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Forest Roads
& Trails

San Dimas, CA

June 1986

Evaluation of Nonmetallic Culverts

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by

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INTRODUCTION

The cost of constructing, reconstructing, and maintaining drainage facilities on Forest Service roads is estimated to be about $45 million per year. A conservative estimate of $5 million is spent on metal culverts (most supplied by two or three major producers) having a diameter of 18 or 24 inches. The metal pipes that the Forest Service uses for culverts in this size range have a number of problems associated with them:

1. High installation costs.

2. Installation damage (that is, denting, collapse, and the like).

3. Corrosion, electrolysis, and abrasion.

4. Waste of excess lengths and special protection needed for field cuts of pipe ends.

5. Lack of price competition among manufacturers.

6. Occasional incompatibility of road/culvert design life.

Developments in the field of nonmetallic culverts have been encouraging. For example, polyethylene culverts are produced in sizes up to 24 inches in diameter. And treated cardboard tubes, up to 48 inches in diameter, are being used to form concrete columns. Such products could be used as culverts—particularly where shorter design life is desired.

To identify new nonmetallic products that could be used as more cost-effective alternatives to traditional metal culvert pipe, the San Dimas Equipment Development Center (SDEDC), undertook an evaluation of these products. This evaluation was conducted in four phases:

1. Market search.

2. Selection of products based on initial cost of material compared to corrugated steel.

3. Laboratory and field tests.

4. Analysis of results.

MARKET SEARCH

Manufacturers and distributors were contacted and questioned about materials and products that could be used as culverts. The search identified the following as potential candidates:

1. Paper/cardboard.
2. Bituminized fiber.
3. Polyethylene.
4. Polyvinylchloride.
5. Fiberglass.
6. Resins (ABS).
7. Polyurethane.
8. Ceramic.
9. Cross-link polyethylene.
10. Butyl rubber.

Clay and concrete were not considered because these materials are traditionally used for drainage products.

Pipe costs were evaluated and compared to corrugated steel pipes. The comparison indicated that bituminized fiber, paper, and polyvinylchloride (PVC) were initially the most cost-effective. However, the manufacturer of bituminized fiber indicated that this product would be discontinued so it was not tested.

PRODUCTS SELECTED FOR EVALUATION

Three products—two grades of PVC and paper—were selected for evaluation. A fourth product, polyethylene (PE), was used as a comparison in many tests. Table 1 lists the products evaluated, as well as metal products for comparative purposes, the unit price (fob, central California, March 1985), and unit weight. The manufacturers of the four products evaluated are listed at the end of table 1.

The first PVC product, the Sono-Loc pipe, is an off-white, ribbed, Series 10 PVC tube. It is made by spirally winding PVC strips into a tube. The seams are joined by mechanical fasteners and adhesives. The second PVC product, the Perma-Loc Series 46, is a turquoise-colored sewer pipe with integral wall bell and spigot joints.

Table 1. Weight and price of metal and nonmetallic products

Material	Price ($/lin ft)	Weight (lb/lin ft)
Sono-Loc	13.80	4
Perma-Loc	15.40	13
Sonotube	4.75	8 (0.5 in thick)
PE (ADS)	6.25	6
Aluminum	10.05	5 (16 gauge)
Galvanized steel	9.30	15 (16 gauge)

MANUFACTURERS

Sono-Loc: Sonoco Products Company
P. O. Box 160
Hartsville, SC 29550
(803) 383-7000

Perma-Loc: Johns-Manville (a subsidiary of Manville Corporation)
P. O. Box 5108
Denver, CO 80217
(303) 978-4900

Sonotube: Sonoco Products Company
P. O. Box 160
Huntville, SC 29550
(808) 383-7000

Polyethylene: Advanced Drainage System, Inc.
3300 Riverside Drive
Columbus, OH 43221
(614) 457-3051

The paper product, brand name "Sonotube," was 0.5-inch thick. Half of these tubes were wax-coated; the other half were not. Because very little or no difference was observed in the performance of the two products, no distinction is made between waxed and unwaxed Sonotubes.

The product used for comparison, a black corrugated polyethylene pipe, is an industry standard and is currently included in the Forest Service's standard specification for construction of roads and bridges.

PRODUCT TESTING

To determine whether the nonmetallic products could be substituted for metal culvert pipe, SDEDC performed both laboratory and field tests on the products. The laboratory test consisted of four parts: Loads and deflections, water-soaked load and deflection, compressive strength, and abrasion resistance. The field tests consisted of two parts: Minimum cover test and forest installations.

Loads and Deflections

Deflections of pipes were compared under parallel plate loading. Pipe stiffness and the stiffness factor were determined. Loads and deflections were measured at five significant events:

1. Linear cracks or craze.
2. Wall cracks.
3. Delamination of pipe walls.
4. Rupture.
5. Yield point.

Each of the tested materials was cut into three 1-foot lengths and measured in accordance with ASTM standards for length,

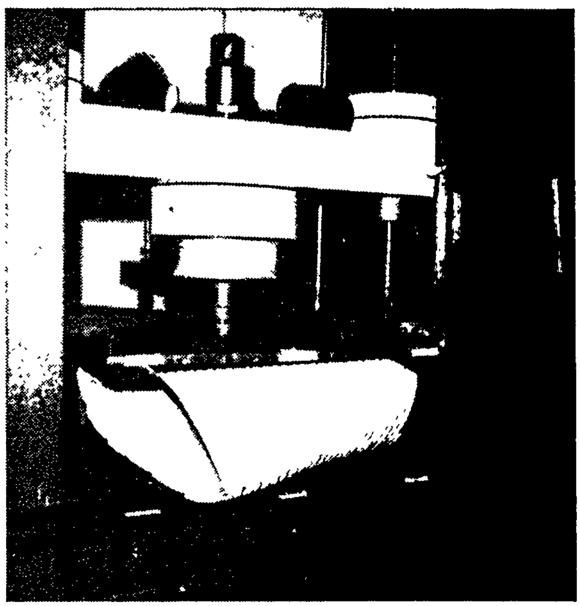

Figure 1. Sono-Loc sample at yield point.

Table 2. Results of measured loads and deflections testing

Material	Durometer hardness	Total load (lb)	Load (lb/lin in)	Deflection (in)	Deflection (%)	Pipe stiffness (lb/in²)	Stiffness factor (lb/in)
Sono-Loc							
Sample 1	86	459	38.5	6.73	39.7	5.72	521
Sample 2	87	445	37.4	6.76	37.8	5.53	500
Sample 3	87	457	38.3	6.60	38.8	5.80	532
Average	87	454	38.1	6.70	38.8	5.68	517
Perma-Loc							
Sample 1	87	1,183	98.9	17.0	93.6	5.83	648
Sample 2	87	1,100	92.1	17.1	87.6	5.40	604
Sample 3	88	1,368	114.8	18.2	100	6.27	711
Average	87	1,217	101.9	17.4	93.7	5.83	654
Sonotube							
Sample 1	48	413	34.3	0.95	5.5	46.4	3,578
Sample 3	53	521	43.3	0.70	4.3	61.9	4,755
Average	50	461	38.2	0.82	4.8	48.1	3,706

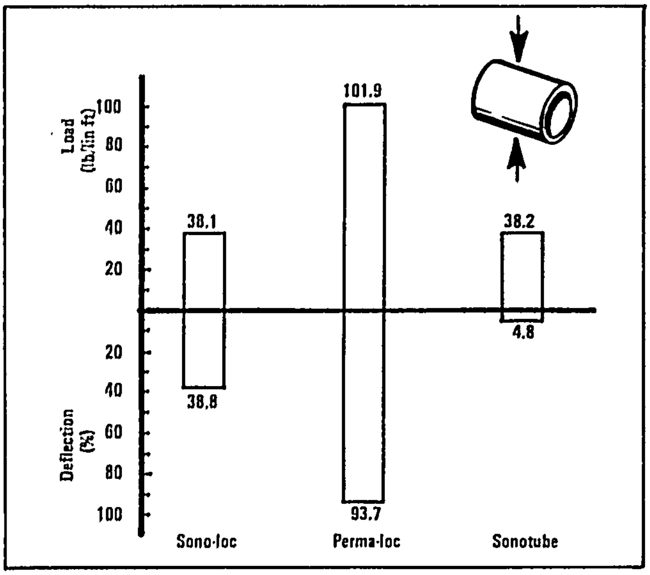

Figure 2. Load deflection.

durometer hardness, wall thickness, and inside and outside diameter. Each was placed with its longitudinal axis parallel to the bearing plates of a Tinius Olson—a tensile and compressive testing machine. The specimen then was compressed. The load and deflection were recorded at the first evidence of any significant event.in our case, the yield point. The test ended when the load on the specimen failed to increase with increasing deflection or when the specimen deflection reached at least 40 percent of the inside diameter. (Fig. 1 shows a Sono-Loc sample being tested.)

Pipe stiffness (PS), pipe deflection (D), and stiffness factor (SF) were calculated from the measured loads and deflections. they are listed in table 2. Figure 2 illustrates load deflection results.

Water-Soaked Load and Deflection

This test measured the yield point (YP) load and deflection of water-soaked pipes. Three 1-foot specimens of each

Table 3. Water-soaked load and deflection testing results

Material	Immersion (hr)	Weight before soak (lb)	Weight after soak (lb)	Durometer hardness	Total load (lb)	Load (lb/lin in)	Deflection (in)	Deflection (%)	Pipe stiffness (lb/in²)
Sono-Loc	96	3.97	3.97	87	458	38.4	7.41	43.6	51.8
Perma-Loc	96	6.8	6.8	88	1,368	114.8	18.24	100	6.29
Sonotube									
Sample 1	24	7.06	16.02	22	57	4.71	93	5.8	5.01
Sample 2	48	7.02	16.63	29	57	4.71	1.0	6.2	4.96
Sample 3	96	7.02	17.27	-	59	4.86	0.69	4.3	7.04

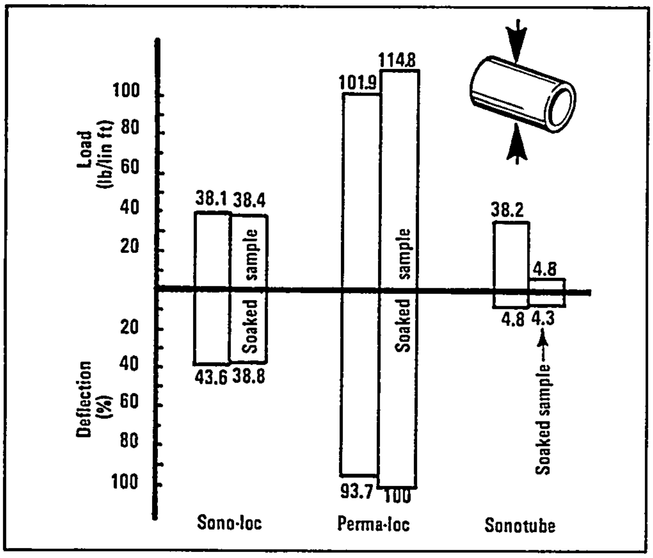

Figure 3. Comparison of soaked (96 hours) and unsoaked load deflection.

material were to be tested. They were immersed in water for 24, 48, and 96 hours, respectively. Each specimen was weighed before and after soaking. Because the Sono-Loc and Perma-Loc pipes did not weigh any more after soaking 96 hours, this test was modified. All three test samples of the Sonotube and only one each of Sono-Loc and Perma-Loc were tested. The results are shown in table 3. Figure 3 compares soaked and unsoaked load deflection.

Compressive Strength

This procedure determined the compressive strength when test samples were loaded at right angles to centerline. Two samples of the three test materials were cut into 1-foot lengths and measured according to ASTM standards for length, wall thickness, and inside and outside diameters. Each test specimen then was placed between the surfaces of the Tinius Olson pressure plates and compressed to the yield point. The results of this procedure are shown in table 4. Figure 4 illustrates compressive strength results.

Table 4. Results of compressive strength testing

Material	*Load at yield point (lb)*	*Deflection (in)*	*Cross-section area (in^2)*	*Pressure at failure (lb/in^2)*
Sono-Loc				
Sample 1	21,000	0.38	6.86	3,061
Sample 2	16,560	0.74	6.86	2,414
Perma-Loc				
Sample 1	6,412	–	3.23	1,985
Sample 2	6,750	0.29	3.21	2,103
Sonotube				
Sample 1	15,080	0.25	24.42	617
Sample 2	15,790	0.28	24.09	655

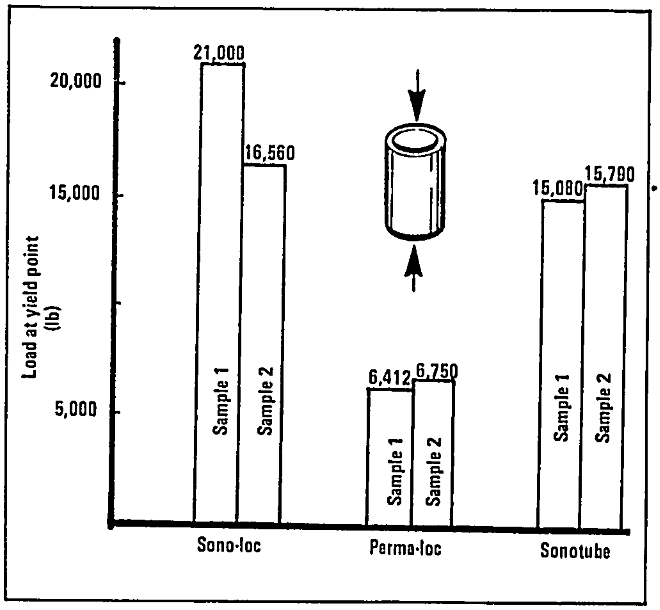

Figure 4. Compressive strength.

Abrasive Resistance

This laboratory test determined the rate of abrasion in pipes, using a constant flow, quantity, size, and particle shape in an abrasive slurry. The slurry consisted of silicon sand graduation D_{50} = 30 mesh and D_{50} = 48 mesh and 40 percent by weight in water. A tank that tilted to and fro in a slow rocking motion was used to hold the test sample. The frequency of the rocking was 16 to 18 cycles per minute so that one cycle corresponded to all of the abrasive materials moving in one direction. Each specimen was measured in accordance with ASTM standards for durometer hardness and wall thickness.

The first two samples were Sonotube pipe. The test ran for 55 days, or 1.4 million cycles. Wall thickness and hardness measurements were taken at least once a day. Measurements were inconsistent because the tubes absorbed water and would expand. When paper lamination eroded, the thickness would decrease, but it would soon expand again. The specimen showed evidence of wear and deterioration

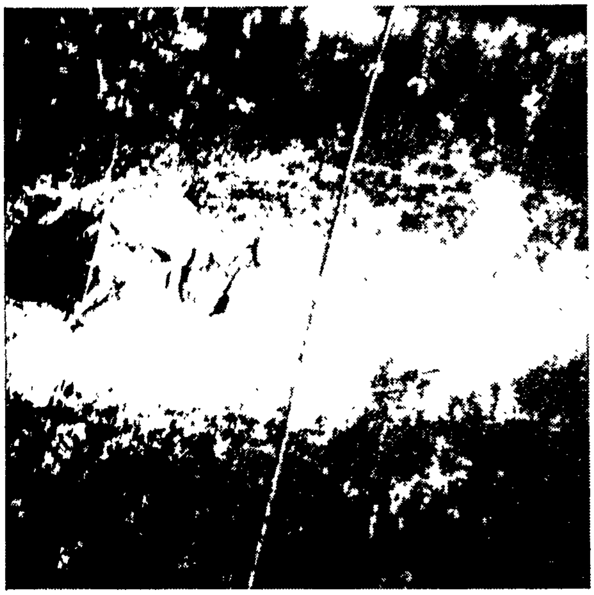

Figure 5. Abrasive wear on the Sonotube after the test run.

at the tube seams through approximately two layers of laminated paper (fig. 5).

The second two specimens tested were Sono-Loc pipe. The test lasted for 86 days, or 2 million cycles. There was no evidence (measured or observed) of any wear or deterioration. Because Sono-Loc showed no abrasion, Perma-Loc was not tested. Perma-Loc is made from the same material as Sono-Loc, but it has an even thicker wall.

Minimum Cover Test

This field test determined the ring deflection when an H-20 (16 kips/dual wheel) was applied under varying soil covers and compactions. A test course (fig. 6) was constructed at SDEDC. The course had sixteen 20-foot pipe installations—six Sono-Loc pipes, six Sonotubes, and four polyethylene pipes. The pipes were installed (fig. 7) in sloping trenches and backfilled to their original soil level to provide a continuously decreasing height from one end of a pipe run to the other. The test was designed for three soil densities: 85 percent, 95 percent, and uncompacted. Natural soil was used for backfill in 10 sites, and crushed aggregate was used in the other 6 sites.

A scraper was used to produce an H-20 load (fig. 8). The exact weight, ring deflection, and soil cover height were obtained for each loading. At some sites, the load was increased above the H-20 load by lifting the wheels of the scraper off the ground and using only the blade to support the scraper. The results of this test are shown in table 5. Figure 9 illustrates deflection at H-20 loading.

Figure 6. Preparation of the test course.

Figure 7. Installed pipes ready for H-20 loading.

Table 5. Minimum cover test results

Backfill	Planned compaction density	Planned height of cover (ft)		Sono-Loc	Material Sonotube	PE
Gravel	None specified	0.15-1.5	Act Den (%)	93	93	88
			Cover (ft	0.8-1.7	0.6-1.5	0.4-1.4
			Def @ H-20 load (in)	0	3/8	3-3/8
			—cover (ft)	1.05	1.24	0.6
			Max def (in)	3/8	Failed	Failed
			—load (kips)	16.3	17.4	18.5
			—cover (ft)	0.95	0.95	0.6
Gravel	None specified	0.5-1.5	Act Den (%)	86	88	89
			Cover (ft)	1.6-2.5	1.3-2.1	1.3-2.4
			Def @ H-20 load (in)	1/8	1/8	0
			—cover (ft)	1/8	1.66	1.6
			Max def (in)	1/4	Failed	0
			—load (kips)	18.5	31.4	17.8
			—cover (ft)	1.8	1.81	1.9
Soil	85	1.0-2.0	Act Den (%)	99	91	80
			Cover (ft)	1.0-2.1	1.0-2.0	1.2-2.2
			Def @ H-20 load (in)	1/8	1/8	0
			—cover (ft)	1.27	1.64	1.71
			Max def (in)	3/8	3/8	0
			—load (kips)	1.57	1.44	1.46
Soil	95	1.0-2.0	Act Den (%)	100	89	92
			Cover (ft)	1.0-2.0	1.0-1.9	1.0-2.1
			Def @ H-20 load (in)	0	0	0
			—cover (ft)	1.32	1.33	1.80
			Max def (in)	1/4	1/4	1
			—load (kips)	18.5	17.4	63
			—cover (ft)	1.52	1.33	1.20
Soil	85	0.5-1.5	Act Den (%)	100	100	100
			Cover (ft)	1.0-2.0	0.3-1.1	0.6-1.5
			Def @ H-20 load (in)	1/8	3/8	1/4
			—cover (ft)	1.4	0.51	0.75
			Max Def (in)	7/8	Failed	1/4
			—load (kips)	55	13	33
			—cover (ft)	1.4	0.33	0.70
Soil	95	1.5-2.5	Act Den (%)	98	94	98
			Cover (ft)	1.5-3.0	1.4-2.5	1.0-3.0
			Def @ H-20 load (in)	0	1/8	0
			—cover (ft)	2.16	1.8	1.8
			Max def (in)	1-1/8	1/4	1/8
			—load (kips)	16.8	16.3	17.8

Figure 8. H-20 loading.

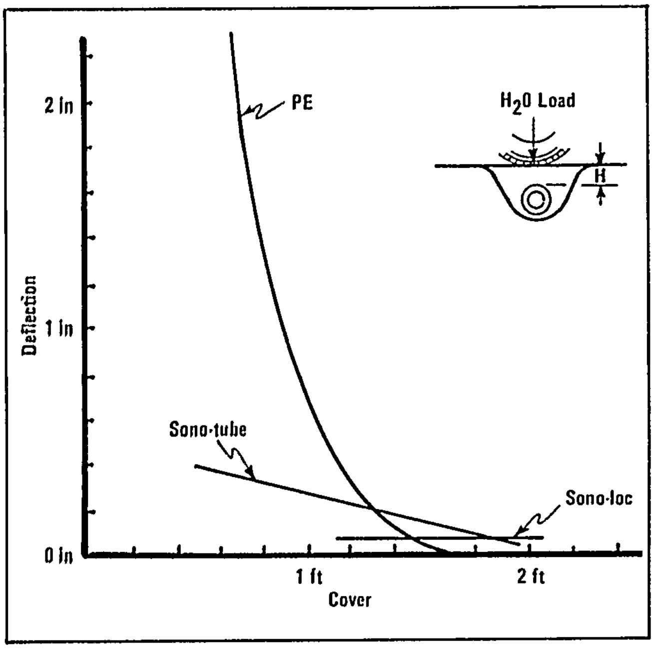

Figure 9. Deflection at H-20 loading.

Field Evaluation

This phase of the testing was designed to observe and document installations in typical drainage applications. Sites were located on the Angeles and Klamath National Forests in the Pacific Southwest Region (R-5), the White River National Forest in the Rocky Mountain Region (R-2), and the Sumter National Forest in the Southern Region (R-8). Experienced Forest Service and contract road crews installed the pipes.

Angeles National Forest

The site in the Angeles National Forest was in a periodic live stream that was large enough for a triple culvert crossing. The road is closed to public vehicles and is used mainly for fire access. In July 1983, a 22-inch diameter Sono-Loc pipe, a 24-inch diameter Perma-Loc pipe, and a 24-inch diameter PE pipe were installed (fig. 10) with grout facings. The soil cover over the pipes was 3 feet. The pipes were long enough so that two or more segments had to be coupled.

Figure 10. Installing the Sono-Loc, Perma-Loc, and PE pipes.

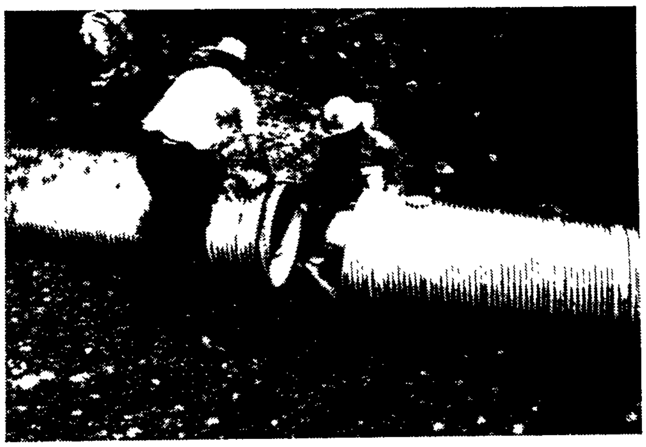

Figure 11. Joining the Perma-Loc with its integral bell gasketed joint.

The Perma-Loc has integral bell gasketed joints (fig. 11). To couple the pipes, the gasket slips into the bell portion of the pipe. This proved to be difficult for the road crew because of the weight and their inexperience working with this type of coupling device. Coupling the PE pipe, which has a collar that screws the two pipes together, was accomplished without difficulty. The Sono-Loc pipe has no particular coupler so the crew used a regular metal dimple band. Because the band was too large, a 1-foot-wide piece of

Sono-Loc was split and then slipped around the two ends to make a tight-fitting connection. This coupler took more time to install because of the time needed to fit the extra material around the pipes. The joint is still functioning satisfactorily after 2 years.

The crew experienced no other installation problems. Installation time was about the same as for a metal culvert installation. Transporting and handling the three nonmetallic pipes were easier than for metal pipes. The Sono-Loc was the lightest and most brittle. Care must be used because the seams can separate, although this did not happen at this location. The Perma-Loc is the heaviest and most difficult to handle.

Figure 12. Sonotube installations in a live stream.

In March 1984, two 24-inch diameter Sonotubes were installed downstream from this site (fig. 12). At that time, water was flowing in the stream. The main purpose of this installation was to observe the water flow through the pipes; there was no road above the pipes. After 6 months of dry weather, including a dry summer, the pipes were still functional. During this time, the stream had not been flowing water for approximately 2 months. Three months later, after rain had soaked the ground, the Sonotubes absorbed the moisture, lost their structural strength, and collapsed.

Klamath National Forest

In July 1984, four 24-inch diameter Sonotubes were installed on a timber road. This road was closed to the public, but 4.5 million board feet of timber was hauled over the road. The road had no drainage ditches, so the pipes were emplaced beneath the roadway for a structural test. The soil cover varied from 2 to 3 feet. There were no structural problems through the test, but the pipes collapsed during the winter.

Sumter National Forest

In July 1983, four 18-inch diameter Sono-Loc pipes (fig. 13) were installed on a newly contracted timber sale road. All pipes were delivered in their required length. One pipe broke during transport, and a metal dimple band was used to couple the two pieces. The coupling was the same as that used on the Angeles National Forest. The only problem with installation was cutting the Sono-Loc pipe. A concrete saw was used to obtain a smooth edge.

Figure 13. Sono-Loc installation during the winter season.

In July 1984, 1.0 million board feet of timber was hauled over the road. No apparent problems were detected, and culverts functioned without any distortions.

White River National Forest

In August 1983, the Forest road crew installed 10 nonmetallic culverts on a newly constructed road. The road was designed for a life of 3 to 5 years and was to be used for a 3-million-board-foot salvage timber sale. The 10 installations consisted of four Sono-Loc pipes, one Perma-Loc pipe, three Sonotubes, and two PE pipes.

The Sono-Loc installation presented no problems. The pipes were coupled together with the five-bolt metal band. At one installation, clay instead of granular material was used for backfill, which had several voids. The next year that culvert was so distorted, because of movement of the backfill, that the pipe had to be replaced. It was replaced with a metal pipe. Forest personnel decided that the problems resulted from an installation error rather than culvert material failure—the pipe would have failed even if a metal pipe originally had been installed. Sono-Loc was flexible enough to conform to mild irregularities in the streambed, yet it also was brittle, and the seam separated on one culvert during transport. In October 1984, the three installations were still functional.

The crew had difficulty handling the Perma-Loc pipes because they were heavy, but no other problems were noted during installation. In October 1984, the culvert was still functional with no apparent problems.

The three Sonotubes were installed without any difficulty. They were coupled together with five-bolt metal bands (fig. 14). The culverts were functional in November 1983. By June 1984, all of the Sonotubes were saturated with moisture, lost all their structural strength, and finally collapsed. All were replaced with metal.

Figure 14. Sonotube with the five-bolt metal coupler.

The two PE's were easily installed. The coupler that was developed for PE (fig. 15) acts as a thread nut joining the two pipe ends. The crew determined that it was easier to use this coupler than the standard five-bolt metal band.

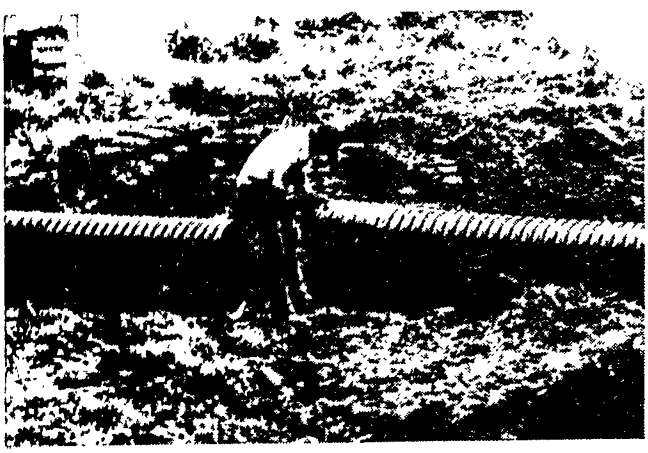

Figure 15. Installing the PE coupler.

The PE was flexible and conformed to the streambeds. As of October 1984, the installations were still functional.

CONCLUSIONS

Sono-Loc

This Series 10 PVC product has proven to be a lightweight culvert material. The laboratory test results showed that it is strong and abrasive resistant. The field evaluations demonstrated that it is easy to install and can handle traffic loads.

Problems associated with Sono-Loc are its tendency to unwind during transport and improper handling, and the lack of a standard coupling, thus requiring one to be improvised. Another drawback of the Sono-Loc pipe is its high cost. The product now is being made in only one or two of its manufacturer's (Sonoco) plants, which results in high shipping costs. However, if the demand for this product grows, Sono-Loc could be produced in all of Sonoco's plants throughout the United States, thereby reducing shipping costs and lowering the price per linear foot (18-inch diameter) to about $6.00. Shipping costs for Sono-Loc also could be reduced if the material were produced in spools. Using a portable mandrel, installers could make Sono-Loc into pipes at the installation site.

If Sono-Loc pipe is to be a common culvert material, it needs further development. The pipe should be fabricated so that its seams will not separate (fig. 16). Either a better locking device or adhesive is needed. A standard coupling

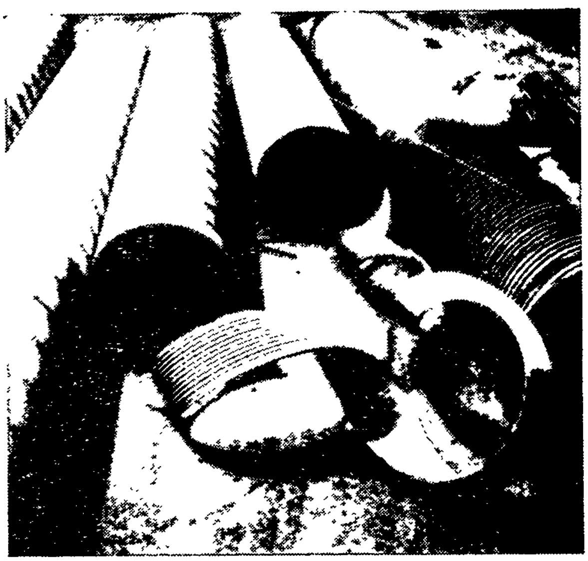

Figure 16. Example of Sono-Loc seam separation.

similar to PE would make the product more attractive to contractors and road crews. Despite these problems, Sono-Loc has great potential as a culvert product, and the Forest Service should monitor its progress.

Perma-Loc

The Series 46 PVC pipe has thick walls and very little ribbing. This accounts for its ability to support heavy loads without collapsing, its low longitudinal compressive strength along the centerline, its heavy weight, and its high cost. For Forest Service culvert installations, this material is over-designed and has only limited applications—for example, where sealed joints are needed, at highly corrosive sites, or to support heaving loads.

The manufacturer of Perma-Loc (John Manville) could manufacturer a Series 10 pipe. It would have thinner walls and cost less, and it could be a cost-effective culvert material. The company, however, has made no commitments to manufacture this pipe, choosing instead to concentrate efforts on the Series 46 (Perma-Loc) pipe.

Sonotube

The load capability of Sonotube in the load deflection test was 38.2 lb/lin ft, which is roughly the same as the others. However, when water soaked, Sonotube could support only 4.8 lb/lin ft. Thus, cardboard pipe can support traffic loads if it is not water soaked by continuously saturated backfills. This reduction also was evident in field installation. The Sonotube could support loads until it was water soaked—then it collapsed. Sonotubes can be installed in live streams and have enough abrasive resistance for the design life of the pipe.

Polyethylene

Even though PE was not evaluated during the project, it was used for comparison during field evaluations. The road crews found that the pipe was lightweight, easy to install, and that the coupling was easy to attach. Once installed, the pipe functioned well.

RECOMMENDATIONS

SDEDC offers the following recommendations regarding the use of the nonmetallic material evaluated:

1. Sono-Loc, Series 10, should not be used until it becomes cost-competitive with metal and PE, until a more practical coupling is developed, and until better seams are manufactured. When these items are satisfactory, it should be used as a "controlled trial use" in contract situations.

2. Perma-Loc, Series 46, should not be used for ordinary logging road culvert installations.

3. Paper material such as Sonotube should be used only in installations with a design life of one dry season. Sonotube has no salvage value and is biodegradable. Therefore, the pipe should be abandoned when no longer useful.