Field Performance of Precast Reinforced Concrete Box Culverts

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A visual inspection was undertaken to determine to what extent, if any, durability problems exist in precast reinforced concrete box culvert exterior top slabs and joints between box sections and what measures have been or could be successful in preventing the problems. From September 1988 through January 1990 133 culverts were inspected throughout Ohio. On the basis of the results, it is recommended that external joint wrap be provided on precast concrete box culvert joints, through-bolted guardrail post connections to box culverts not be permitted, ½-in. cover be provided over longitudinal reinforcing at mating surfaces at joints, and top surfaces of box culverts be sealed.

Within the past decade large prefabricated culvert structures have become economical alternatives to conventional bridges and cast-in-place box culverts for the replacement of deteriorating small bridges. Prefabricated culvert structures include reinforced concrete arches, three-sided concrete box structures, four-sided concrete box culverts, corrugated metal long-span structures, and metal box culverts. The field performance of four-sided precast reinforced concrete box culverts is addressed.

From 1979 to the time of this study the Ohio Department of Transportation (ODOT) had installed 256 precast reinforced concrete box culverts ranging in size from 6- to 12-ft spans. The locations of these structures are shown in Figure 1.

Invert durability of precast reinforced concrete pipe has not been a problem in Ohio (*1–3*). Therefore, the invert durability of precast reinforced concrete box culverts was not expected to be a problem when they were first used. The flow in box culverts is less confined, and any corrosive effects from surface mining or other causes are generally less severe because of dilution from greater dry weather flow from larger drainage basins.

Previous work on metal box culverts (*4*) and structural plate pipe arches (*5*) indicates a potential for corrosion at seams on the top of these shallow structures. This is primarily due to exposure to water containing deicing salts. Furthermore, ODOT maintenance experience with cast-in-place concrete box culverts indicated the existence of reinforcing steel corrosion at joints or cracks. Therefore, questions arose concerning the durability of precast reinforced concrete box culvert external top surfaces and joints between box sections.

This study was undertaken to determine to what extent, if any, durability problems exist in precast reinforced concrete box culvert exterior top slabs and joints between box sections and what measures have been or could be successful in preventing the problems.

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DATA COLLECTION

An inventory of precast reinforced concrete box culverts was prepared from bid-letting pamphlets for contract installations and from maintenance records of ODOT force account or purchase order installations. The following information was obtained from contract plans and maintenance records and was verified during field inspection.

- Culvert location: The county, route, and section mile mark were recorded and the culverts plotted on a highway map.
- Culvert size: The span and rise of the culvert in feet were recorded. The culvert spans ranged from 6 to 12 ft.
- Box type: Either ASTM C850 for culverts with less than 2 ft of cover or ASTM C789 for culverts with 2 or more ft of cover were recorded.
- Cover: The height of cover in feet over the top surface of the box culvert was recorded. The height of cover over the box culverts inspected ranged from 0.5 to 12 ft.
- Joint material: ODOT specifications allow the use of either bituminous plastic cement (mastic) joint filler or preformed butyl rubber joint material for concrete pipe culvert joints. Joint material for some of the concrete box culverts studied was limited to butyl rubber. The type of joint material specified was recorded. The exterior joint gap on the top of all precast reinforced concrete box culvert joints is filled with portland cement mortar.
- External joint wrap–surface treatment: The type of treatment used on the top exterior of the box culverts included complete field-applied membrane waterproofing of the top surface with multiple layers of asphalt-saturated fabric, 9-in.-wide external joint wrap meeting ASTM C877 with or without an application of a clear concrete sealant on the exterior top surface, or no treatment at all. Membrane waterproofing extended 1 ft down the sides of the culverts. The ASTM C877 joint wrap extended down to the base of the culvert to provide anchorage. The clear sealant was applied to the tops and 1 ft down the sides and joints of the box sections.
- Shear connectors: Although ODOT no longer requires shear connectors on concrete box culverts (*6,7*), some early installations of C-850 boxes had shear connectors at culvert joints. The presence of shear connectors was recorded.

From September 1988 through January 1990, 133 culverts were inspected. The culvert locations are shown in Figure 2. Inspection trip itineraries were selected to provide reasonable coverage of the state while maximizing the number of in-

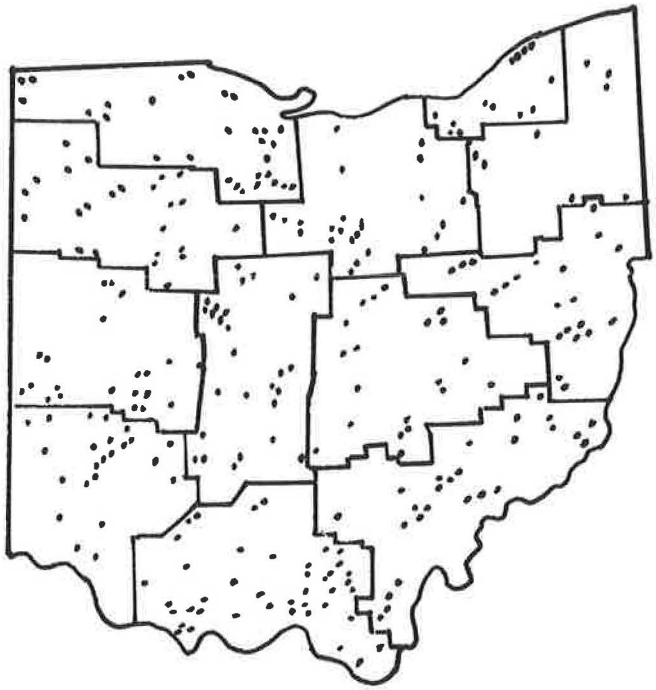

FIGURE 1 Locations of precast reinforced concrete box culverts installed by ODOT.

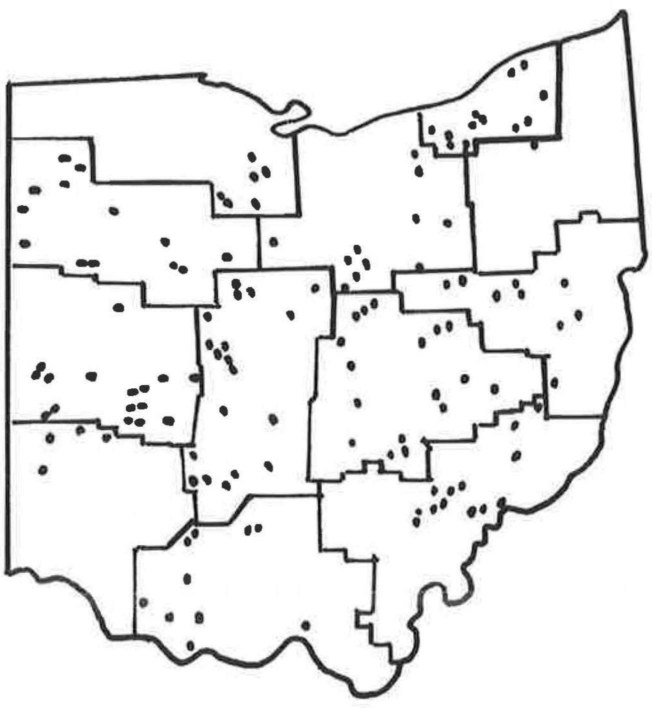

FIGURE 2 Locations of inspected culverts.

spections per trip. Inspections were conducted until it appeared that as many culverts with varying joint-surface treatments and site conditions as necessary had been inspected to allow reasonable conclusions to be drawn. The following information was obtained from field inspections:

- Joint configuration: Specific joint configurations for tongue and groove joints for precast reinforced concrete box culvert sections are not given in either ASTM C789 or ASTM C850. Therefore, joint dimensions for each culvert were recorded on a sketch similar to Figure 3.
- Guardrail connections: Where guardrail posts were connected to the culvert top slab, the type of connection, either inset bolts or through-bolting, was recorded. Connections to culvert top slabs are used on shallow culverts where no other mounting method has been proved impact safe by crash tests.
- Joint gap: The typical joint gap between the mating surfaces of the box sections was recorded. Any significant difference in box dimensions at the joint for abutting box sections was also noted.
- Steel exposure: Any exposed reinforcing steel on the mating surfaces of joints or on internal surfaces of the box was noted. The specified minimum cover over all reinforcement for internal surfaces is ⅝ in. The specified minimum cover for circumferential wires on mating surfaces is ½ in. Ends of longitudinal wires may be exposed at mating surfaces. Ends of spacers and stirrups used to position reinforcement may also be exposed.
- Manufacturer: Box culvert size, design data, manufacturer, and so forth are required to be marked on the culvert. If this marking was on the interior surface, the manufacturer was recorded. In many instances, however, the information was missing or marked on the external surface.
- Lift hole and guardrail bolt holes: The condition of the concrete around the bottoms of lift holes and guardrail bolt holes where through-bolting was used was noted. Any damage to the concrete was recorded and later subjectively rated as slight, significant, or severe. Serious spalling around guardrail bolt holes is shown in Figure 4.
- Joint leakage and corrosion: The evidence of any joint leakage, road salt deposition, or corrosion of steel was noted

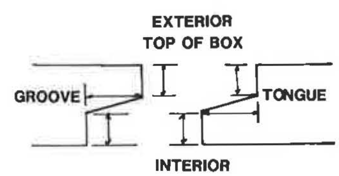

FIGURE 3 Joint configuration of precast reinforced concrete box culverts.

FIGURE 4 Spalling of concrete around guardrail bolt holes.

and recorded. On the basis of ODOT's experience with bridge deck and cast-in-place box culvert deterioration, there was concern that joint deterioration might cause progressive deterioration of the culvert tops and affect the condition of the highway fill or the road surface, or both. Joint leakage was later rated from photographs and descriptions as slight, significant, or severe. Severe joint leakage, salt deposits, and corrosion are shown in Figure 5.

- Leakage and corrosion at lift holes and guardrail bolt holes: The same information taken at joints was taken for lift holes and guardrail bolt holes.
- Condition of exposed top surface: The condition of exposed box culvert top surfaces outside the pavement or backfill was observed. Any spalling or other deterioration or damage was noted. Spalling on the unprotected top surface of one box culvert is shown in Figure 6.
- Additional information: Other observations, such as cracks in box sections, knocked-out pieces of concrete at joints, poor-quality concrete, and so forth, were also recorded.

Observation of the joints on many box culverts was difficult because additional bituminous plastic cement joint filler had been spread around the exposed interior joint gap (see Figure 7). Some ODOT district construction personnel interpret the ODOT specifications as requiring this application, whereas others do not. This not only prevents adequate inspection of the joint but also may trap moisture and salt in the joint and induce or aggravate deterioration.

FIGURE 5 Serious joint leakage, salt deposits, and corrosion.

FIGURE 6 Spalling on top surface of box culvert.

FIGURE 7 Joint material spread on inside of joint.

ANALYSES OF DATA

Because the data compiled were qualitative in nature and did not involve precise numerical measurements, statistical analyses (such as analysis of variance or convariance and regression analysis) were not performed. Instead chi-square contingency tests of grouped data were used to determine the statistical significance of relationships between culvert and site parameters and culvert performance.

The severity of joint leakage was related to box culvert manufacturer, culvert type, joint configuration, joint fit, type of specified joint material, type of joint wrap, culvert location, culvert age, height of cover, and so forth. The only significant relation observed was that between the severity of joint leakage and the type of joint wrap provided. Table 1 indicates that use of an external joint wrap (total membrane waterproofing or ASTM C877 joint wrap) prevented significant joint leakage. In all cases where leakage was observed on culverts with wrapped joints, it was limited to one spot on 1 or 2 joints out of approximately 10 joints per culvert.

Unwrapped joints sealed only with mastic or butyl joint material were ineffective in preventing leakage. This was true regardless of joint material, joint configuration, or joint fit. Leakage, salt deposition, and corrosion observed on joints were limited to the top of the box culvert and did not appear on the sides. The absence of any relationship between leakage severity and culvert age is probably due to a combination of the small age range of the culverts inspected and the ineffectiveness of the internal joint material in preventing leakage.

TABLE 1 JOINT LEAKAGE BY TYPE OF JOINT WRAP

	Joint Leakage			
Joint Wrap	None	Slight	Significant	Severe
Membrane	62	5	0	0
ASTM C-877	8	4	0	0
None	11	15	18	4

Joint leakage on unwrapped box culvert joints was significantly worse in northeastern Ohio and grew progressively less severe toward northwest, southwest, and southeast Ohio, in that order. Figure 8 shows district groupings used in the comparisons given in Table 2. Winter weather (both precipitation and temperature) decreases in severity from northeast Ohio in the same counterclockwise direction. No other site parameter affected the severity of joint leakage on culverts with unwrapped joints. No significant infiltration of backfill was observed on any culverts. It appears that the mastic and butyl joint seals were effective in this regard.

Leakage at lift holes and guardrail bolt holes was also compared with various culvert and site parameters. Full membrane waterproofing prevented leakage through lift holes, whereas some slight leakage at lift holes was observed on approximately one-third of the culverts without full membrane waterproofing. No particular factor affecting lift hole leakage on the culverts without membrane waterproofing could be identified. It appears that the care used in plugging the lift hole after the culvert had been set was the sole factor in determining whether leakage occurred.

Membrane waterproofing did not prevent leakage through guardrail bolt holes on those culverts with through-bolting of guardrail posts. More than one-half of the culverts with through-bolted guardrail post connections experienced leakage through the bolt hole. As with lift hole leakage, no particular factor affecting leakage could be identified.

FIGURE 8 District groupings.

TABLE 2 JOINT LEAKAGE ON CULVERTS WITH UNWRAPPED JOINTS BY ODOT DISTRICT

	Joint Leakage			
ODOT District	None	Slight	Significant	Severe
3·4·12	1	2	7	2
1·2	1	3	3	1
6·7·8·9	1	8	4	1
5·10·11	8	2	4	0

The presence of road salt deposits and evidence of reinforcing steel corrosion on those culverts having joint, lift hole, or guardrail bolt hole leakage were compared with various culvert and site parameters. Although the presence of salt deposits became slightly more severe with age, no culvert or site parameter could be identified that affected these conditions. As with metal box culverts (*4*), it did not appear that an increase in depth of cover significantly reduced the severity of road salt deposits or corrosion at joints. Strangely, the severity of salt deposition and corrosion at joints did not significantly decrease from the northeast area of Ohio counterclockwise as did leakage, even though salt usage in Ohio decreases dramatically from north to south.

The severity of salt deposits and corrosion on culverts with joint, lift hole, or guardrail bolt hole leakage is summarized in Tables 3 and 4. The evidence of corrosion at the joints is probably due to exposed longitudinal reinforcement, which is allowed by the ASTM specifications for precast concrete box culverts. Approximately 20 percent of the culverts observed had longitudinal steel exposed on the end box section. This percentage is a minimum estimate of occurrence on all culvert joints, because observation was based on the end sections that could be observed. Several end sections were covered by end treatment such as headwalls and wingwalls.

Corrosion at guardrail bolt holes is in part due to exposure of steel at the side of the hole. However, more severe corrosion occurs when a large part of the inner reinforcing cage is exposed by spalling of concrete, as shown in Figure 4. Seventeen of the 23 culverts with through-bolted guardrail connections had spalling rated severe or significant around the bottom of the bolt holes. This is thought to be caused by the impact of the drill striking the inner cage of reinforcement.

Some spalling was observed in nineteen culverts around the lift holes, which was probably caused by contact with lifting devices. However, this spalling was not nearly as severe as that around the guardrail bolt holes, and it did not expose the inner reinforcing cage.

TABLE 3 SALT DEPOSITS ON CULVERTS WITH LEAKAGE AT JOINTS, LIFT HOLES, AND GUARDRAIL BOLT HOLES

	Severity of Salt Deposits			
Location	None	Slight	Significant	Severe
Joint	9	12	13	3
Lift hole	7	8	2	0
GR bolt hole	5	3	4	1

TABLE 4 CORROSION ON CULVERTS WITH LEAKAGE AT JOINTS, LIFT HOLES, AND GUARDRAIL BOLT HOLES

	Severity of Corrosion			
Location	None	Slight	Significant	Severe
Joint	20	9	8	0
Lift hole	14	2	1	0
GR bolt hole	8	4	0	1

ADDITIONAL OBSERVATIONS

Some additional observations concerning general culvert conditions made during the inspections are given in this section.

Surface deterioration of the top slab of the end sections on nine culverts was observed (see Figure 6). To date this has been limited to culverts without clear sealant or membrane waterproofing and with total earth and pavement cover less than or equal to 3 ft. The deterioration is probably due in part to exposure to roadway deicing salts. Air entrainment was suggested as a remedy for the surface deterioration. However, maintenance of consistent levels of air in the precasting process has been difficult for other precast structures.

The condition of all culvert inverts was excellent. No deterioration due to flow was observed.

Longitudinal hairline cracks were observed on the interior top slab of one or two sections on seven culverts. These cracks were much smaller than a 0.01-in. crack used as a structural design basis for round concrete pipe. In only one case did it appear that leakage from a joint progressed down the crack. These cracks did not appear to pose a top slab durability problem.

To date no problems with progressive top slab deterioration or highway fill and road surface condition have been observed on any of the culverts with joint problems. Therefore, no specific remedial action has been programmed for the immediate future. Large culverts are inspected annually, and repairs will be scheduled when it appears that joint deterioration poses a threat to the rest of the box culvert top or to the highway itself.

RECOMMENDATIONS

On the basis of the observations and data analyses performed, the following recommendations are presented:

1. External joint wrap should be required on the tops and sides of precast reinforced concrete box culvert joints. If full membrane waterproofing of the top is provided, it need only extend 1 ft down the sides of the culvert.

2. A surface sealer (either full membrane waterproofing or clear sealant) should be required on the external top slab of precast reinforced concrete box culverts, especially those with less than 3 ft of cover. The sealer should extend approximately 1 ft down the sides of the culvert.

3. A minimum cover of ½ in. over both circumferential and longitudinal reinforcement should be required at the mating surfaces of precast reinforced concrete box culvert joints.

4. Lift holes should not be permitted unless full membrane waterproofing is provided over the precast box sections or approved joint wrap material is applied over the lift hole.

5. Where guardrail posts must be mounted to the precast box culvert tops, through-bolting should not be permitted.

6. Additional joint material should not be placed in the inside of the joint on the top and sides of the box culvert.

7. The manufacturer's name and required product information should be placed on the inside of the precast box culvert section within the top half of the culvert.

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