

assessment of its cost-effectiveness would have to be made.

#### COST SAVINGS

Based on Caltrans SSPP culvert research, the allowable overfill for a 60-in. (0.109-in.-thick) SSPP has been increased from 42 to 57 ft; for a 240-in. (0.280-in.-thick) SSPP it has been increased from 36 to 44 ft. The estimated savings over the full range of pipe sizes used in California is \$150,000 per year.

#### ACKNOWLEDGMENT

Al Banke and Craig Chatelain of Caltrans also contributed to the development of the rational design method for SSPP now used in California.

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## Construction and Field Evaluation of Precast Concrete Arch Structures

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#### ABSTRACT

A construction and field evaluation is presented of the precast concrete arch structures (BEBO of America) that have been constructed in Minnesota since 1980. Fabrication, construction, and follow-up inspections of the arch structures have revealed certain construction techniques and structural deficiencies that require correction. Settlement and movement of selected arch structures have been monitored to determine deformation and related results. A construction time frame and an estimated cost comparison of alternative structures are also included.

The details and design of the precast concrete arch structures built in Minnesota are presented. The locations of these structures and their individual data are given in Figure 1 and Table 1. The plant

fabrication and material specifications are related in general terms.

Field installation and follow-up inspections are presented that disclose structural inadequacies

TABLE 1 Concrete Arch Structure Data

CITY LOCALE	EDINA	WATERTOWN	CYRUS	GOLDEN VALLEY	DUMFRIES	EAGLE BEND	EAGLE BEND CLARISSA	GOLDEN VALLEY	COON RAPIDS
Bridge	27652	95154	91940	R0030	95675	95116	95117	95924	95884
S.P. Number	-	1007	61-603-14	-	7903	7708	7708	-	-
Year Built	1981	1982	1982	1982	1983	1983	1983	1983	1983
Arch Width	41'	31'	41'	31'	41'	41'	41'	31'	41'
Arch Height	9'-8"	13'-8"	9'-8"	11'-4"	9'-8"	9'-8"	9'-8"	11'-4"	9'-8"
Spread Footing Width	8'-6"	8'-0"	7'-0"	5'-0"	8'-0"	6'-0"	6'-0"	5'-0"	8'-0"
Spread Footing Depth (Below arch section) (which includes leveling pads)	2'-6"	2'-7"	3'-4"	1'-8"	2'-8"	1'-10"	1'-10"	1'-8"	2'-11"
Bottom of Footing Elevation	817.5	944.0	1115.2	830.1	771.83	1348.90	1324.67	829.0	845.5
Channel Bottom Elevation	821.0	948.5	1118.5	833.6	773.5	1350.7	1326.00	831.9	848.4
Type of Scour Protection	Rock Rip Rap	Not Req'd	6' Wide/ Sloped Rip Rap	Rock Rip Rap	Rock Rip Rap	Rock Rip Rap	Rock Rip Rap	Rock Rip Rap	Rock Rip Rap
Hydraulic Flow Q100	1350 cfs. @ 5.0 fps.	(None)	1440 cfs. @ 5.1 fps.	860 cfs. @ 4.8 fps.	2200 cfs. @ 7.6 fps.	1450 cfs. @ 5.6 fps.	1700 cfs. @ 6.5 fps.	860 cfs. @ 4.5 fps.	1000 cfs. @ 3.6 fps.
Barrel Length	72'	90'	66'	84'	66'	58' <sup>a</sup>	54'	90'	90'
Cover Over Arch Sections at C/L Roadway	2'-8"	4'-7"	4'-9"	2'-0"	3'-0"	1'-6"	3'-6"	9'-9"	1'-8"
Type Roadway Over	5 1/2" Bit.	Bit.	Bit.	Bit.	Bit.	Bit.	Bit.	Bit.	Bit.
Traffic Over: ADT	5200 (81)	1750 (80)	472 (99)	400 (87)	475 (82)	1750 (82)	1800 (82)	4850 (81)	6300 (82)
Speed on Roadway Over	30 MPH	50 MPH	50 MPH	30 MPH	55 MPH	30 MPH	55 MPH	30 MPH	30 MPH
Roadway Over Alignment	Curve & Stop Sign	Straight	Straight	Straight, Bottom of Hill	Straight	Straight	Straight	Straight	Straight
Slope Protection	Sodded	Sodded	Sodded	Sodded	Sodded	Seeded	Seeded	Sod & Seed	Sod & Seed
Angle of Wingwalls to Barrel	Square	Square	Square	Square	30° Flare	30° Flare	30° Flare	Square	30° Flare
Fence Over Headwall & Wingwalls	Railing	5'-0" High wire fence & posts	Woven & barb wire fence	Black pipe railing	None	Guardrail	Guardrail	None	Fencing
Soil Condition	Peat and Silty Sand	Generally clay loam till	SC stiff to very stiff	Medium to Coarse Sand	Sl. Pl. SiL.	Very Stiff to hard clay loam till	Sand and gravel	Si Clay Very Stiff trace of Sand	Silty Sand Loose to Medium Dense
Subcut Depth Under Ftg.	6 to 8 feet	4' on North ftg & 8' on South ftg.	2 feet	None	Subcut to Elev. 769 3 feet	2 feet	1 foot	None	6 feet
Backfill Placed Under Footings	Select Granular Borrow per Spec. 3149.2B 100% Density	Select Granular Borrow per Spec. 3149.2B 100% Density	Select Granular Borrow Per Spec. 3149.2B 100% Density	Granular Bedding Spec. 3149.2F 100% Density	Granular Bedding Spec. 3149.2F 100% Density	Granular Bedding Spec. 3149.2F 100% Density	Granular Bedding Spec. 3149.2F 100% Density	Granular Bedding Spec. 3149.2F 100% Density	Granular Bedding Spec. 3149.2F 100% Density
Type of Backfill Placed Around and Over Structure	Granular Material 100% Density	Granular Borrow spec 3149.2A 100% Density	Granular Borrow spec 3149.2A 100% Density	Granular backfill 3149.2D 100% Density	Granular backfill 3149.2D 95% Density	Granular backfill 3149.2D 95% Density	Granular backfill 3149.2D 95% Density	Granular backfill 3149.2D 100% Density	Granular backfill 3149.2D 95% Density

NOTE: All structures are designed for HS20 loading.

<sup>a</sup>Two at 5-ft wide arch sections were used to obtain 58-ft length.

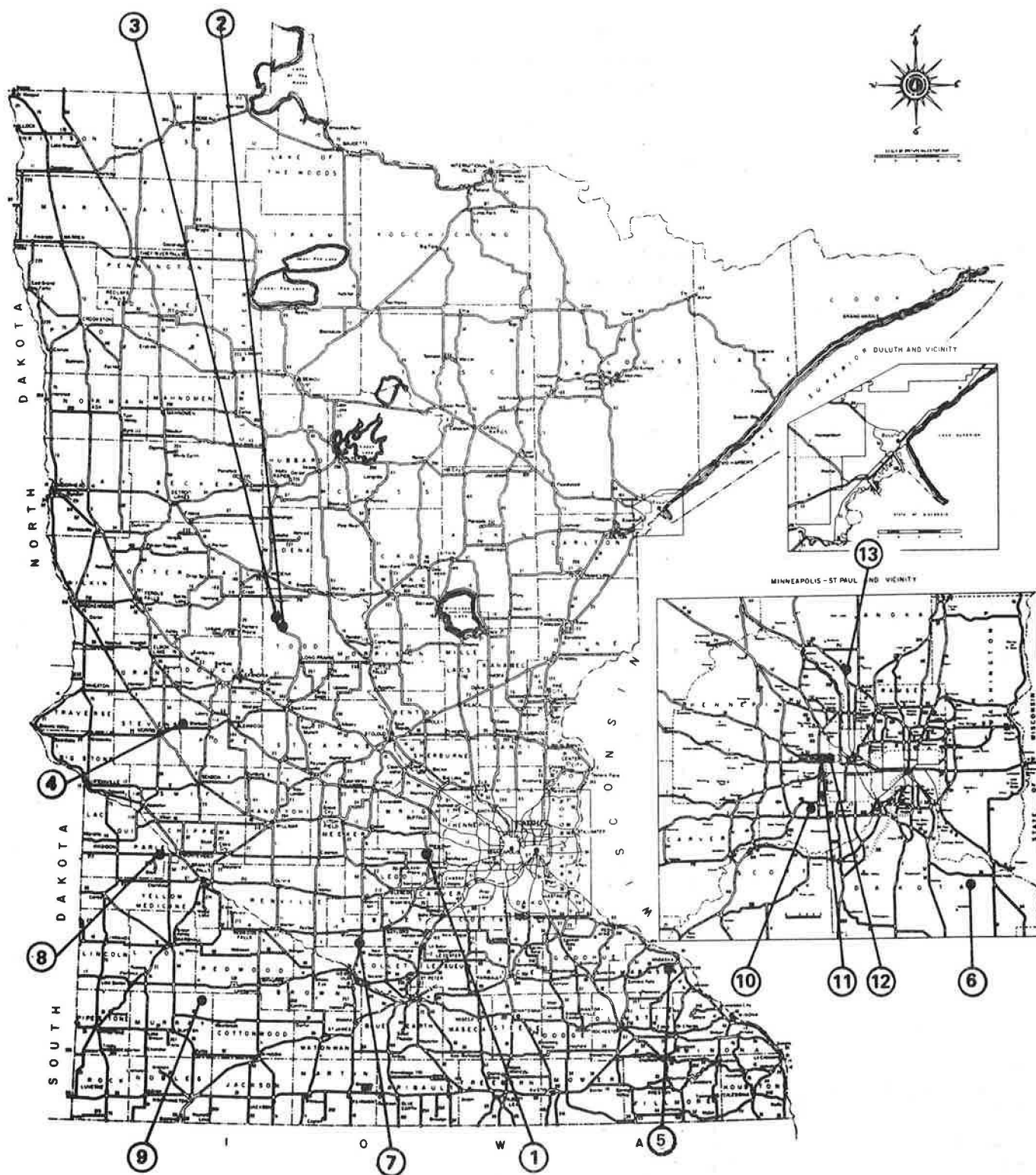


FIGURE 1 Location of precast concrete arch structures in Minnesota.

needing revision. Settlement and movement of three structures are given; concrete cores were taken on one structure for crack studies.

Cost comparison tables and a construction time frame are given. Finally, conclusions and additional experimental concerns are presented with regard to the policy of the Minnesota Department of Transportation (Mn/DOT) toward the structures.

#### STRUCTURE DETAILS

Precast concrete arch structures are composed of curved arch sections, generally 5 ft 11 1/2 in. wide placed on spread-type concrete footings that are cast in place. The arch sections are 10 in. thick and reinforced with two layers of steel according to the manufacturer's design (1). The sections span 30

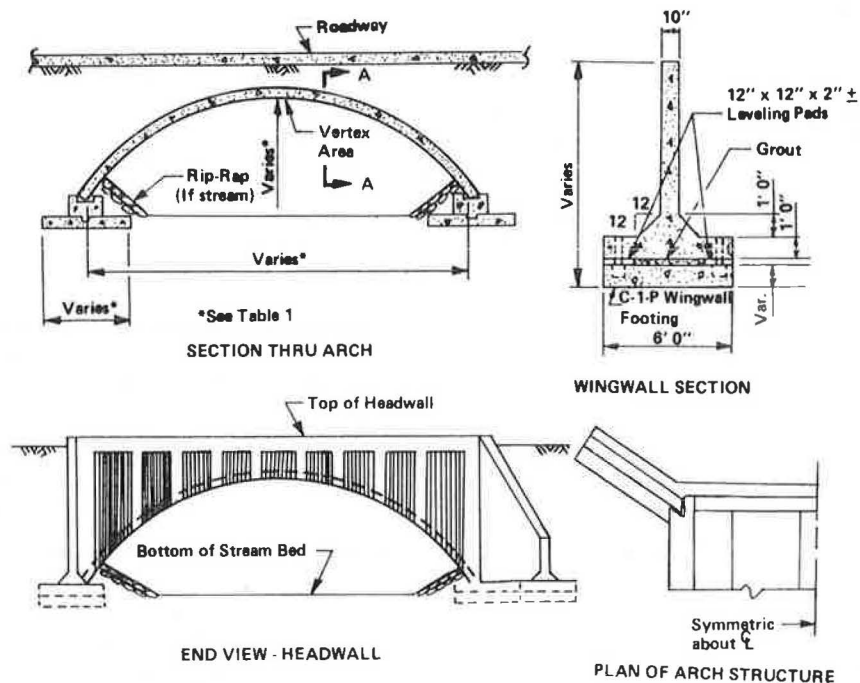


FIGURE 2 Details of arch structure (March 1983 to May 1984).

and 40 ft with heights varying from 9 ft 8 in. to 14 ft 6 in., depending on design opening requirements (Figure 2).

The precast arch sections are placed on mortar leveling pads  $\pm 2$  in. deep by 12 in. wide in the notches on the concrete footings and shimmed in behind with concrete block and steel shims at each joint. Grout is later placed in the notch for additional bearing capacity to complete the bedding support of the arch sections.

Precast concrete headwalls (1 ft thick) are placed on the cast-in-place concrete footings at each end of the structure. These headwalls, which have alternating vertical striated or smooth finishes on their exposed faces, are held to the outside arch sections with two stainless steel rods (1-in. diameter) encased in 3-in. plastic tubes and covered with grout.

In addition, precast concrete wingwalls shaped in the form of a tee are placed into the headwall vertical notch (to help interlock and hold each other in place) and then anchored to the footing to hold back soil fills. These sections were developed basically from precast concrete wingwall sections of Mn/DOT's standard box culvert structures.

Design of the arch section is based on the two-hinged arch concept. Only the soils directly above the arch sections are included in the design dead load. Symmetrical and asymmetrical truck loadings are placed over the arch for design live-load conditions (1). To date, soil interaction has not been used to help resist the forces acting on the arch section because of the smooth concrete surface.

The horizontal panel arch sections used in Europe are different from the circular arch sections that have been constructed in an experimental program in Minnesota since 1979.

#### LOCATION OF ARCH STRUCTURES

As part of the plan for evaluating the precast concrete arch structures, nine experimental concrete

arches were approved for construction by Mn/DOT at the following locations (numbers correspond to numbers in Figure 1):

1. Bridge 95154, Trunk Highway (TH) 25 over Luce Line Trail at Watertown;
2. Bridge 95117, TH-71 over Eagle Creek, 3 miles southeast of Eagle Bend;
3. Bridge 95116, TH-71 over Eagle Creek, south edge of Eagle Bend;
4. Bridge 91940, County State Aid Highway (CSAH) 3 over Chippewa River 1 mile north of Cyrus;
5. Bridge 95675, TH-60 over stream, 1 1/2 miles west of Dumfries;
6. Bridge 95874, 170th Street east over Vermillion River, in Marshan Township;
7. Bridge 95828, TH-15 over S.D. 23A, 2 miles south of Winthrop;
8. Bridge 95152, TH-212 over Ten Mile Creek in Lac Qui Parle County; and
9. Bridge 92395, CSAH-22 over Plum Creek in Murray County.

Structures 1-6 and 8 have been constructed. In addition, evaluations of the Edina (one structure), Golden Valley (two structures), and Coon Rapids (one structure) concrete arch installations (10-13, Figure 1), which were built in the summers of 1981, 1982, and 1983, respectively, are included in this study. Structures 7 and 9 will be placed in the summer of 1985.

#### FABRICATION AND SPECIFICATIONS

The concrete arch sections are manufactured in curved steel side forms that are placed on a steel bottom form plate. Reinforcement used in the sections consisted of two cages of wire fabric (or reinforcing bars) with additional rebars for the handling anchor systems. Concrete cover on the reinforcement was as follows:

1. On outside face (against soil), 2 in.;
2. On inside face (exposed), 1 1/2 in.; and
3. On sides, 1 3/4 in.

Strength of the wire fabric was based on a minimum yield of 65 ksi and that of the reinforcement bars on a minimum yield of 60 ksi. Concrete used in fabrication of the sections had a minimum yield strength of 4,200 psi and allowable slumps of 3 or 4 in.

Compression strength tests at 28 days for the 3W46 concrete used in arch structure 4 (Bridge 91940), which was fabricated at the plant in Hancock, Minnesota, ranged from 4,770 to 6,650 psi. The concrete slump varied from 3 3/4 to 4 1/2 in. and the air content varied from 5.7 to 6.5 percent.

Concrete compression strength tests at 28 days for the 3W36 concrete of arch structure 1 (Bridge 95154), which was fabricated by the Cannon Falls, Minnesota, plant, averaged 7,000 psi. However, the concrete slump varied from 2 1/2 to 2 3/4 in. and had only a 4.1 percent air entrainment.

The 3W46 concrete mix was designed for  $4 \pm 1$  in. slump and air content variance of  $5.5 \pm 1.5$  percent. The 3W36 concrete mix was designed for  $3 \pm 1$  in. slump and  $5.5 \pm 1.5$  percent air content. The 4.1 percent air content just barely conformed to the minimum air content requirement despite the use of 10 oz of air-entraining agent per yard of concrete. (Eight ounces of air-entraining agent is used to obtain 5.5 percent air content in concrete with a 4-in. slump.)

The concrete was vibrated by using high-frequency form vibrators and steam cured for about 8 hr. The arch section was removed from the forms in about 24 hr.

Results of the fabrication of various arch sections with regard to surface pocketing and voids at both plants were consistent, with 3/8-in. maximum diameter surface voids, which are sparsely located. Edges of some of the wingwall sections, which did not have vee strips, exhibited some raveling. These edges are now required to have 3/4-in. vees, which has eliminated the raveled edges.

Failure of the brake system of a crane led to cracked areas (6 by 8 by 1 1/2 in. deep) on four arch sections at a Golden Valley installation. Approved epoxy coating material and methods are now specified to properly protect the exposed reinforcement at cracked and spalled locations.

Arch structures may be placed in situations where handling is difficult. For example, an arch structure was placed with a sewer pipe and telephone cable remaining in place on temporary bents over the structure site.

#### CONSTRUCTION INSPECTIONS

All structures were placed on cast-in-place concrete footings that varied in width from 5 ft to 8 ft 6 in. and in depth from 1 ft 8 in. to 3 ft 4 in. Subcuts and removal of unsuitable material beneath the footings ranged from none when medium to coarse sands were in place to 8 ft when peat soils were encountered. Granular bedding backfills per Mn/DOT Specification 3149.2F were then placed and compacted in 8-in. layers to 100 percent density by mechanical compactors.

Backfill placed around and over the structure was granular material per Mn/DOT Specification 3149.2D. However, only 95 percent or better density was required in placing this material.

Compaction within 3 ft of the arch was required to be made by using hand-operated soil compactors.

Backfill was placed and compacted in 8- to 12-in. layers simultaneously on both sides of the arch to prevent distortion and movement. Horizontal movement of the arch structure was minimal during backfilling operations.

Placement of an arch section was successfully accomplished by using a beam and cable system and a heavy lifting crane of 75-ton capacity or greater as shown in Figure 3.



FIGURE 3 Lifting system for placement of arch sections.

The arch sections, which were trucked to the structure sites on their sides, were raised by four cables and a steel beam, which was used to counteract tensile forces acting on the concrete. The arch sections were then slowly and carefully turned 90 degrees to their final resting position by means of four additional cables. During this operation, the weight of the arch is transferred to the four cables from the steel beam and its cable system.

Structure 1, located at Watertown, was placed over a recreation trail that required a 14-ft 6-in. vertical clearance. To gain this height, the bases of the arch sections were extended in length so that they rested flat in the footing notch (Figure 4). The headwalls rested on pedestals, which were built about 2 ft high to gain the correct height (Figure 5). Tops of several pedestals were ground smooth to provide good seats to receive the headwall sections.



FIGURE 4 Arch section with vertical bases.





FIGURE 5 Pedestal base for headwall.

The bolting details and procedure that secured the headwall to the arch sections with 1-in.  $\varnothing$  tie rods were revised on later installations because the receiving hole in the headwall was too small.

In the first arch installations, plywood shims were used between the arch sections and footing notch walls as well as under some wingwall sections for leveling and controlling the location of the sections (Figure 6). Use of wood shims was discontinued, and only permanent shims were allowed on later installations to minimize settlement and movement.



FIGURE 6 Use of shims.

Also on later installations, concrete leveling pads approximately 2 in. high were used under the wingwall tee sections to eliminate shimming. However, careful placement of mortar grout beneath the wingwalls still had to be specified to obtain total filling of the gap between the top of the wingwall footing and the bottom of the wingwall tee sections. A maximum slump of 6 in. on the mortar grout is now specified to hold it in place.

The mortar grout is currently placed on the footings and leveled out with the concrete leveling pads as shown in Figure 7. On some installations, the concrete leveling pads for the arch and wingwall



FIGURE 7 Placement of mortar grout.



FIGURE 8 Unformed leveling pads under arch sections.



FIGURE 9 Unformed leveling pads under wingwall sections.

sections were unformed, as shown in Figures 8 and 9. This caused some of the arch sections to rest on their corners, and in one case a steel shim was required under an arch section (Figure 10) for good bearing.

Flat butt joints between arch sections were close and in some installations tight together (Figure 11). This caused a small piece of concrete (3 x 5 in. by about 3/4 in. deep) to chip off an arch section, as shown in Figure 12. Plywood shims (3/8 or 1/2 in. thick) must be used to maintain the joint

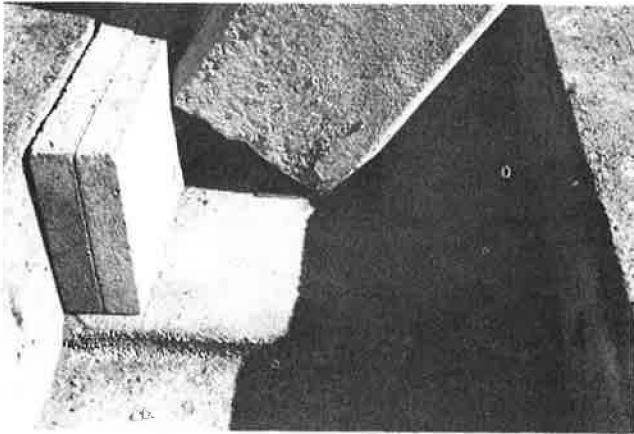


FIGURE 10 Arch base resting on steel shim.

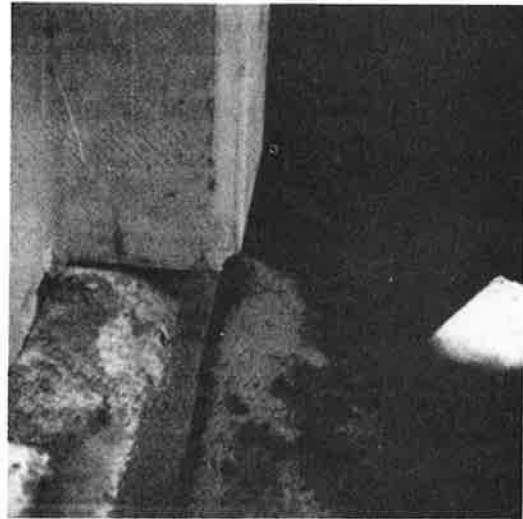


FIGURE 13 Headwall overhanging footing support.

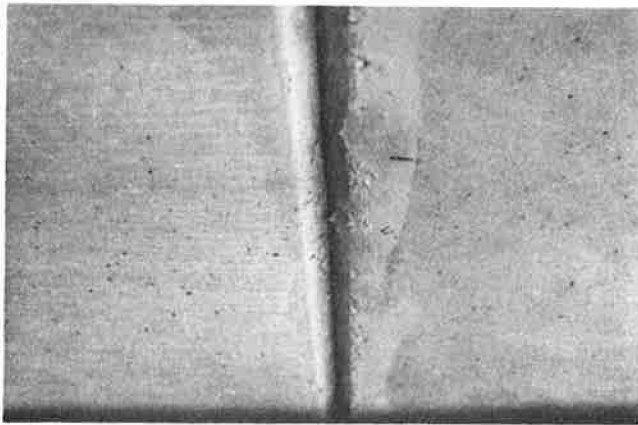


FIGURE 11 Joint between arch sections.

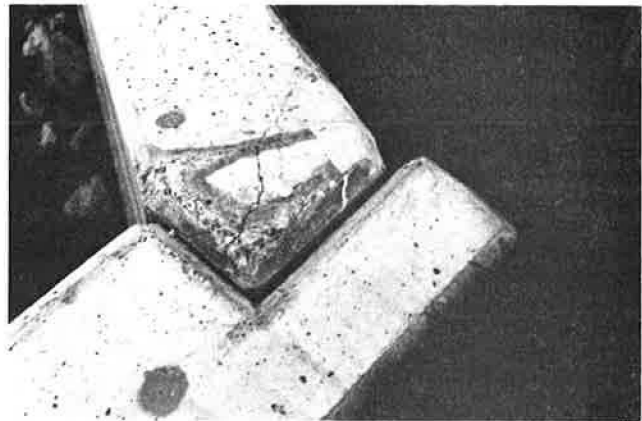


FIGURE 14 Crack across top of wingwall.

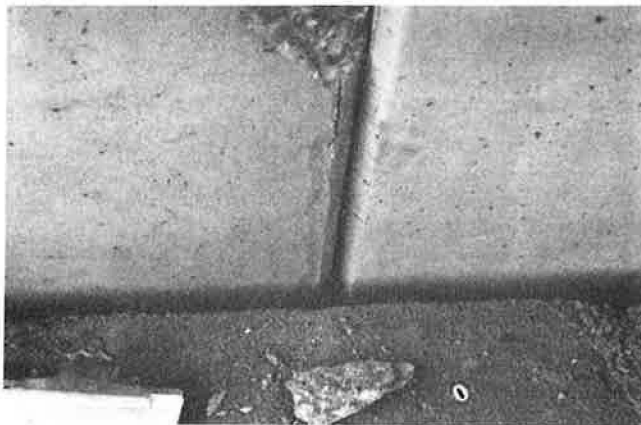


FIGURE 12 Arch section with chipped concrete edge.

space between arch sections to eliminate chipped concrete edges. Placement of the center arch section and progressive placement of sections outward to the headwalls will minimize the headwall overhang of its footing support. An accumulated error in spacing resulted in the overhang projection shown in Figure 13.

Mastic rope was hammered into the joints between the arch sections to fill the joint opening. Geotextile fabric (12 in. wide) was placed over the

mastic and joint to allow moisture to seep through the joint but to retain the soil fill. This system appears to be working satisfactorily on all installations.

#### FOLLOW-UP INSPECTIONS

Inspection of the wingwalls in 1984 indicated slight inward tipping of the upper wingwall sections caused by soil pressure against the wingwall and restraint of the headwall. A crack developed across the top of the northwest wingwall as a result of this pressure (Figure 14). Inspection of another structure under similar conditions revealed a shear crack at the top of the wingwall section that traveled down about 6 in. (Figure 15).

To successfully place an arch structure, the following requirements are recommended:

1. All concrete leveling pads should be formed to provide level bearing surfaces.
2. Vees of 3/4 in. should be used on vertical edges of arch, headwall, and wingwall sections to prevent raveling and spalling.
3. Handling holes should be filled with grout or equivalent to eliminate rusting of the handling eyes.

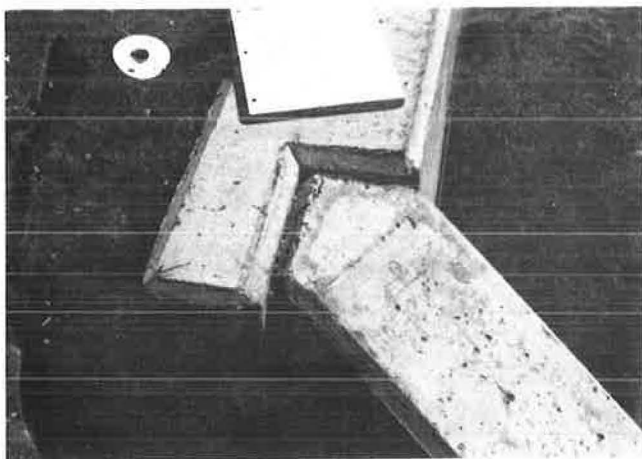


FIGURE 15 Shear cracks at top of wingwall.

4. Wood shim blocks should not be used. Variable-thickness concrete block shims and steel plate shims or some other suitable material of a permanent nature should be used.

5. The top 18 in. of the headwall notch should be recessed 1/2 in. to eliminate shear stress cracks at this location. Bituminous felt or equivalent should be placed in this gap between the wingwall and the headwall. A minimum of 1 1/2 in. of cover on reinforcement in the headwall and wingwall should be maintained.

6. Holes in the wingwall footings to receive the

special footing dowels should not be drilled completely through the concrete footing.

7. Ditch drains should not be placed adjacent to the wingwalls unless special riprap is placed to eliminate scour.

8. The grout used beneath the arch sections and wingwall footings and in handling holes should be approved by the engineer and have a maximum slump of 6 in. Also, the grout in the footing notch should slope down as it goes out from the arch sections.

9. Any concrete sections from which small parts have broken off should be patched by an approved standard repair procedure.

10. To obtain good compaction immediately adjacent to the arch structure, hand-held vibratory compactors should be used within a minimum of 3 ft from the sides and 1 ft from the top of the structure.

11. Filter cloth or equivalent should be placed behind the wingwall weep holes to prevent them from plugging up.

12. To prevent deterioration of the reinforcing steel in the vertex of the arch, the steel should be epoxy coated unless other approved methods are determined from experimental alternatives that are now being or will be evaluated.

#### SETTLEMENT AND MOVEMENT

According to the designer of the precast concrete arch structures, the following tolerances on settlement and movement are allowed (1):

1. Settlement differential of 2 in. between footings,

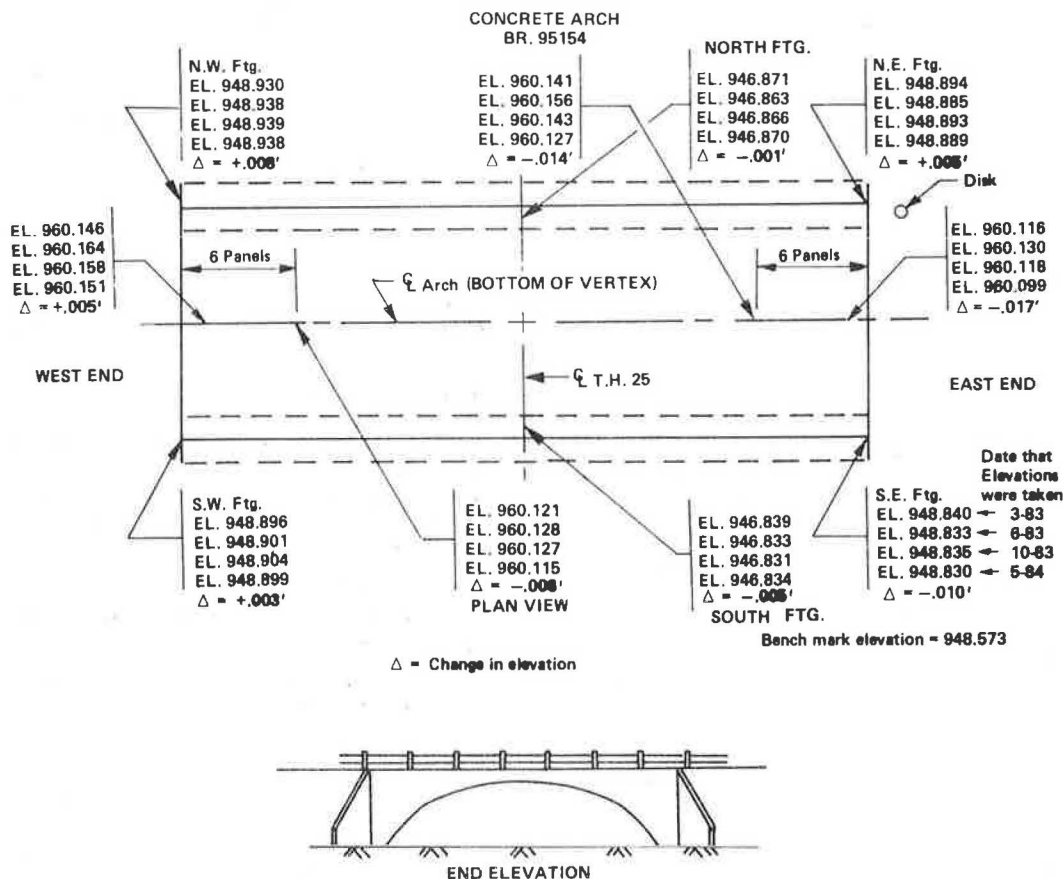


FIGURE 16 Changes in elevation of arch structure 1 (March 1983 to May 1984).



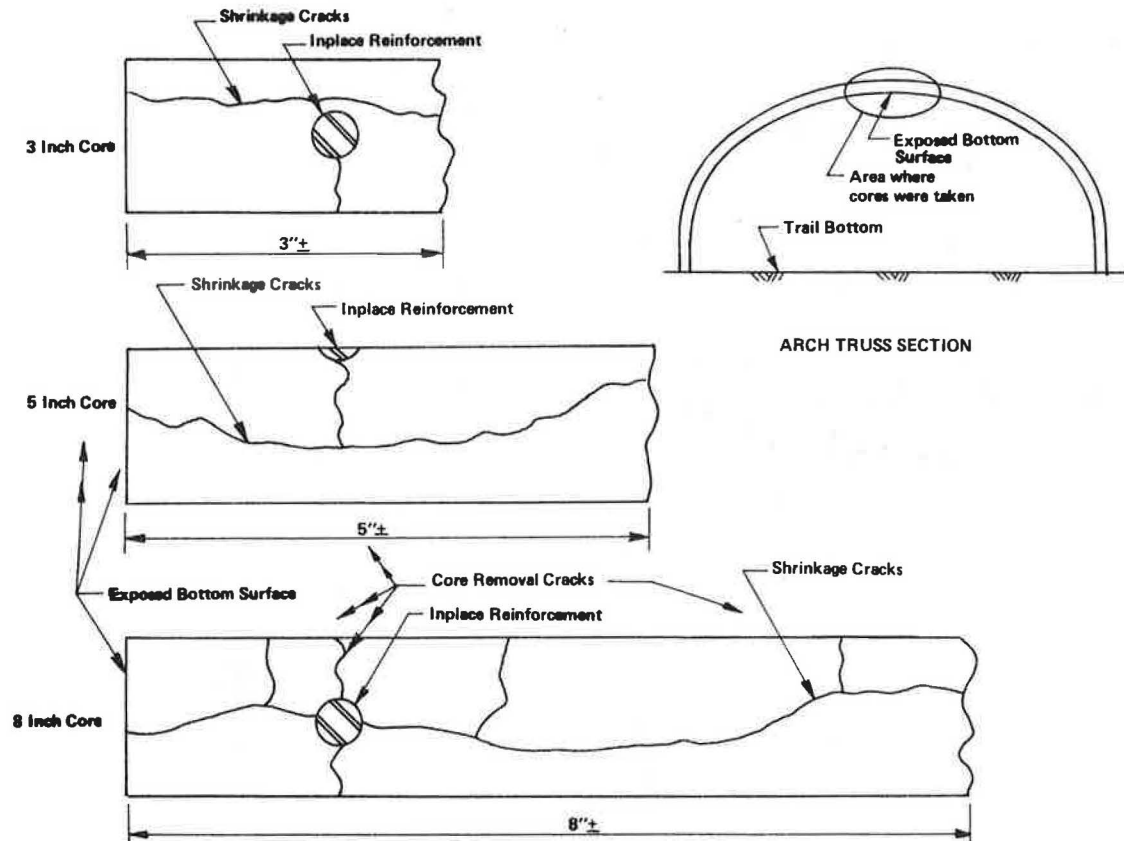


FIGURE 17 Cross sections of concrete cores.

TABLE 2 Arch Section Settlement

	At Vertex (in.)	Above Springline (in.)
Structure 5		
After backfill		
Center arch section	1 1/4	1/2 on south side 3/4 on north side
End arch sections	3/4	1/4 on south side 1/2 on north side
Nine months after backfill		
Center arch section	1 1/4	3/4
End arch sections	1 1/8	3/4
Structure 3		
After backfill		
Center arch section	3/4	1/2 on south side 5/8 on north side
End arch sections	1/2	3/8 on south side 3/8 on north side
Three months after backfill		
Center arch section	1 5/16	1
End arch sections	7/8	3/4
Structure 2		
After backfill		
Center arch section	5/8	5/8 on south side 1/2 on north side
End arch sections	5/8	5/8 on south side 1/2 on north side
Three months after backfill		
Center arch section	1 1/8	1 on south side 3/4 on north side
End arch sections	7/8	3/4 on south side 5/8 on north side

- Settlement differential of 1/2 in. per 30 ft of footing length, and
- Horizontal movement of 1 in. in the footings.

Elevation changes at the vertex and top of footings at corner locations generally indicate settlement of the structures. Results of a survey taken of Structure 1 are shown in Figure 16 in which differential settlement and upward movement of the arch structure from frost and related action are given.

On three selected structures (2, 3, and 5) special elevation and horizontal distances were taken before and after backfill on the structure. Results are shown in Tables 2 and 3.

Hairline cracks are apparent in the vertex of nearly all arch sections (at least one per section) as well as in the headwalls. To determine the cause and type of cracks, on April 26, 1984, three cores (2-in. diameter) were taken from three different concrete arch sections of Structure 1 in their vertex areas at hairline crack locations. The depth of one core was 3 in., another core was 5 in., and the last core was 8 in. These hairline shrinkage cracks projected upward through or close to the transverse reinforcing steel, directly through the concrete (Figure 17).

#### COST COMPARISONS

Comparison of costs between precast concrete arch structures and structures with equivalent cross-sectional areas has been by cost estimates only. Until

TABLE 3 Horizontal Movement of Arch Sections

	Center Arch Section (in.)	End Arch Sections (in.)
Structure 5		
After backfill	3/8 outward	3/8 outward on south side 1/4 outward on north side
Nine months after backfill	1/2 outward	3/8 outward on south side 1/2 outward on north side
Structure 3		
After backfill	1/16 inward	1/8 inward
Three months after backfill	—	1/4 inward on south side 1/8 inward on north side
Structure 2		
After backfill	1/16 inward	1/4 inward on south side
Three months after backfill	1/8 inward	3/4 inward on south side 1/8 inward on north side

July 1984, all arch structures were considered experimental and were not subjected to the competitive bidding process. As of July 1984, certain structural conditions (fills less than 6 ft and fills less than 2 ft with a concrete slab or equivalent placed over the structure) were no longer considered experimental. It is now required that these precast concrete arch structures be competitively bid against alternative structures.

The estimated cost comparisons given in Tables 4 and 5 are subject to the conditions stated on each table. It is difficult to obtain equivalent alternatives because grading and backfill required for installation of precast concrete arch structures and

metal long-span structures are placed in the approach grading and not included in the structure cost. Bridge structures that do not have the extensive excavation and backfill over them are estimated with a completed roadway. Also, the requirement that bridges over waterways have 2 ft of freeboard in addition to the waterway opening increases their costs because of the resultant longer spans.

## CONSTRUCTION TIME FRAME

Construction time for arch structures consists mainly of excavation, placement of concrete footings, and backfill work. Subject to some variances, the installation time frame in Table 6 has been observed to date.

## Mn/DOT POLICY

The following provisions represent Minnesota's policy toward the precast concrete arch structures as of July 1984:

1. Based on the performance of all in-place structures, precast concrete arch structures that have 2 to 6 ft of fill (at centerline roadway) over them may be considered nonexperimental, provided that they are competitively bid against similar alternative structures such as concrete box culverts or long-span corrugated steel arch structures. Arch structures with less than 2 ft of fill and covered by a reinforced concrete slab should also be considered nonexperimental, provided that they are competitively bid against alternative structures.

TABLE 4 Estimated Cost Comparisons of Concrete Arches and Alternative Structures

STRUCT NO.	CONCRETE ARCH *****				HEADWALL (SPANDREL)		FOOTINGS	REBARS	⑤ TOTAL MATERIALS & INSTALLATION
	BUILT	BRIDGE	SIZE	ARCH UNITS	WINGWALLS	WALLS			
5.	June 1983	95675 (Dumfries)	A41X10	11 @ 669.70	4 @ 3600.00	2 @ 6600.00	113 cy @ 147.00	5500 @ .54	91,381.20
1	Aug. 1982	95154 (Watertown)	A31X14	15 @ 761.23	4 @ 7221.05	2 @ 6853.00	111 cy @ 155.00	10909 @ .50	133,850.90
4	Sept. 1982	91940 (Cyrus)	A41X10	11 @ 1000.00	4 @ 5000.00	2 @ 7500.00	168 cy @ 140.00	4508 @ 1.00	129,028.00
① CONCRETE BOX CULVERT ALTERNATES *****									
		BRIDGE	EQUIVALENT STRUCTURE	TOTAL COST					
5	95675	3 @ 12x8 barrels					133,179		
1	95154	2 @ 10x10 barrels (15@6') 90° long with wingwalls			(2) (90) (481.24) + 4 (7652) =		117,231		
4	9140	Alternate Not Estimated							
① STEEL LONG SPAN STRUCTURE ALTERNATES *****									
5	95675	3 barrels 66 ft. long of long span structures					132,000		
1	95154	90' of high parabola with 22'-11" span & 14'-0" rise					90,000 (2)		
4	91940	Alternate Not Estimated							
① BRIDGE ALTERNATE *****									
		BRIDGE	EQUIVALENT STRUCTURE	TOTAL COST					
5	95675	1 span bridge (quad tee)	40' wide x 52' long (\$65/ft. <sup>2</sup> ) =				\$135,200		
1	95154	1 span quad tee bridge 50 x 56 long (\$50/ft. <sup>2</sup> )							
		2 x 20' + 16' = 56 (based on 1 to 1 slopes)					\$140,000		
4	91940	Alternate not estimated							

① These alternates are estimated & are included for informational purposes.

② The high profile arch shape used best fits the trail dimensions & reflects the somewhat lower cost.

③ The total cost shown does not require additional grading or pavement work as required in the other 3 structure types which is not included in the costs of the other three alternates.

④ This box culvert alternate does not yield an actual 16' by 10' clear opening for the trail, but does yield an equivalent opening area.

⑤ Actual Contract Costs

TABLE 5 Cost Comparison of Precast Concrete Arches and Alternative Structures

Structure No.	Structure Type/Size	Barrel Units	Wingwalls	Headwalls/End Sections	Footings	Rebars	Total Material & Installation 3, 4, 5
3	A41	58'x\$8000/FT.	4x\$4500 EA.	2x\$6500 EA.	70 CY x \$200/CY	4140 lb. x \$1/lb.	\$ 98,254 1
	2 @ 12'x8' & 2 @ 10'x6' Concrete box	144'x\$474/FT. + 144'x\$357/FT.		4x\$6464 EA. + 4x\$4002 EA.			\$161,528 2
2	A41	54'x\$800	4x\$4500 EA.	2x\$6500	66x\$200	3880x\$1	\$ 93,304 1
	3 @ 10'x8'	3x72x\$141		6x\$5698			\$123,612 2
8	A41	90'x\$869	4x\$4118	2x\$3649	147x\$125	8270x\$.35	\$128,649 1
	3 @ 12'x10' Conc. Boxes	3x148x\$572					\$305,142 2
	1 @ 20'-1"x13' + 2 @ 14'-8"x9'-4" Horiz. Ellipse, SSP	148'x\$390+ 2x142'x\$330	6x\$8529				\$151,440 2
7	A31	72'x\$556	4 @ \$3787	2 @ \$5008	98x\$160	5184x\$.35	\$ 97,694 2,6
	2 @ 12'x10' Conc. Boxes	2x100'x\$572		4 @ \$8529			\$148,500 2
	25'-5"x16'-9" Horiz. Ellipse, SSP	108x\$700		2 @ \$2300			\$ 80,200 2

1. Bid prices already awarded (w/o Exc. &amp; Backfill)

2. Estimated prices (by Designer) w/o &amp; Backfill)

5. Costs of the alternate structures are estimates only. Also, all the costs shown are construction costs only, and do not represent life cycle costs.

3. Backfill requirements for the various alternates may vary depending on the structure type and the soils conditions

4. Cost of riprap is included in total cost shown for precast concrete arch structures

6. Concrete Arch has 0.1' less backwater than Horiz. Ellipse for both Q<sub>50</sub> and Q<sub>100</sub>, but it is the smallest size available which results in somewhat higher costs.

TABLE 6 Installation Time Frame

Construction Work	Time (days)
Bypass work for stream flow and excavation for structure <sup>a</sup>	5-8
Subcutting and placement of granular backfill for footings <sup>b</sup>	2-4
Formation and placement of concrete footings for arch and wingwall sections	5
Curing of concrete in footings <sup>c</sup>	2-3
Placement of arch, headwall, and wingwall sections, including grouting and related work	2-4
Backfill in 8- to 12-in. lifts and compaction accordingly	3-5
Placement of roadway surface	1-2
Placement of riprap, sodding and seeding of slopes, and miscellaneous work	3-5

<sup>a</sup>Additional time may be required for dewatering and rerouting of streams during periods of heavy runoff and high water.<sup>b</sup>This construction is not required when the natural soil material will support the footing loads according to the soils engineer.<sup>c</sup>This time may be increased for lower ambient temperatures.

2. Arch structures not meeting the foregoing requirements or with flows greater than 7.5 fps should be considered experimental and subject to the appropriate experimental procedures.

3. Scour protection for these structures should be as recommended by or approved by the Mn/DOT hydraulics engineer.

4. Soil surveys, borings, and so on should be made for each structure subject to the approval of the Mn/DOT soils engineer.

## GENERAL CONCLUSIONS

From the experimental results, it appears that movement and settlement of the structures are within tolerances. Cracking of arch sections at the vertex area occurs, but the resultant hairline crack widths are somewhat less than the generally accepted maximum allowable crack width of 0.01 in.

Scour of the footings is prevented by using filter material and rock riprap, which are sized to meet the stream velocities.

The potential use of these proprietary structures is restrained because FHWA requires competitive alternative structures when proprietary products are used. This will generally require designers to make alternative plans available for each site at which an arch structure is selected.

## REFERENCE

1. W. Heierli. Precast BEBO Bridge: Static Calculations for the Standard Design. BEBO of America, Kensington, Md., Nov. 28, 1980.

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