contemplated for the other eight. Another difficulty in pipe investigations is the establishment of objective and equal rating classification systems. For example, in the Ohio study concrete pipe was rated poor when there was significant loss of mortar and aggregate or when concrete was in a softened condition, whereas the corrugated steel pipe was rated poor when the invert was lost, there was perforation, or when the pipe could be penetrated by a geologist's hammer. These are clearly not comparable ratings, which indicate that the predictive equations for concrete pipe are conservative and that the predictive equations for corrugated steel pipe are liberal. If, as for corrugated steel pipe, concrete pipe was rated poor only when its invert was lost, then the service life of concrete pipe would be unlimited in even adverse environments.

In his discussion Hirsch devotes five sentences to an off-hand review of my paper and several pages to a critique of the Ohio study paper by J.C. Hurd (whose paper is also in this Record). I suggest that Hirsch's comments on the Ohio study should be directed to authors of that report.

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For Want of Air, a Drainage System Was Nearly Lost

CARL F. CRUMPTON, GLEN M. KOONTZ, and BARBARA J. SMITH

ABSTRACT

The omission of entrained air from a concrete pipe end section in 1972 set up a chain of events that could have been much more destructive. Freezing and thawing, which were aided and abetted by salty meltwater from de-icing salts running over the exposed invert of the end section, caused the pipe to scale. By the end of 10 winters the scaling had worked completely through the pipe invert, allowing runoff water to erode beneath the end section and the adjacent concrete ditch liner. The end section and a large portion of the ditch liner were lost. Minor slides and soil slumping at the toe of the fill began. The damaged end section and portions of the ditch liner were removed and replaced in 1983. Had corrective action not been taken, a much larger portion of the drainage system and the fill could have been lost. To paraphrase Ben Franklin in Poor Richard's Almanac of 1758: For want of air, an invert was lost; for want of an invert, an end section was lost; for want of an end section, a ditch liner was lost, being undercut and destroyed by uncontrolled runoff, all for want of care about entrained air.

Kansas published its pipe culvert study results i 1970, 1971, and 1972 (1-3). Therefore, for thi symposium, the authors chose to follow a sequence o events in one 1972 installation to illustrate wha can happen when one little detail is overlooked o ignored.

This brief account is related to an omission of a extremely cheap substance--entrained air--from co crete. The entrained air was something that coul have been had for almost nothing (4). Yet its omis- sion did not violate any applicable Kansas Depart- ment of Transportation (KsDOT), AASHTO, or AS specifications. But the concrete could not survive in its salty, freeze-thaw environment without that small amount of air; the results of omitting it were expensive.

More specifically, this short narrative is about end sections of 42-in.-diameter concrete pipe. They were manufactured, tested, and installed as part of I-635 in Kansas City during 1972. This is an area of severe weathering, which experiences an average of more than 60 freeze-thaw cycles, 20 in. of snow in five of six snowstorms, and two or three sleet or ice storms each winter. Thus the end sections were destined to undergo hundreds of freeze-thaw cycles and many exposures to de-icing salts.

None of the applicable specifications at that time required air entrainment in concrete pipe or end sections. During 1970 and 1971, however, TRB Research Results Digest 17 (5) and NCHRP Report 116 (6) had recommended air entrainment when concrete pipe culverts were to be exposed to de-icing salts. In 1971 Smith (7) warned that engineers have to be quality motivated and that somebody has to care that little bit extra when concrete is designed and made.

In Poor Richard's Almanac of 1758, Ben Franklin reminded his readers that the lack of care usually is a bigger problem than the lack of knowledge (8,p.36). Because a little neglect can cause much grief, Franklin advised care even in the minutest of matters. (Useful air voids are minute.) As an example, he added: "For want of a nail, the shoe was lost; for want of a shoe, the horse was lost; and for want of a horse, the rider was lost, being overtaken and slain by the enemy, all for want of care about a horse-shoe nail." Franklin was a bit careless himself in that he did not bother to note that the "for want of a nail" proverb was from George Herbert's "Jacula Prudentum" published in 1651. But then this is a type of omission that all authors tend to make in their lectures and writings. Otherwise they would be cluttered with references that are best left to books of familiar quotations, such as Bartlett's (9).

The knowledge of what could happen was available. Yet that extra bit of care and caution was not exercised to determine if the end sections were air entrained. The contractor installed 184 ft of 42-in.-diameter reinforced-concrete crossroad pipe covered by as much as 15 ft of fill. At each end of the crossroad pipe was a 42-in.-diameter reinforced-concrete end section obtained from a different source than the pipe. The inlet end section receives water from the pavement and adjacent slopes by way of 115 ft of paved ditch liner, which used 244 yd^2 of portland cement concrete. The outlet end section feeds the crossroad water into a portion of a 290-ft-long ditch liner paved with 588 yd^2 of portland cement concrete. This ditch has up to 14.2 percent slope and carries excessive pavement runoff water.

The first clue that the pipe end sections were probably not air entrained came in the form of minor scaling, as seen in Figures 1-3. (In Figure 1 note that the larger scales are 0.5 to 0.35 in. across. The scaled spots are scattered but not connected. In Figure 2 the scaled area extends with increasing freeze-thaw cycles. Note that the ruler is marked in inches.) But no one paid much attention until the pipe had experienced 10 winters, 3 of which were severe. By then scaling of the outlet end section had progressed completely through the invert, and undercutting of soil was occurring (Figure 4). By early spring of 1982 the undercutting and erosion was severe enough that the end section was completely separated from, and was about 3 ft lower than, the rest of the pipe (Figure 5).

Test reports indicated that the end sections had meet all the specifications. However, the absorption

FIGURE 1 Scaling of concrete pipe end section.

FIGURE 2 Close-up of scaled area showing a new scale.

FIGURE 3 End section showing moderate scaling of entire invert.

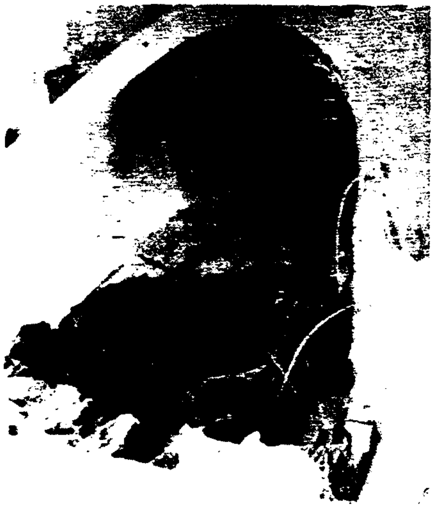

FIGURE 4 Invert of end section completely deteriorated after 10 winters.

FIGURE 5 End section completely undercut, disconnected, and now about 3 ft lower than the next section of pipe, which is air entrained.

FIGURE 6 Erosion of toe of fill adjacent to disconnected end section.

was 8.49 percent (9 percent limit) and the unit strength was 4,210 psi (4,000 psi minimum). Samples of the deteriorated concrete end sections were examined microscopically. It was verified that the concrete was not air entrained. The deterioration was typical of freeze-thaw damage that is aided and abetted by de-icing salts acting on non-air-entrained concrete. The concrete pipe and the ditch liner adjacent to the end section were air entrained and did not scale. The inlet end section has scaled but not clear through its invert.

As seen in Figure 5, the erosion was also undercutting the section of pipe directly behind the end section. The spring of 1983 was unusually rainy for Kansas. The turbulence caused by the heavy runoff and the 3-ft waterfall at the nonconnected pipe was eroding a portion of the toe of the fill slope (Figure 6). (Note that the undercut concrete ditch liner broke and fell into the eroded ditch.) Some minor slides occurred, but the slide material was quickly removed by the heavy rains. The two pipe sections nearest the outlet end section were moving downslope slightly. The joint between the first and second sections opened 1 in. and the joint between the second and third section opened 0.5 in. The other joints were not affected by the downslope movement. Otherwise the air-entrained pipe has performed satisfactorily.

The grief continued. Erosion undercut the concrete ditch liner, which broke and dropped into the newly eroded ditch (Figures 6-8). The erosion would have been much worse, except that some of the concrete ditch liner was resting on the weathered top of bedrock. This ledge of rock, partially observable at the base of the ditch liner in Figure 8, slowed and controlled the progress of erosion in a critical area. Figure 9 gives an overall view of the fill, showing the erosional scar in the toe of the fill slope a few weeks before repair activities began in late spring 1983. Had repairs not been made, most of the ditch liner would have been lost. Fill slides would have increased because erosion was moving toward the thicker part of the fill, as seen in Figure 9.

Repair involved removal and replacement of the damaged end section. The damaged and undercut portion of the concrete ditch liner was also removed and the eroded ditch was filled in with recycled concrete, bricks, and limestone rubble (Figure 10). (Note that unsized rubble lines the ditch.) An overall view of the repair in the same general perspective as Figure 9 can be seen in Figure 11, where it may be noted that all of the erosional scars were not yet corrected.

To sum up: For want of air, an invert was lost; for want of an invert, an end section was lost; for want of an end section, a ditch liner was lost, being undercut by uncontrolled runoff water, all for want of care about entrained air.

Therefore, it is concluded that air entrainment or other valid protection measures should be used in concrete pipe and end sections if they are to be

FIGURE 7 Broken concrete ditch liner no longer supported by soil below.

FIGURE 8 Portion of concrete ditch liner resting on bedrock.

FIGURE 9 General view of fill showing erosional scars before repairs.

FIGURE 10 A used end section in place.

FIGURE 11 General view after repair from same perspective as Figure 9.

exposed to de-icing salts and freeze-thaw conditions. To do otherwise may cause problems because Nature rejects imperfect work.

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Innovated Repair of a Large Failing Structural Steel Plate Pipe Arch Culvert

CHARLES R. DUNCAN

ABSTRACT

A value-engineering team studied alternatives to replacing a failing structural steel plate pipe arch culvert 14 ft x 9 ft 8 in. x 260 ft long. Their proposal consisted of rolling a slightly smaller asbestos-bonded asphalt-coated pipe through the existing culvert and grouting between them. The cost was $169,957, which represented a savings of $92,000, or 54 percent of the cost to replace the culvert. The contractor's procedures, the problems encountered, and recommendations for future projects of this kind are discussed herein.

A structural steel plate pipe (SSPP) arch culvert 14 ft x 9 ft 8 in. x 260 ft long constructed in 1969 under I-90 in southeastern Montana 7 miles west of Hardin was failing because of severe corrosion. The material hauled in from an adjacent cut was extremely hot; the pH varied between 5.8 and 8.9 with a resistivity range of 125 to 222 ohm-cm. Because of this material, the 12-gauge culvert had an estimated average life of less than 10 years. The native material around the bottom half of the pipe was not corrosive. Typical corrosion in this culvert is shown in Figure 1. The perforations varied in size from that of a fist and smaller.

The initial proposal was to replace the culvert and the surrounding corrosive backfill material. However, the construction procedures would have required temporary shoring and heavy investment in equipment to remove and replace the 20 ft of fill and to replace the pipe. Furthermore, extensive traffic control would have exposed the motorist to unnecessary safety risks. The estimated cost was $262,000.

In light of a then-recent National Highway Institute value-engineering (VE) course, the Montana Department of Highways established a VE team to study the problem. This multidisciplinary team consisted of a hydraulic engineer, a chemist, a district construction supervisor, a roadway designer supervisor, and an FHWA bridge engineer. Based on the VE con-