AIR FORMED ARCH CULVERT CONSTRUCTION
Washington County

FINAL REPORT
IOWA HIGHWAY RESEARCH BOARD
PROJECT HR-313

FEBRUARY 1994

Highway Division

Iowa Department of Transportation

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AIR FORMED ARCH CULVERT CONSTRUCTION
WASHINGTON COUNTY

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7. ACKNOWLEDGEMENT OF COOPERATING ORGANIZATIONS

R. G. Elder and Son Company
Washington County Secondary Roads Department

8. ABSTRACT

Iowa's secondary roads contain nearly 15,000 bridges which are less than 40 ft (12.2 m) in length. Many of these bridges were built several decades ago and need to be replaced. Box culvert construction has proven to be an adequate bridge replacement technique. Recently a new bridge replacement alternative, called the Air-O-Form method, has emerged which has several potential advantages over box culvert construction. This new technique uses inflated balloons as the interior form in the construction of an arch culvert. Concrete was then shotcreted onto the balloon form.

The objective of research project HR-313 was to construct an air formed arch culvert to determine the applicability of the Air-O-Form technique as a county bridge replacement alternative.

The project had the following results:

- The Air-O-Form method can be used to construct a structurally sound arch culvert.
- The method must become more economical if it is to compete with box culverts.

Continued monitoring should be conducted in order to evaluate the long-term performance of the Air-O-Form method.

9. KEY WORDS	10. NO. OF PAGES
Air-O-Form Method Inflated Balloon Shotcrete Bridge Replacement Culverts	29

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DISCLAIMER

The contents of this report reflect the views of the authors and do not necessarily reflect the official views of the Iowa Department of Transportation. This report does not constitute any standard, specification or regulation.

INTRODUCTION

Iowa's secondary road network contains nearly 15,000 bridges which are less than 40 ft (12.2 m) long. Many of these bridges were constructed several decades ago and are now becoming either structurally deficient or functionally obsolete.

One method often used to replace such a bridge is to construct a single or multiple box culvert. This type of construction has proved to be an adequate replacement for bridges. However, box culvert construction can be expensive and time consuming. Construction is slowed because forms cannot be removed and reused until the poured concrete reaches an acceptable strength.

Recently, a new method of culvert construction has been developed. The Air-O-Form technique, as it is known, uses an air inflated balloon as the inside form for the construction of an arch shaped culvert. The balloon can be inflated quickly, saving time the contractor would otherwise spend forming the box culvert. The balloon used can also be made to fit a variety of shapes and sizes.

The arch shape offers several advantages over a box. First, the arch is structurally more efficient than the box. A culvert of greater strength can be constructed using less steel and concrete. Also, the arch can be hydraulically more efficient. A third advantage is the absence of a wall in the center of the

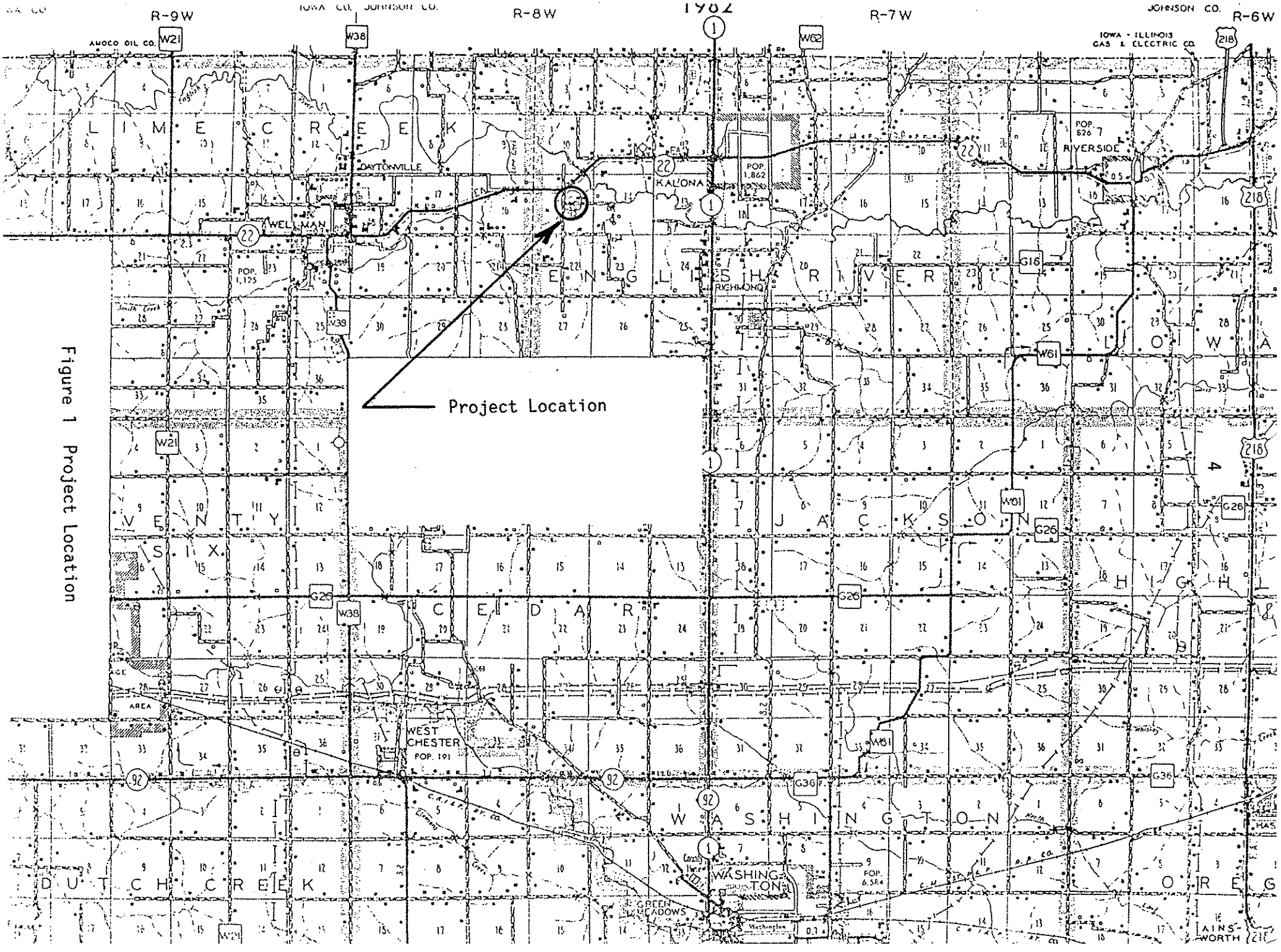

Figure 1 Project Location

Pre Culvert Work

Before the contractor began constructing the culvert, bridge removal and excavating work were required. Washington County hired a local contractor to remove the existing bridge and abutments. The county then proceeded with tree removal and reshaping of the stream channel. This work was completed by September 26, 1988.

Culvert Floor and Headwalls

On October 3, 1988 the contractor began work constructing the arch culvert. Although the contractor had experience in other types of concrete work, this was the first experience the contractor had constructing a culvert. Therefore, it was very important Washington County had an experienced inspector on hand. The inspector assigned to the project was very capable and offered valuable suggestions to the contractor throughout construction of the floor and headwalls.

Because of its size, the floor was divided into halves for ease in construction. The south half was constructed first. Poor weather conditions and the length of time required to unload concrete from the ready mix truck made it difficult to prevent cold joints. The second half of the floor went much more smoothly. Favorable weather conditions and improved contractor efficiency resulted in the pour being completed much more quickly.

The headwalls were treated in the same manner. The south walls were formed and poured first, then the north walls. Rather than pouring around the walls in 3 to 4 ft (0.9 to 1.2 m) lifts until completed, the contractor poured each wall full depth before pouring the adjacent wall. The contractor had difficulty consolidating the concrete uniformly using this technique. A significant amount of honeycombing of the walls resulted. These areas required patching with mortar before being backfilled.

Arch Construction

Once the floor and headwalls were completed, the contractor began work on the air formed arch. Three deflated balloons were positioned on the floor. The contractor then began placing the metal straps over the deflated balloons.

The first step in this process was to bolt a perforated angle iron on each side of the floor at the location where the floor meets the arch. Metal straps were then cut to the desired length and attached to the angle irons through the perforations. The straps were spaced 8 in. (200 mm) apart.

Once the straps were fastened, the three balloons were inflated. As the balloons were inflated, the straps were lifted into place. There was some difficulty keeping the straps evenly spaced during inflation. The straps tended to slide together in groups of two or three as the balloons were inflated. However, by slightly

deflating the balloons and repositioning the straps, the contractor was able to correct the problem.

After inflating the balloons to the necessary air pressure of 0.81 psi (5.6 kPa), the contractor began placing reinforcing steel. Number 4 bars (13 mm) were used for longitudinal steel reinforcement and were placed at 8 in. (200 mm) spacings. Number 5 bars (16 mm) were then used for transverse reinforcement and spaced 3.75 in. (95 mm) apart. The reinforcement was set away from the balloons by strings of steel chairs placed around the arch. The entire operation, from positioning the deflated balloons to finishing placing the reinforcing steel, took three days. Once the steel was in place the arch was ready to be shotcreted.

Prior to shotcreting the arch, a test panel was prepared to be shotcreted to ensure all pumping equipment was in good working condition. Two days before the arch was scheduled to be shotcreted, the contractor attempted to shotcrete the test panel. However, the concrete was too stiff to be pumped through the hose lines. It was determined that not enough fines were present in the fine aggregate (6.1% passing #50, 0.3% passing #100). A new fine aggregate source was located and aggregate was hauled in for the project. This material, a masonry type sand from Ideal Sand in Farmington, Iowa, contained 21% material passing the #50 sieve and 3.7% passing the #100 sieve. A new mix design was prepared

and the following day the test panel was successfully shotcreted. The final aggregate gradations and mix design are given in Appendices B and C. Originally, 800 pounds of cement per cubic yard (475 kg/m³) were to be used. However, since there was not time to test the new aggregate mix for strength, an additional 20 lbs (9 kg) of cement were added to offset any strength loss due to the new fine aggregate.

Having successfully shotcreted the test panel, the contractor was ready to shotcrete the arch. Two experienced shotcrete nozzlemen were brought from Arizona to shotcrete the arch.

On Thursday, October 27, 1988 the arch culvert was shotcreted. The two nozzlemen worked on opposite sides of the arch in order to keep the weight of the shotcrete evenly distributed around the balloons. Shotcrete was applied full depth in approximately 4 ft (1.2 m) lifts along the length of the culvert. The entire process took approximately eight hours.

The shotcreting operation proceeded relatively smoothly. However, on two occasions the hoses became plugged, resulting in delays of nearly one-half hour each. It was determined these delays were due to the pump operator trying to pump concrete having insufficient slump.

Washington County and Iowa DOT personnel were present and performed testing throughout the shotcreting operation. Test results are listed in Appendix D.

After the arch was completed, the contractor applied a white pigment curing compound and covered the arch with insulated blankets. The balloons were kept inflated while the arch developed enough strength to support itself. A determination was made by Washington County to keep the balloons inflated until a shotcrete strength of 3500 psi (24150 kPa) was reached as determined from cylinders made when the shotcreting was completed. This requirement was met in two days, at which time the balloons were deflated and removed.

POST CONSTRUCTION OBSERVATIONS

After the balloons were removed, the interior of the arch could be observed. Two relatively large cracks had already appeared, one on each side of the arch approximately 4 ft (1.2 m) above the floor. These cracks ran nearly the length of the culvert. It was determined these cracks were the result of cold joints which formed while the pump hoses were plugged.

Further visual observation also revealed numerous instances where the shotcreting operation had punctured small holes in the balloons. These holes allowed air to escape, forming small pockets in the culvert. Both the cracks and the air pockets were filled with mortar by the contractor.

These defects should not damage the structural integrity of the arch. Since any load applied would result in compression of the concrete the horizontal cracks should close. The air pockets should not have a significant effect on the arch integrity.

FIELD REVIEW

Visual examinations were performed on the Air-O-Form arch culvert annually. The examinations found the culvert to be structurally sound. Some cracking did develop at both ends of the culvert near the top. The cracks appear to have started in the end wall. The cold joints that formed during construction are now allowing some seepage of ground water (see photo No. 7 and No. 8 in Appendix E). This seepage may cause future distress if freeze/thaw cycles deteriorate the concrete at the cold joints.

The culvert allowed free flow of water and debris. This was important since a small wooded area lies upstream of the culvert. To demonstrate how much open area was available, the county engineer parked and photographed three pickups side by side in the cross section of the arch. Photo #9 shows the culvert in April of 1993. Note, there is no debris or blockage of flow in the cuvlert or stream bed.

PROJECT COST

The contract price for the Air-O-Form semicircular arched culvert was $81,349.58. The culvert was 52 ft (15.8 m) long with a

12 ft. (3.66 m) radius. The price included the footing and headwalls. The bid was more than $10,000 over the cost estimate for a similar sized box culvert. One reason for the higher cost is the fact that this was the first time the Air-O-Form method was performed in Iowa and by the contractor.

CONCLUSIONS

The objective of this research was to demonstrate the applicability of the Air-O-Form method of arch culvert construction. In this respect, the project was successful. However, claims of this method being faster and less costly than normal box culvert construction techniques were not met. The strength and durability properties of the shotcrete used in the structure was acceptable. However, care and precautions should be taken so cold joints will not form during construction. The arch culvert has shown good performance to the current time. The long-term structural capacity of the arch looks good, but only time will allow an accurate estimate of design life . Continued monitoring should be done in 5 or 10 years in order to evaluate its performance on a longer term.

ACKNOWLEDGEMENTS

This research project was sponsored by Washington County and the Iowa Department of Transportation through the Iowa Highway Research Board. Partial funding for this project was from the Secondary Road Research Fund in the amount of $28,900.

The authors wish to extend appreciation to the Washington County Board of Supervisors and the Iowa DOT for their support in developing and conducting this project. The Washington County inspection personnel also deserve recognition for the extra effort put forth on this project.

Appendix A
Contract

Form 383 4-72

CONTRACT

Kind of Work Air Form Concrete Arch Culvert Miles

Project No. B-153 Reseach Proj. HR-313 County Washington

THIS AGREEMENT made and entered by and between Washington County, Iowa, by its Board of Supervisors consisting of the following members: Robert L. Pearson, M. R. Flickinger and Edward Brophy

, party of the first part, and

G. Elder and Son Company, Inc. of Des Moines, IA , party of the second part.

WITNESSETH: That the party of the second part, for and in consideration of Eighty one thousand three hundred forty nine and 58/100 ---------- Dollars ($ 81,349.58) payable as set forth in the specifications constituting a part of this contract, hereby agrees to construct in accordance with the plans and specifications therefore, and in the locations designated in the notice to bidders, the various items of work as follows

Item No.	Item	Quantity	Unit Price	Amount
1.	Structural Concrete Footing & Headwalls	256.21 CY	194.00	49,704.74
2.	Reinforcing Steel Footing & Headwalls	27,497 Lbs	0.40	10,998.80
3.	Structural Concrete for Arch	54.50 CY	255.92	13,947.64
4.	Reinforcing Steel for Arch	8,871 Lbs.	0.40	3,548.40
5.	Class 20 Excavation	210 Cu. Yds	15.00	3,150.00
6.	Removal by County			
Total				$ 81,349.58

Said specifications and plans are hereby made a part of and the basis of this agreement, and a true copy of said plans and specifications are now on file in the office of the County Auditor under date of , 19 .

That in consideration of the foregoing, the party of the first part hereby agrees to pay to the party of the second part, promptly and according to the requirements of the specifications the amounts set forth, subject to the conditions as set forth in the specifications.

That it is mutually understood and agreed by the parties hereto that the notice to bidders, proposal, the specifications for Project No. , County, Iowa, the within contract, the contractor's bond, and the general and detailed plans are and constitute the basis of contract between the parties hereto.

That it is further understood and agreed by the parties of this contract that the above work shall be commenced on or before, and shall be completed on or before:

	Approx. or Specified Starting Date or Number of Working Days	Specified Completion Date or Number of Working Days

That time is the essence of this contract and that said contract contains all of the terms and conditions agreed upon by the parties hereto.

It is further understood that the second party consents to the jurisdiction of the courts of Iowa to hear, determine and render judgement as to any controversy arising hereunder.

IN WITNESS WHEREOF the parties hereto have set their hands for the purposes herein expressed to this and three other instruments of like tenor, as of the 6th day of September, 1988.

Approved:
IOWA STATE HIGHWAY COMMISSION

By Richard L. Nunn
County Contracts Engineer

Date 9/6/88

Washington County, Iowa
Party of the first part

By Robert L Pearson
Chairman

R. G. Elder and Son Company Inc.

By R. G. Elder Pres.

Appendix B
Aggregate Gradations

Coarse Aggregate
Source: River Products' Conklin Quarry, Coralville

Sieve Size	% Passing	ACI Code Recommendation
3/4"	100	100
1/2"	99	90-100
3/8"	58	40-70
4	5.6	0-15
8	0.8	0-5
#200	0.8	---

Fine Aggregate
Source: Ideal Sand Pit, Farmington

Sieve Size	% Passing	ACI Code Recommendation
3/8"	100	100
4	100	95-100
8	99	80-100
16	97	50-85
30	70	25-60
50	21	10-30
100	3.7	2-10
200	3.4	---

Appendix C
Mix Design

Mix Design
Dry Batch Weights

Material	1 Yard	$1 m^3$	7 Yards	5.355 m^3
Cement	820 lb.	487 kg	5740 lb.	2604 kg
Coarse Aggregate	874 lb.	520 kg	6244 lb.	2775 kg
Fine Aggregate	1994 lb.	1182 kg	14539 lb.	6595 kg
Water	35 gal.	173 L	245 gal.	927 L
Air Entraining Admix.	2.14 fl. oz.	54.73 ml	15 fl. oz.	443.0 ml
Water Reducing Admix. (WRDA w/Hycol)	4 fl. oz./cwt.	2.6 ml/kg	231 fl. oz.	6790 ml

Appendix D
Concrete/Shotcrete
Testing

HR-313
Air Formed Arch Culvert Construction
Washington County

CONCRETE/SHOTCRETE PROPERTIES

Truck Load No.	Truck No.	Time	%Air Before Shot.	%Air After Shot.	Slump Before Shot.	Slump After Shot.
1	732	11:30	7.0	5.0	2 1/2	1 1/4
2	670	12:30	6.6	4.7	2.0	1.0
3	706	1:00	5.7	3.9	3 1/2	1 5/8
4	732	2:00		4.9		
5	799	2:30	6.8		2 1/4	
6	686			4.5		
7						
8						
9						
10	706	6:45		4.7		1.0

*1 in. slump = 25 mm slump

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The following table lists the test cylinders made and the truck load number from which the concrete/shotcrete was obtained.

Truck Load No.	Cylinder No.'s
2	S1, S2, S3 H1, H2, H3
4	S4, S5, S6 H4, H5, H6
6	S7, S8 H7, H8, H9
10	Block 1, Block 2 (filled by hose)

Cylinders S1-S6 were made by IDOT in steel molds. Shotcrete was shot into the molds from the nozzle.

Cylinders S7, S8 were shot into plastic cylinders.

Cylinders H1-H9 Shotcrete was shot into a 5 gallon bucket. The material was then scooped into cylinders and rodded in a conventional manner.

Cores D1 - D7 and E1 - E7 were drilled from two panels (block 1 and block 2 above) which were shotcreted immediately following completion of the arch

Form 820259
6-83

Misc.Conc.
K.Jones
M.Callahan

Iowa Department of Transportation

MATERIALS DEPARTMENT

TEST REPORT - MISCELLANEOUS MATERIALS

AMES LABORATORY

Material Concrete Shoterete Cylinders Laboratory No. ACC8-812-831

Intended Use Air Formed Arch Culvert

County Washington Proj. No. HR-313

Producer Wilson Concrete Co. Contractor R.G. Elder & Son Co.

Source

Unit of Material Air Formed Arch Culvert (S,H,D,E, Cylinders) and test panel (A,B,C, Cylinders)
6 X 12 Cylinders

Sampled by Mark Callahan Sender's No.

Date Sampled 10-26-88 Date Rec'd 10-28-88 Date Reported 11-28-88

	LabNo.	CylinderNo.	Total Load Lbs.	Age	PSI
ACC8-	812	H-1	125000	7 Day	4420
	813	H-2	126400	" "	4470
	814	H-3	119400	" "	4220
	815	S-1	121800	" "	4310
	816	S-2	154800	" "	5480
	817	S-3	120000	" "	4260
	818	H-4	126500	14 Day	4470
	819	H-5	125000	" "	4420
	820	H-6	100500	" "	3550
	821	S-4	133000	" "	4700
	822	S-5	138000	" "	4880
	823	S-6	140000	" "	4950
	824	H-7	147000	27 Day	5200
	825	H-8	149000	" "	5270
	826	H-9	142500	" "	5040
	827	S-7	95500	" "	3380
	828	S-8	103500	" "	3660
	829	A	120500	28 Day	4260
	830	B	126000	" "	4460
	831	C	147000	" "	5200

DISPOSITION:

Signed Testing Engineer

Form 820259
6-83

Misc.Conc.
K.Jones
M.Callahan

Iowa Department of Transportation

MATERIALS DEPARTMENT

TEST REPORT - MISCELLANEOUS MATERIALS

AMES LABORATORY

Material Concrete Shoterete Cores Laboratory No. ACE8-1501-1516

Intended Use Air Formed Arch Culvert

County Washington Proj. No. HR-313

Producer Wilson Concrete Co. Contractor R.G. Elder & Son Co.

Source

Unit of Material Air Formed Arch culvert cores 4" Cores

Sampled by Mark Callahan Sender's No.

Date Sampled 10-26-88 Date Rec'd 10-28-88 Date Reported 11-28-88

	Lab.No.	CoreNo.	Total Load Lbs.	Age	Cut Length	PSI
ACE8-	1501	D-1	59400	7 Day	4.4	4250
	1502	D-2	65600	" "	4.7	4830
	1503	E-1	62400	" "	4.9	4650
	1504	E-2	56800	" "	6.1	4350
	1505	D-3	68400	14 Day	4.6	5010
	1506	D-4	71200	" "	4.7	5250
	1507	E-3	71400	" "	6.2	5480
	1508	E-4	72800	" "	6.5	5620
	1509	D-5	80400	27 Day	4.6	5880
	1510	D-6	88400	" "	4.6	6470
	1511	D-7	81600	" "	4.7	6010
	1512	E-5	74800	" "	6.6	5780
	1513	E-6	76000	" "	6.6	5880
	1514	E-7	76200	" "	6.5	5890
	1515	B-1	102000	28 Day	5.5	7710
	1516	B-2	102800	" "	8.8	8310

*1 lb. = 0.4535 kg
1 psi = 6.9 kPa
1 in. = 25 mm

DISPOSITION:

Signed [signature] Testing Engineer

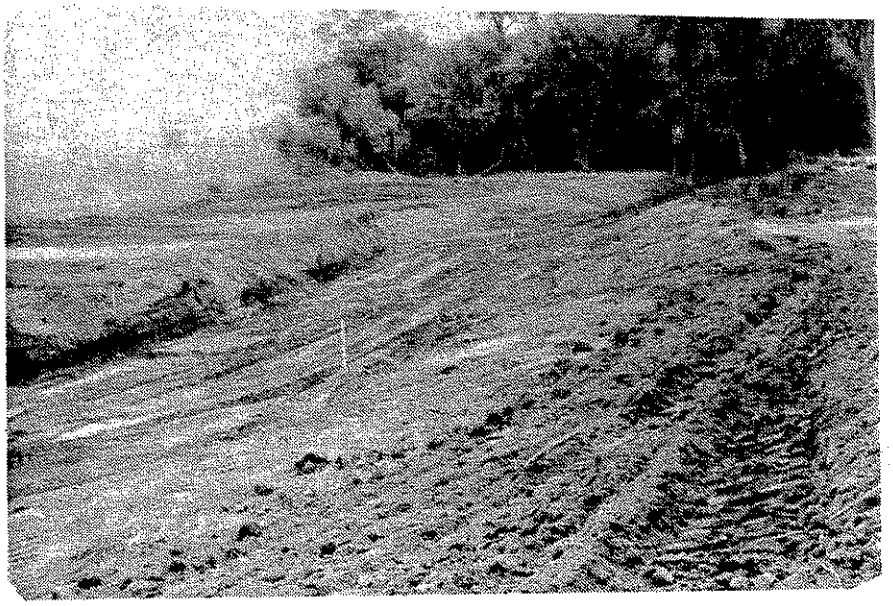

Photo 1: Culvert location prior to construction

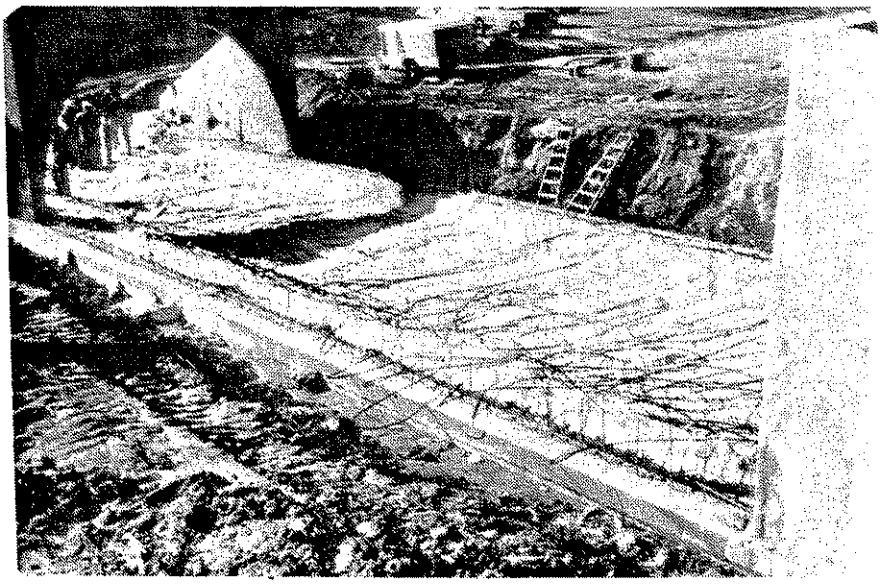

Photo 2: Metal band installation prior to balloon inflation

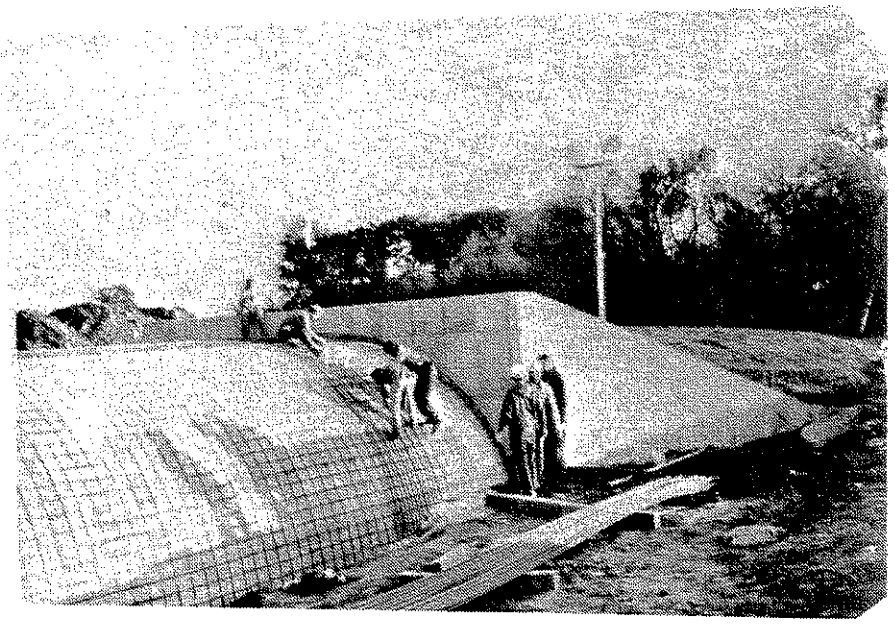

Photo 3: Reinforcing steel placement on inflated balloon

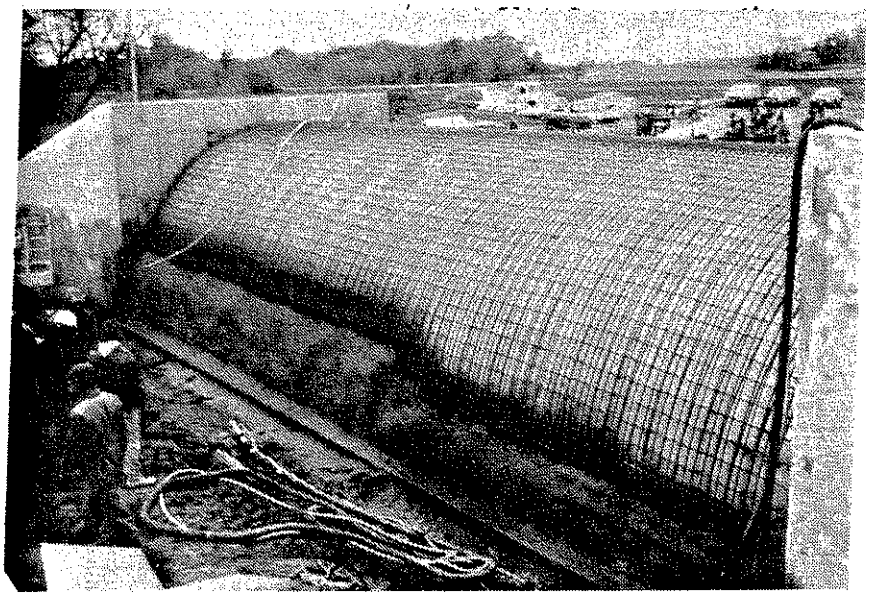

Photo 4: Early stage of shotcreting operation

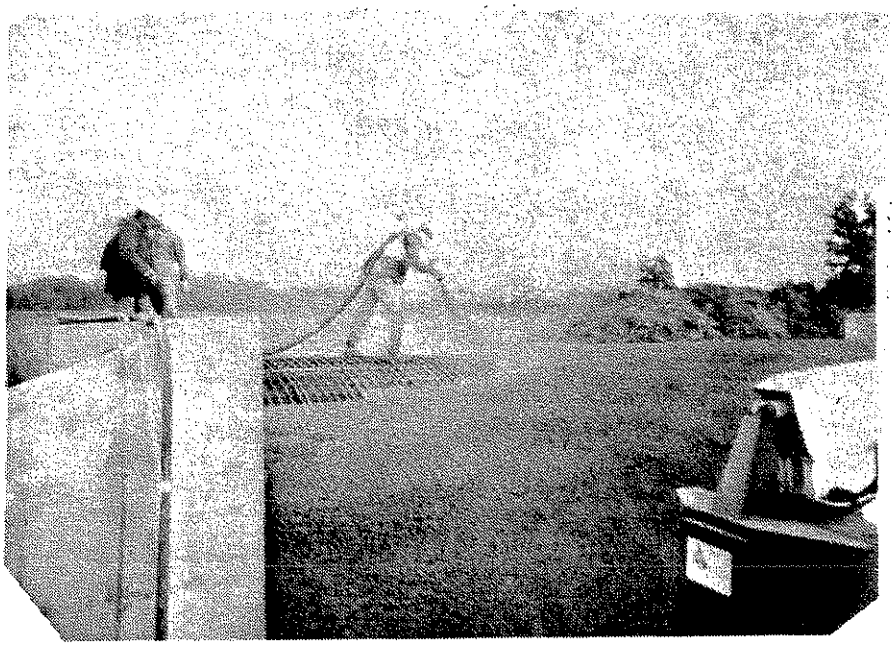

Photo 5: Completing shotcreting operation

Photo 6: Concrete arch culvert in place

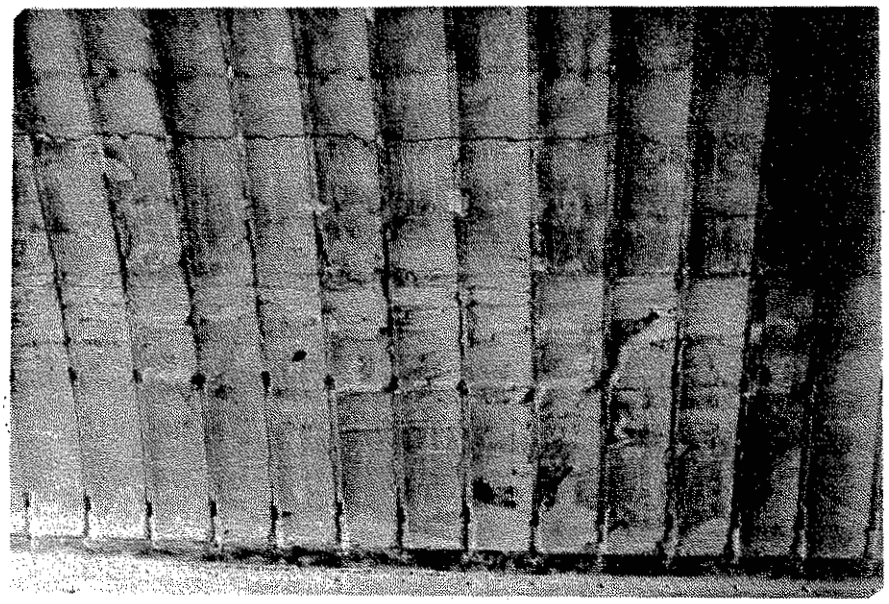

Photo 7: Longitudinal crack inside arch

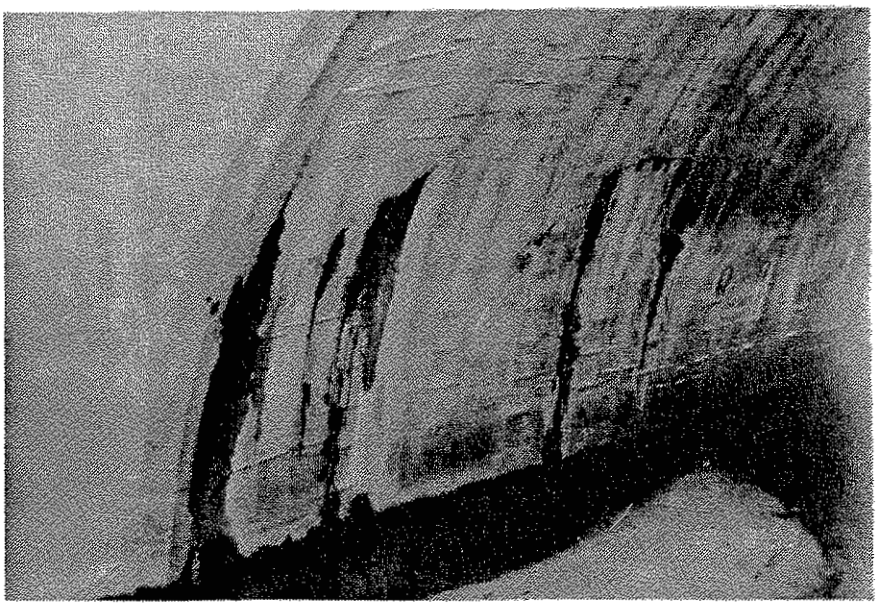

Photo 8: Seepage of ground water through longitudinal crack

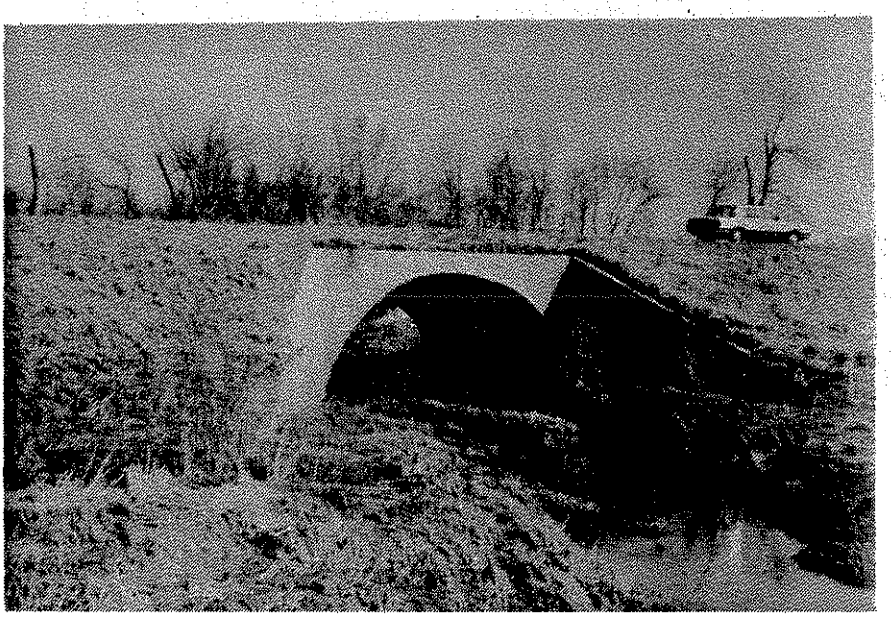

Photo 9: No debris or blockage of culvert
as of April 1993
(south end of culvert, culvert entrance)