabrasive to extremely abrasive.

Although no estimate of service life could be made because of the small age range of the culverts studied, an indication of the durability of corrugated polyethylene pipe can be obtained by looking at the worst-case installation. A 24-in. corrugated polyethylene pipe culvert was installed at NOB–145–3.58 in 1981. This culvert is shown in Figure 7. There is constant acidic dry weather flow at the site, and storm flows carry a bed load of abrasive cobbles. The pile of sediment on the bank of the outlet channel shown in Figure 8 is indicative of the force generated by the storm water flowing through the culvert. After 4 years this culvert is in good condition. The invert of the polymeric-coated galvanized corrugated steel pipe previously at this location completely deteriorated in less than 1 year.

Additional Observations

Damaged ends were observed on seven of the culverts inspected. Three appeared to have been damaged during installation. Three appeared to have been run over by errant vehicles or mowers. The tops of the corrugations on the end of one culvert with minimal cover on a side road appeared to have been sheared off by a snowplow. Although damaged ends do not present a structural problem, they could affect hydraulic performance. Therefore, vulnerable culvert ends should be delineated or protected, or both. This is especially true for shallow installations. There was no apparent deterioration of exposed ends due to ultraviolet sunlight rays.

FIGURE 7 24-in. corrugated polyethylene pipe culvert at NOB–145–3.58: low pH and severely abrasive flow.

FIGURE 8 Outlet channel debris at NOB–145–3.58 indicative of force of storm flow.

ANALYSES OF DATA

Various statistical analysis procedures including regression analysis, analysis of variance, and χ^2 tests were applied to the data to determine if deflection, flattening, or buckling was affected by any site parameters. Those parameters were pipe diameter, pipe cover, backfill type, culvert age, average daily truck traffic, average daily car traffic, culvert alignment, and county of installation.

None of the parameters studied had any quantifiable effect on average deflection. There was slight correlation between average deflection and average daily car traffic. As car traffic increased so did average deflection. However, this correlation accounted for only 2 percent of the scatter in the average deflection data. It is questionable whether light automobile loadings would affect deflection. County personnel interviewed indicated that installations were in general more rapid on highways with greater traffic. This could result in less dense backfill and thus greater average deflection.

None of the parameters studied had any quantifiable effect on maximum deflection or buckling. However, there was strong correlation between maximum deflection and culvert size and between occurrence of buckling and culvert size. As observed in the field, the incidence of large maximum deflections and buckling was significantly greater for 12- and 15-in. culverts than for 18- and 24-in. culverts. This is contrary to standard flexible pipe deflection theory, which is the basis for ASTM structural requirements for corrugated polyethylene pipe. Theoretical ring stiffnesses ($53.77\ EI/D^3$) of 12- and 15-in. corrugated polyethylene pipe are greater than those of 18- and 24-in. pipe, and measured ring stiffnesses of the various sizes are about the same *(10–14)*.

However, it can be seen in Figure 9 that the wall thicknesses of the 12- and 15-in. pipes are considerably thinner than those of the 18- and 24-in. pipes. Although theoretical flexibility factors (D^2/EI) for 12- and 15-in. pipe are slightly less than those for 18- and 24-in. pipe, actual measured flexibility factors for the smaller pipes were larger *(10–14)*. It was previously noted that the 12- and 15-in. pipe was much more difficult to handle than the 18- and 24-in. pipe. It is possible that with variable loadings and large local deflections as shown in Figure 6 the thinner walls of the "more flexible" 12- and 15-in. pipe allow a flattening (reduction in the rise) of the corrugation profile during bending in the longitudinal direction. This in turn would significantly reduce the ring stiffness of the pipe and allow bending in the circumferential direction. Observation of culverts with severe deflection and buckling showed a definite flattening of corrugation profile at points of maximum deflection.

The incidence of alignment changes was significantly greater for 12- and 15-in. pipe than for 18- and 24-in. pipe. Accomplishing an alignment change requires a flattening of the corrugation profile on the outside of the bend. The thinner walls of the more flexible 12- and 15-in. pipe allow this much more readily than in 18- and 24-in. pipe. Movement of the pipe during backfill will lead to differential loadings, causing the culvert not to behave in a theoretical ring compression-deflection manner.

The incidence of large maximum deflection and buckling was significantly greater in two counties than in the rest. This would indicate that large deflections and buckling are caused by backfill compaction quality control problems. These differences were most noticeable in the 12- and 15-in. culverts.

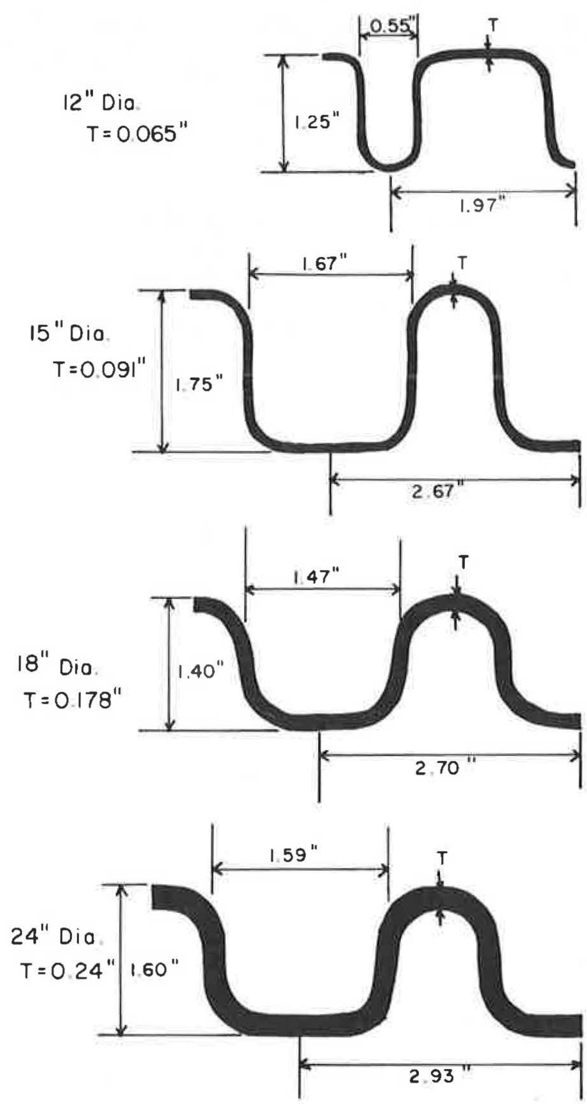

FIGURE 9 Corrugated polyethylene pipe corrugation profiles.

CONCLUSIONS

On the basis of field observations and data analyses the following conclusions can be drawn:

1. Because of their greater flexibility and much thinner walls, 12- and 15-in. corrugated polyethylene pipe culverts are more susceptible to bending moment stresses in both the circumferential and longitudinal directions. Thus the smaller pipes are much less installation proof than 18- and 24-in. corrugated polyethylene pipe culverts.
2. There is no increase in pipe deflection after 2 to 4 years in corrugated polyethylene culverts with small to moderate initial deflections (less than 10 percent deflection).
3. Four years' data indicate that corrugated polyethylene pipe appears to be resistant to abrasive flows.
4. Shallow cover and heavy truck traffic do not appear to be detrimental to the structural performance of corrugated polyethylene pipe culverts. Deflection appears to be built into the culverts instead of caused by highway loadings.
5. Exposed culvert ends are vulnerable to damage by mowing machines and other maintenance equipment. Exposure to sunlight did not appear to affect the condition of the exposed ends.

RECOMMENDATIONS

On the basis of these conclusions, the following recommendations are made:

1. The wall thickness of 12- and 15-in. corrugated polyethylene pipe should be increased, or pipes of these sizes should be securely anchored in the trench during backfill operations to provide a larger factor of safety against less than optimal installation methods.

2. Revision of ASTM structural requirements for corrugated polyethylene pipe to include consideration of flexibility and resistance to bending moment should be considered.

3. Culverts with moderate to large initial deflections (10 percent or greater) under the roadway should be observed periodically to determine if any increase in deflection occurs with time for this range of initial deflections.

4. Corrugated polyethylene pipe culvert ends should be delineated and protected with headwalls under minimal cover conditions.

ACKNOWLEDGMENT

The author wishes to thank all of the ODOT and county personnel who aided in the data collection phase of the study. Special thanks are given to James B. Goddard of ADS, Inc., for providing field equipment and assistance in data collection.

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This study was funded by the Ohio Department of Transportation. The findings and opinions expressed herein are those of the author and do not constitute a standard or policy of the Ohio Department of Transportation.

Publication of this paper sponsored by Committee on Culverts and Hydraulic Structures.