Figure 4. - A-joints on the left abutment that were nearly normal to the dam axis.

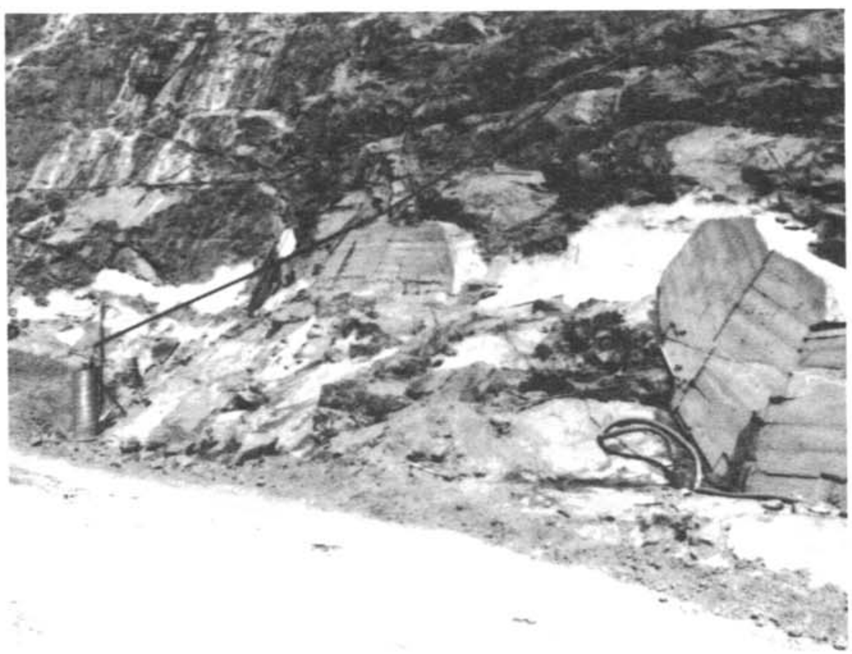

Figure 5. - Overhangs were backfilled by installing bulkheads and filling with conventional concrete.

Figure 6. – Shear zones were removed with a hand-held air spade.

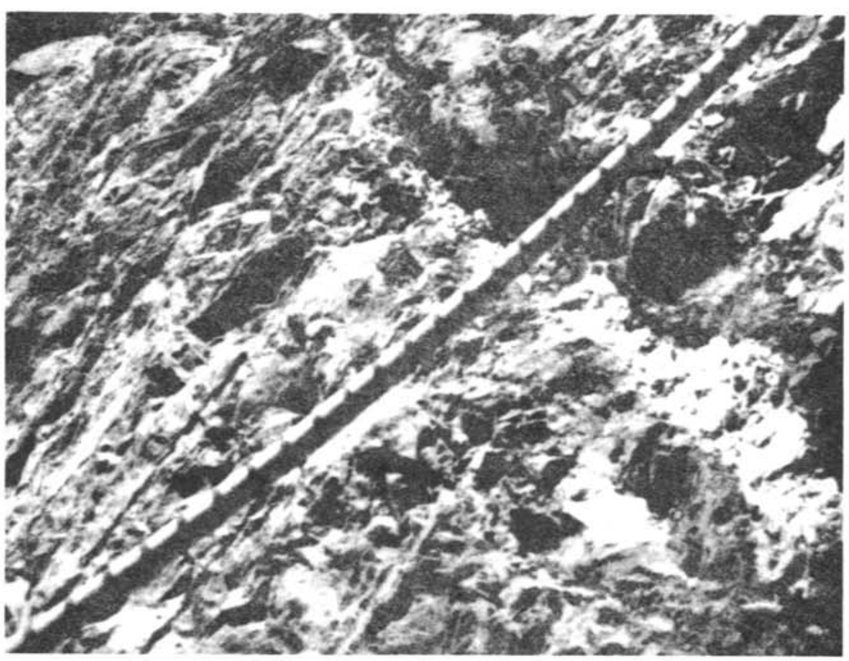

Figure 7. – A joint shear. Across the upper right corner.

Figure 8. – Pneumatically applied concrete being placed on foundation material as protection against weathering.

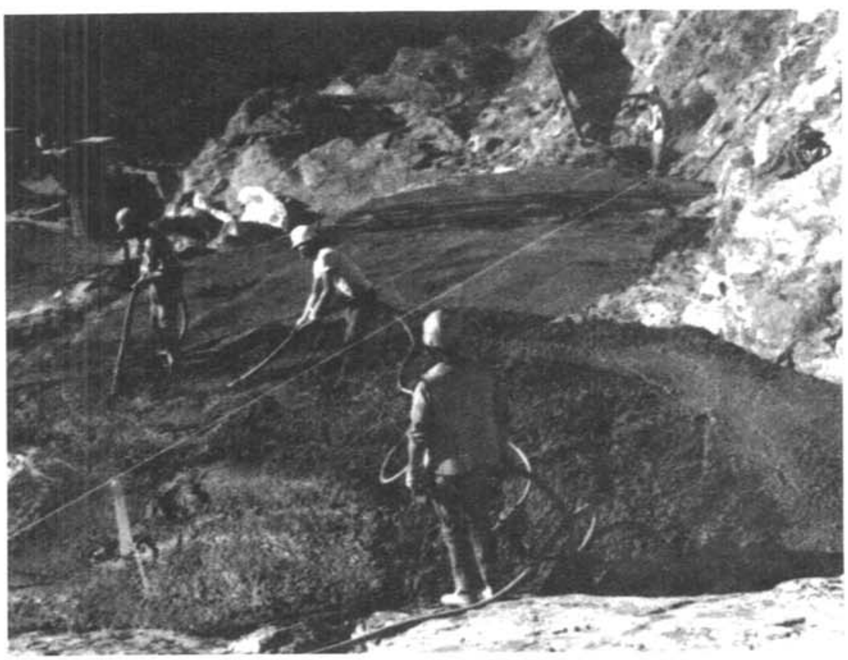

Figure 9. – Placing low slump dental concrete on a large bench along the right abutment. A crane and bucket were used for transporting and placing the concrete.

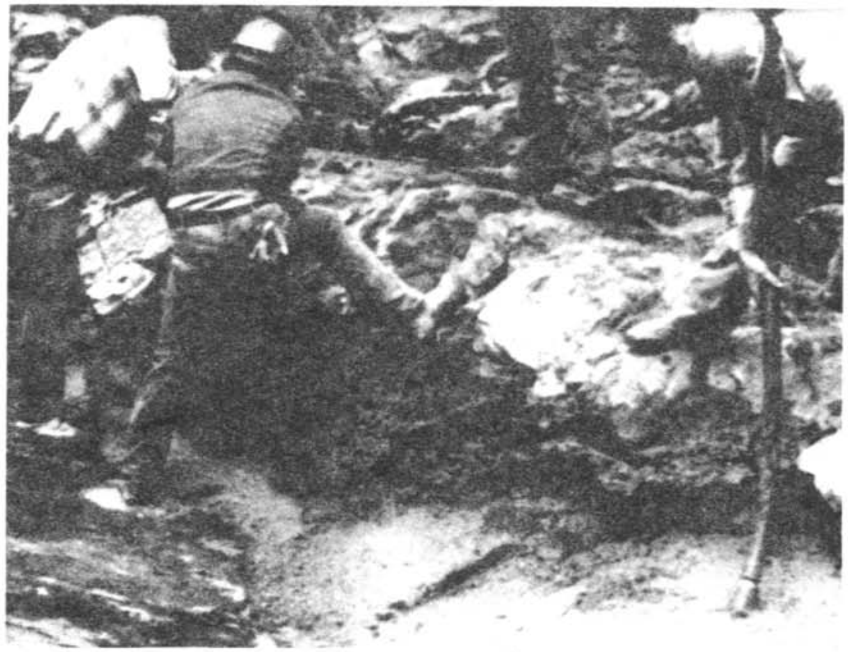

Figure 10. – Large holes in the river bottom were filled with dental concrete. Concrete was dumped from transit mixers and consolidated with a 3-inch vibrator.

Figure 11. – Transit-mix truck delivering high slump concrete to the Thomsen 875 concrete pump. The truck boom and concrete delivery line are fully articulated and capable of rotating 360°.

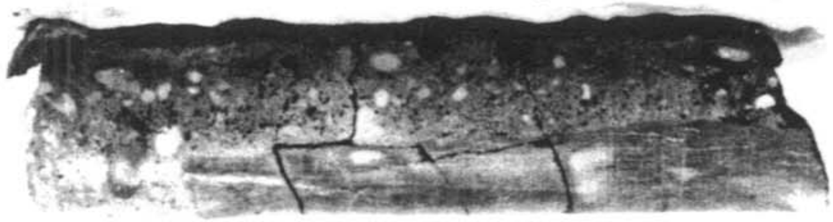

Figure 12. - NX core sample taken from the left abutment.

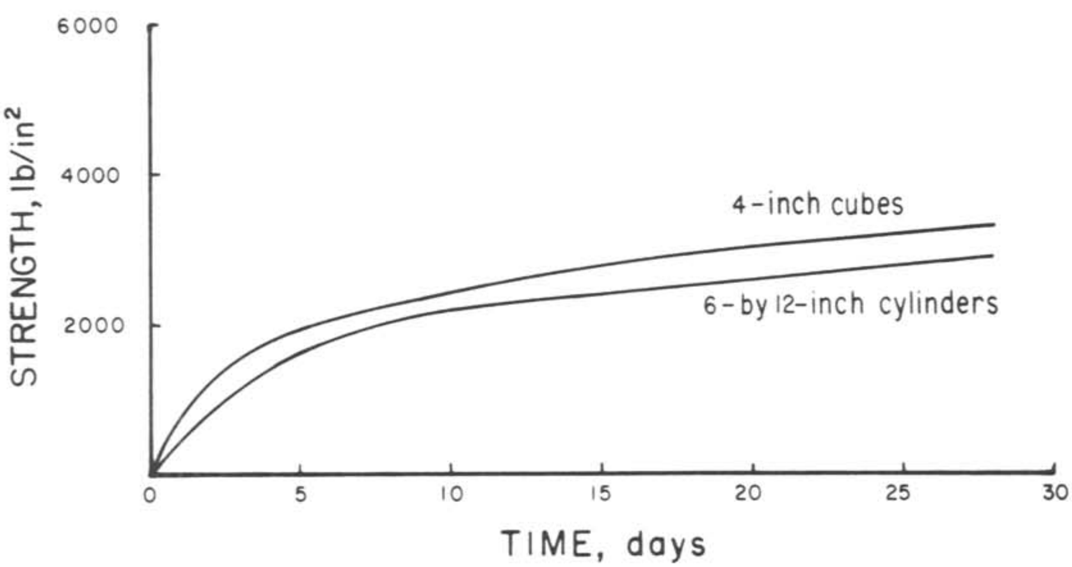

Figure 13. - Compressive strength of pneumatically applied concrete. A comparison of strength determined by testing 4-inch cubes and 6- by 12-inch cylinders.

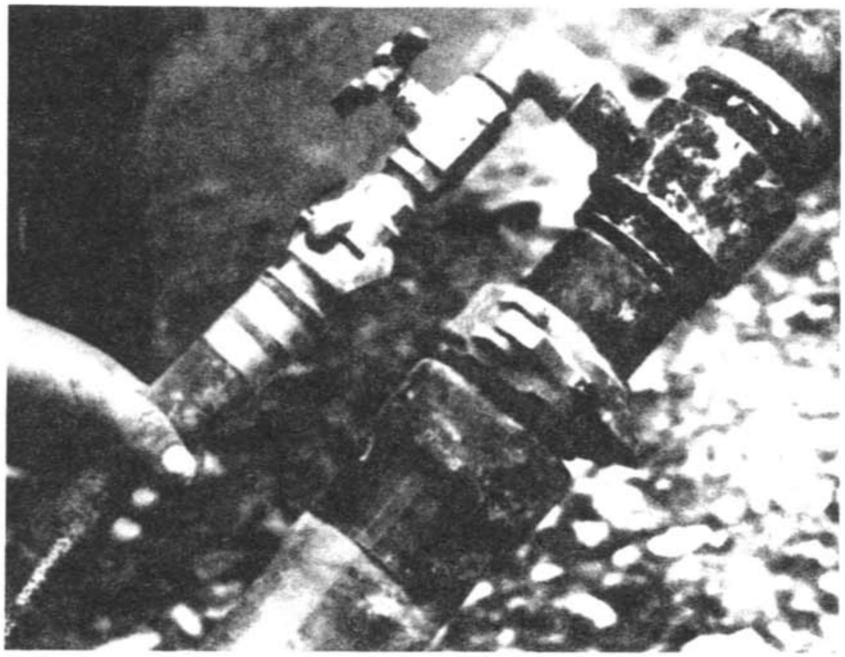

Figure 14. - Shotcrete nozzle attached to delivery line. Note the air valve on the left. Compressed air is used to accelerate the velocity of the concrete as it leaves the nozzle.

SEALING CONTRACTION JOINTS AND RANDOM CRACKS IN CONCRETE-LINED CANALS

by Jay Swihart[6]

Lining canals with portland cement concrete has many advantages, including reduced seepage, lower friction, less maintenance, steeper side slopes and higher velocities. However, the rigid nature of concrete results in cracks as contraction occurs from drying, shrinking, and changes in temperature. To control this cracking, weakened planes are created at intervals along the canal which develop into contraction joints. However, some additional cracking (random cracking) will usually occur because of subgrade movement or excessive loads on the concrete (fig. 1).

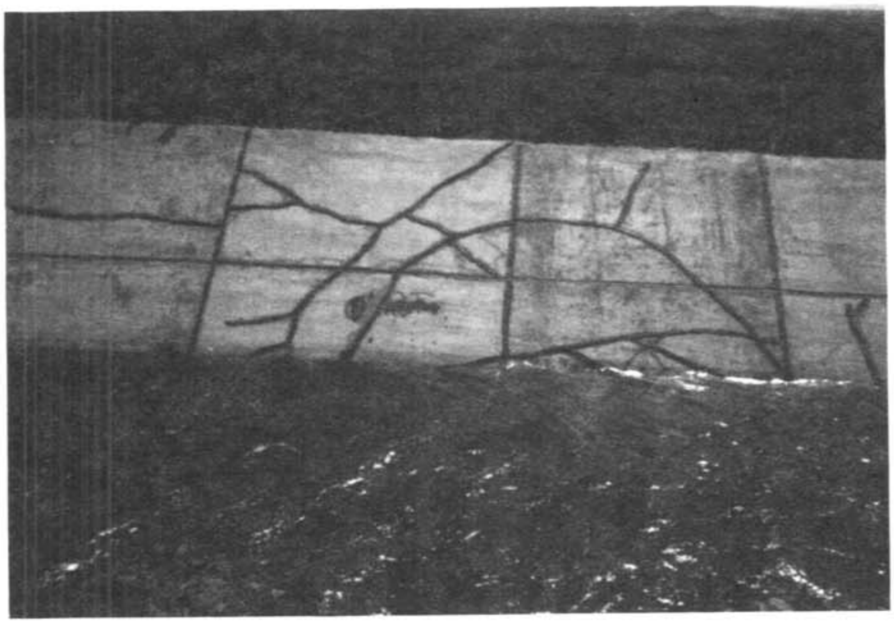

Figure 1. – Elastomeric sealant was used to seal both contraction joints and random cracks on the Mirdan Canal in Nebraska.

Experience over the last several years has resulted in the development of two basic systems for sealing contraction joints and two systems for sealing random cracks. The two contraction joint systems (figs. 2a. and 2b.) are the PVC (polyvinyl chloride) strip and the elastomeric sealant. The two systems for random cracks (figs. 3a. and 3b.) are the elastomeric cap-seal and the reinforced asphalt tape.

---

[6] Jay Swihart is a Materials Engineer, employed at the Bureau's Engineering and Research Center, PO Box 25007, Denver, Colorado 80225, (303) 236-6195.

Contraction Joints

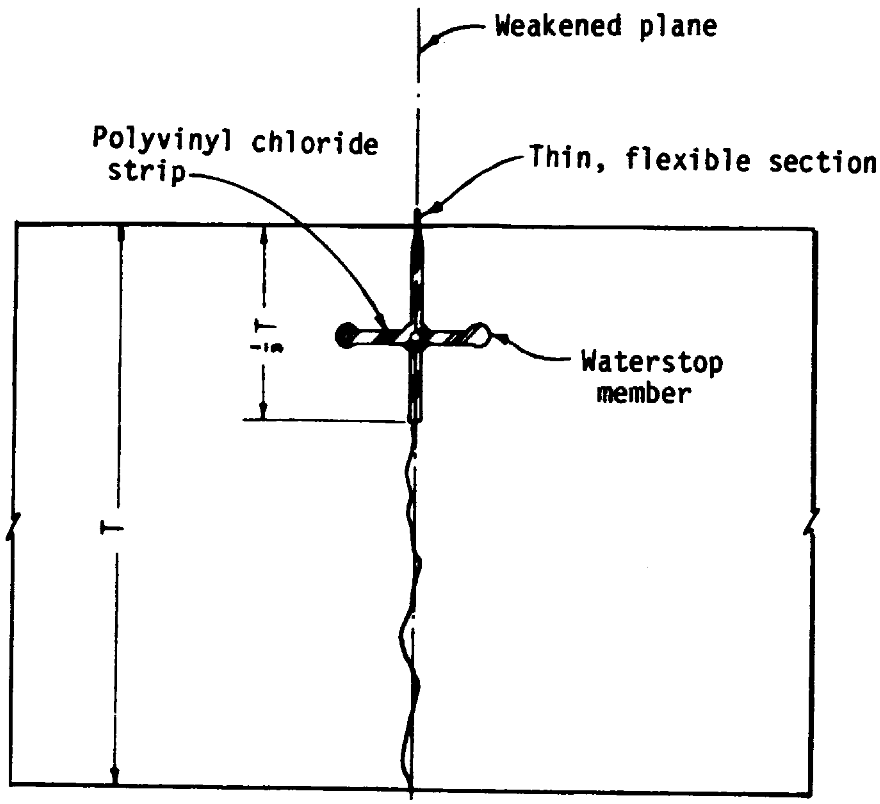

Figure 2a. - PVC (polyvinyl chloride) sealing strip. The vertical member creates a weakened plane for crack control, and the horizontal waterstop section seals the joint.

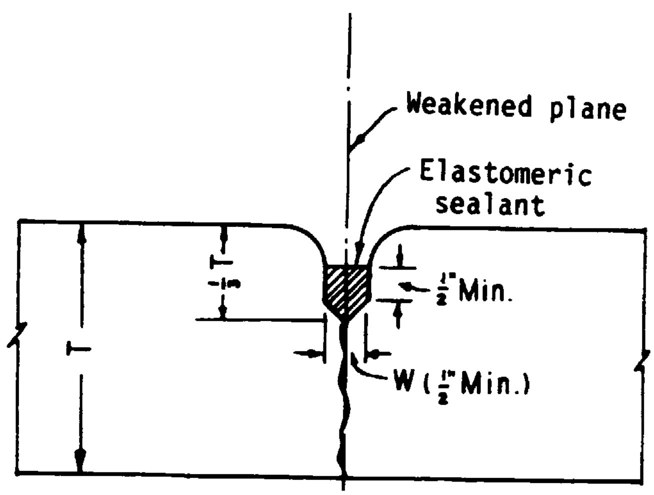

Figure 2b. - Canal contraction joint used with elastomeric sealant. The V-shaped groove is tooled into fresh concrete and creates the weakened plane.

Random Cracks

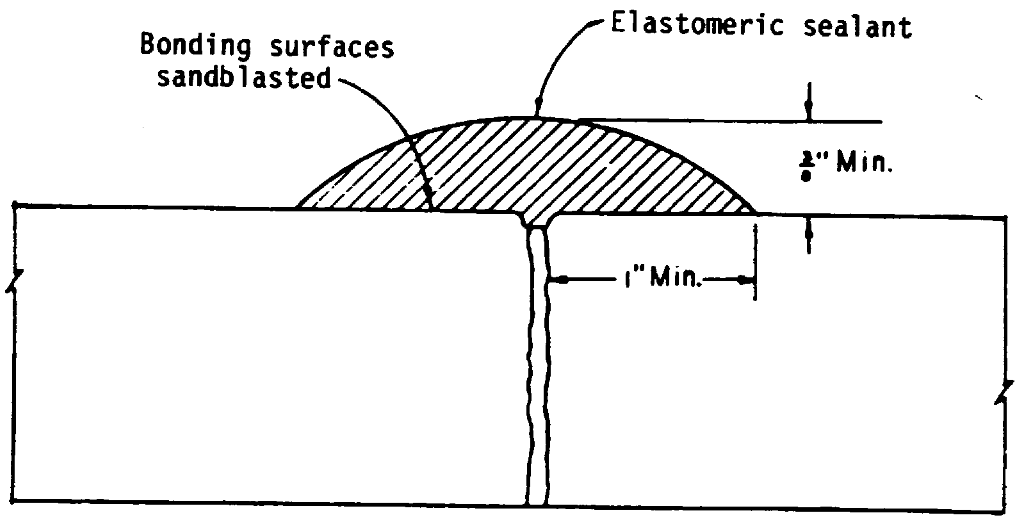

Figure 3a. - Elastomeric cap-seal for sealing random cracks.

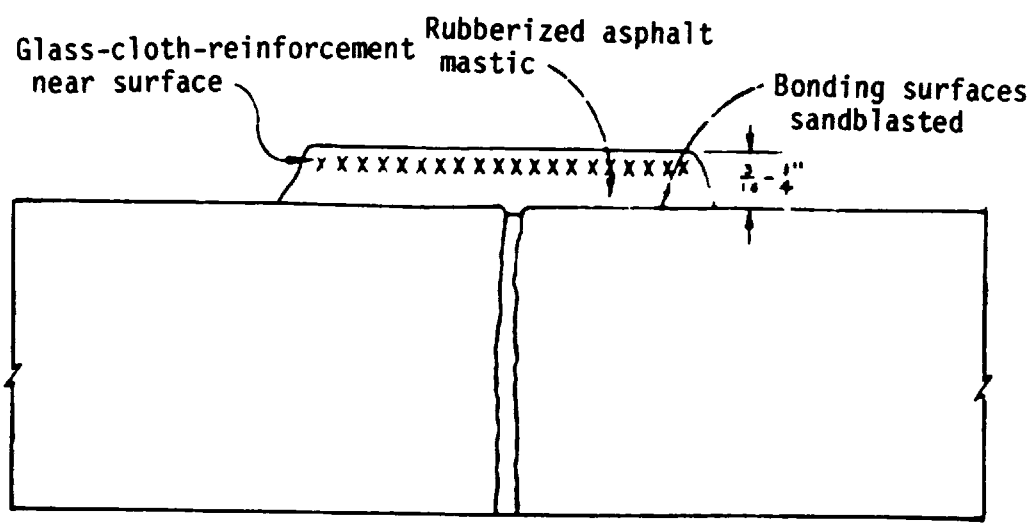

Figure 3b. - Glass-cloth-reinforced, rubberized asphalt mastic tape for sealing random cracks.

PVC Strip

The PVC strip is the most durable and trouble-free sealing technique for new construction. Installation is highly mechanized and reasonably complex; however, for large jobs where mechanized installation is available, the installed cost is quite low. The PVC strip is supplied to the jobsite on large reels and is inserted into the freshly placed concrete during the canal lining operation (fig. 4). The vertical fin creates a weakened plane for crack control, while the horizontal waterstop section seals the joint and accommodates both shear and lateral movement. The strip must be oriented within 10° of vertical and must be placed very close to the top surface of the concrete or the resulting crack may run through the sealing end-bulb (fig. 5), and the joint will not be watertight. Also, to assure good consolidation, the concrete must be well vibrated in the area of the strip, or once again the joint will not be watertight. Intersections of the longitudinal and transverse strips require removal of a small piece of the vertical member of the longitudinal strip to accommodate the crossover (fig. 6). Leakage at the intersection is believed to be quite small, and the intersection can be cap-sealed if a "bottletight" lining is required.

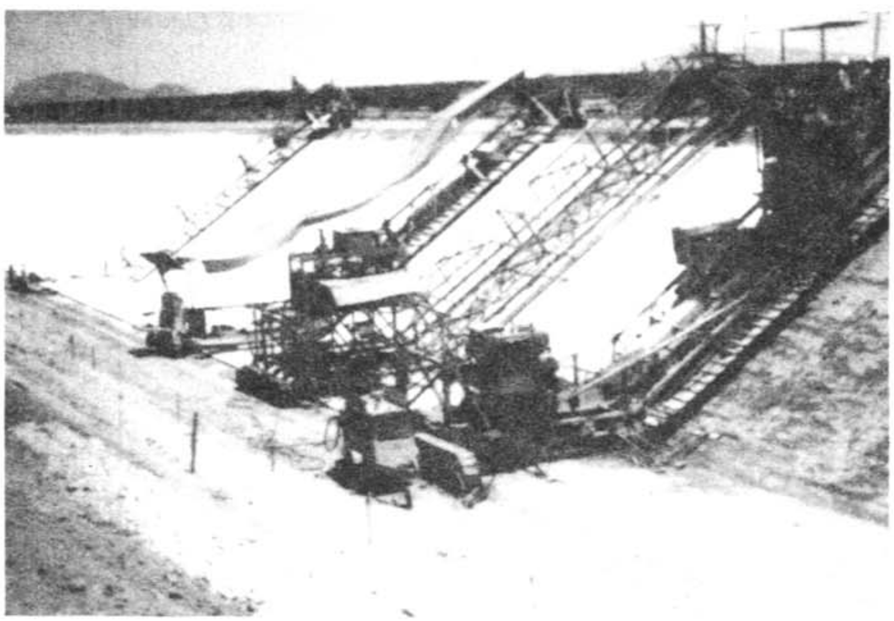

Figure 4. – The first jumbo (right) places the concrete and installs the PVC strip. The trailing jumbos finish the concrete and apply the curing compound.

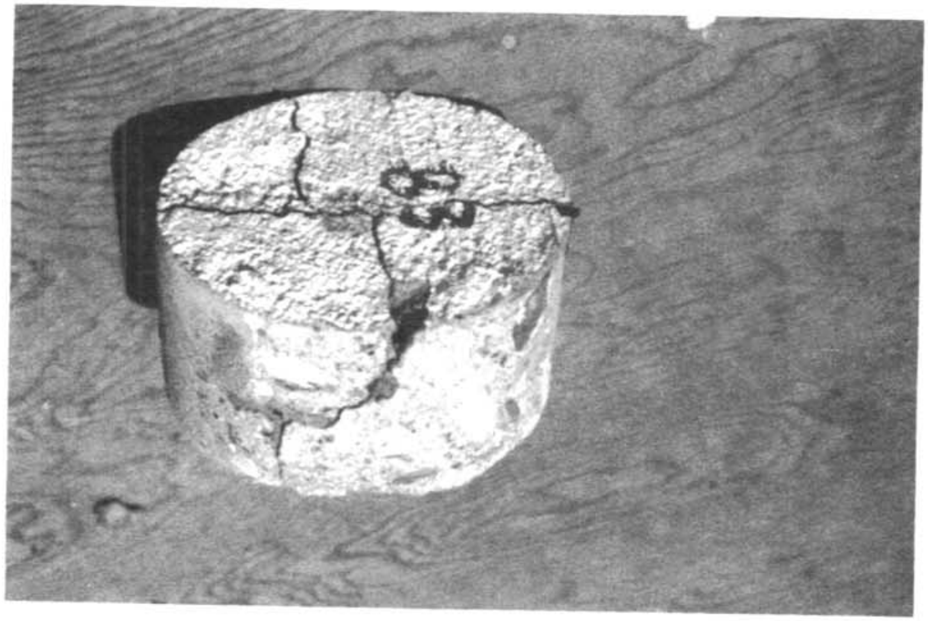

Figure 5. – PVC strip has been installed too deep and the crack has formed through the sealing bulb and not through the vertical fin. Joint will not be watertight.

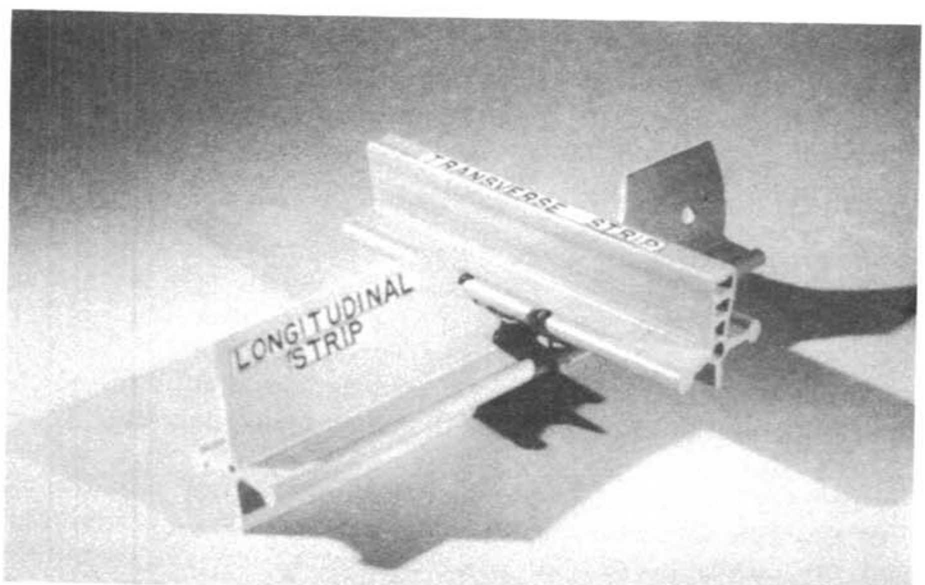

Figure 6. – A small piece of the longitudinal strip is removed to accommodate the crossover of the transverse strip.

The PVC strip requires no maintenance as it is a chemically inert plastic; and when embedded in the relatively benign environment of concrete, it will last for the design life (usually 50 years) of the project. Some hardening of the PVC strip occurs with time at high temperature because of plasticizer loss, but laboratory tests have shown that even in warm climates the PVC strip retains adequate flexibility to accommodate the expected movement. Further advantages of the PVC strip are that it is a manufactured item subject to high-quality control standards; and because it seals by waterstop action, it can withstand high-hydrostatic pressures and substantial joint movement.

Elastomeric Sealants

Elastomeric sealants can be used both as a sealant for contraction joints and as a cap-seal for random cracks. For contraction joints, a groove is tooled into the fresh concrete and develops into a contraction joint as the concrete cures. Once the concrete is a minimum of 7 days old, these mastic-type materials are extruded into the contraction joint or over the random crack and then cure into a rubberlike mass.

The obvious function of the elastomeric sealant is to provide an effective, durable seal. To do this, it must:

1. *Resist water pressure*. – Hydrostatic pressure must not cause the sealant to extrude through the crack or become disbonded. Thus, the sealant must have adequate cohesive and bond strength to withstand the expected water pressure.

2. *Accommodate joint movement*. – Both lateral and vertical movement can take place in a crack. Thus, the sealant must have adequate tensile and shear properties (elongation, strength, and bond). Also, since movement is often cyclic, the sealant should not be susceptible to fatigue.

3. *Withstand its environment*. – Above the waterline, a sealant must resist the effects of heat, cold, ultra-violet radiation, and oxidation. Below the waterline, the sealant must resist excessive water absorption, and excessive bond weakening. At the waterline, often the point of failure, the sealant must withstand all of these effects. Other environmental items a sealant must resist are physical damage during canal cleaning, bacterial attack, salts, and other chemicals that may be in the water.

There are many different types of elastomeric sealants. They can be self-leveling or nonsag, single or multiple component, and hot or cold applied. Chemical composition is usually based on either polysulfide, polyurethane, coal-tar, asphalt, or silicone. Examination of asphalt sealant installations has shown them to be the least durable of these materials. However, they are sometimes used where immediate cost is the primary concern. Silicone sealants are great for above-grade applications but do not retain their bond to concrete when under water for long periods; so, they are not recommended for canal work. Other important considerations for selecting a sealant are cure time, ease of application, and sensitivity to application conditions.

The Bureau's "M-41" Specification for Elastomeric Canal Sealant separates the sealants into several classes. A brief description of each class follows, and this information is summarized in table 1.

Class C, hot-applied, single-component, coal-tar. – This material has been used for many years in highway construction and is now gaining limited use for canal work because of its low cost. The California Department of Water Resources has been using this type of material to seal contraction joints on the California Aqueduct for the last couple of years with no reported problems. The Bureau has experimental installations and limited use on the CAP (Central Arizona Project), and these installations show that hot-applied sealants can be sensitive to inadequate surface preparation, application during cold weather, and may vary in quality from different heating practices during application. Although some of the sealant was removed because of poor bond, the rest looks good after 1 to 3 years' exposure in the Arizona sun.

The application equipment needed for this material (figs. 7 and 8) is similar to that for hot-applied asphalt. The Willows, California, office has such equipment and has been using hot-applied asphalt for many years. They are now switching to hot-applied coal-tar because of its superior performance at an only slightly higher price.

Figure 7. – Contractor seals contraction joints with hot-applied sealant on California Aqueduct.

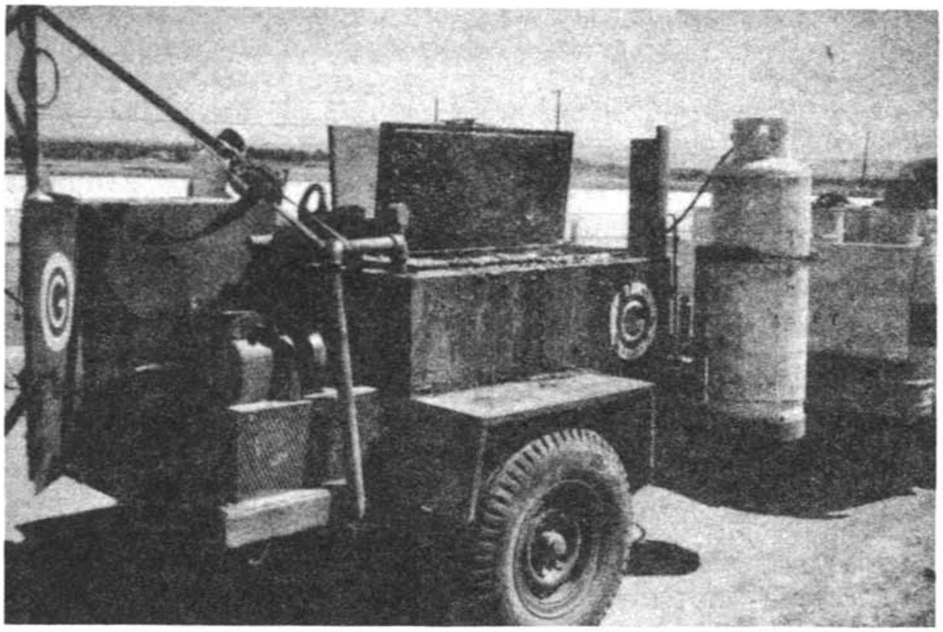

Figure 8. - Closeup of hot-melter used for hot-applied sealants.

Class B, single-component, cold-applied sealants. - These materials usually cure by reacting with moisture from the atmosphere. The Bureau has used this type of product successfully for many years, and it is estimated that the higher-quality products of this type will perform satisfactorily for 15-20 years. Their relative high cost is offset by their ease of installation. These products are available in almost any quantity depending on the size of the job (1/12-gallon caulking tubes, 20-ounce sausages, 5-gallon buckets, and 55-gallon drums). However as one might expect, the price increases drastically as the quantity decreases. Also, the price of equipment varies inversely with its efficiency. Hand-operated caulking guns are available for less than $10; air-powered caulking guns (for use with 20-ounce sausages) are available for around $100; and finally, high-pressure, positive-displacement pumps cost around $4,000. This versatility makes these single-component sealants excellent candidates for remedial repair work.

Class R, two-component, rapid-setting (machine-applied), coal-tar polysulfide.–Cost of this material falls somewhere between the hot-applied coal-tar and the cold-applied single component. The Bureau has used this material extensively on the CAP as both a sealant for contraction joints and as a cap-seal. This product has the best proven performance of any sealant the Bureau uses and should last approximately 20 years. Specifically, a recent examination of a 17-year-old installation on the California Aqueduct showed that this material was still performing adequately, but was showing signs of compression set failure and would probably need replacement within the next 5 years.

The drawback with this material is that it requires some rather special (expensive) application equipment (figs. 9 and 10) and an experienced crew to assure proper proportioning, mixing, and application. The CAP has purchased such equipment, and the cost for just the pair of positive displacement pumps was approximately $10,000. This need for special equipment precludes the use of this product on small jobs.

Figure 9. - Rapid-set, two-component sealant is used to seal both longitudinal and transverse contraction joints.

Figure 10. - Elastomeric cap-seal is tooled to correct shape with aid of a "shoe."

Classes S and A, slow-set (hand-mixed) two-part polysulfide and slow-set, two-part polyurethane. — These sealants are slightly more expensive than the rapid-set but do not require the special application equipment. Commonly used both in contraction joints and as cap-seals (figs. 11 and 12), quality products of these types should also demonstrate durability approaching 20 years.

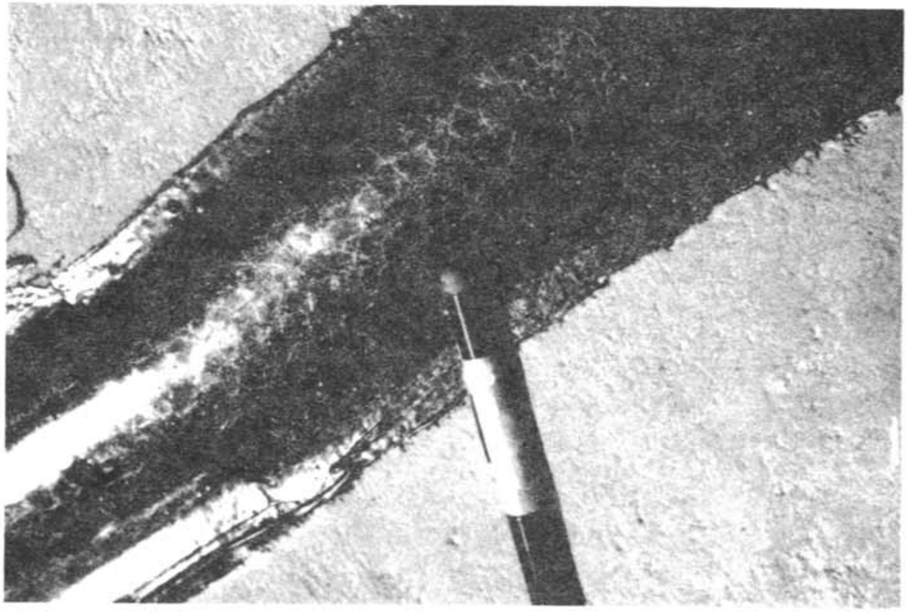

Figure 11. - Surface crazing of elastomeric cap-seal has minimal effect if correct shape and thickness are obtained.

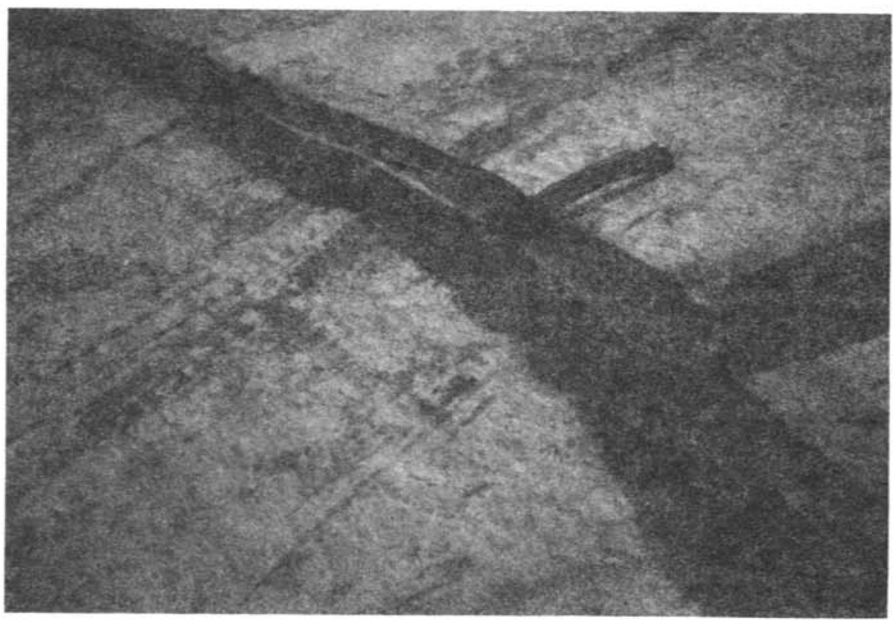

Figure 12. - Hand-trowled cap-seal is variable and liable to be quite thin directly over the random crack.

Reinforced Tape

Reinforced-asphalt mastic tape is also used as a cap-seal for random cracks, but it is not covered under the Bureau's M-41 Specifications. The reinforcement prevents cohesive failure, while movement is accommodated by shear within the thin mastic layer. This product can be used on any size job by an inexperienced crew because no special equipment is needed. Material costs are competitive with the previously mentioned products, but application is very labor intensive and installed costs may prove to be higher. Also, this material has questionable durability. An application in Ord, Nebraska, showed signs of deterioration after only 2 years; and it is doubtful if this material could last more than 5-10 years (fig. 13).

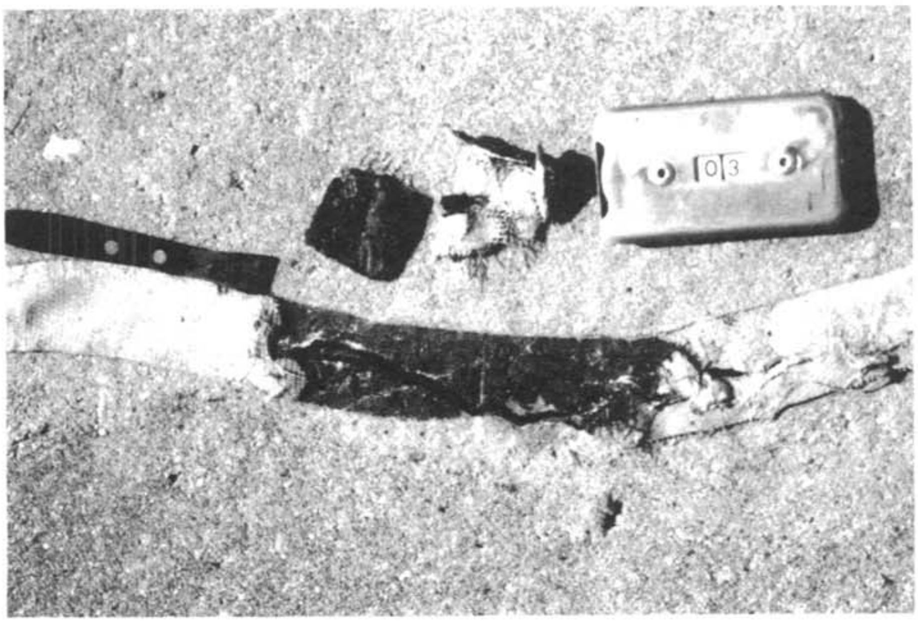

Figure 13. – Reinforced-asphalt mastic tape tends to deteriorate rather quickly, has relatively weak bond, and is difficult to center over wandering cracks.

Surface Preparation and Application of Elastomeric Sealers

Proper surface preparation is essential when using elastomeric sealants because these products require good bond with the concrete to function properly. The concrete surfaces must be clean; dry; and free of curing compound, loose material, and unsound concrete. Removal of contaminants may be accomplished by water washing, sawcutting, wire brushing, routing, or sandblasting. Although sandblasting is more expensive, it is more likely to succeed and is required for removal of wax-based curing compounds. Solvents which are intended to remove oils and contaminants usually have the opposite effect and carry contaminants further into the pores of the concrete. However, solvents are useful in cleaning nonporous surfaces such as glass or metal.

Immediately prior to sealant application, the concrete should be blasted with oil-free compressed air to remove sandblast residue, dust, dirt, and debris. Concrete and ambient temperatures should be a minimum of 5 °F. The sealant is then extruded over the crack or into the joint and then worked into intimate contact with the concrete without entrapping air. Finally, the top surface of the sealant is tooled to the specified shape, making sure the minimum sealer thicknesses are obtained. For cap-sealing, use of a "shoe" facilitates the tooling operation.

As shown in figure 14, it is generally cheaper to provide good initial surface preparation than to do the job over.

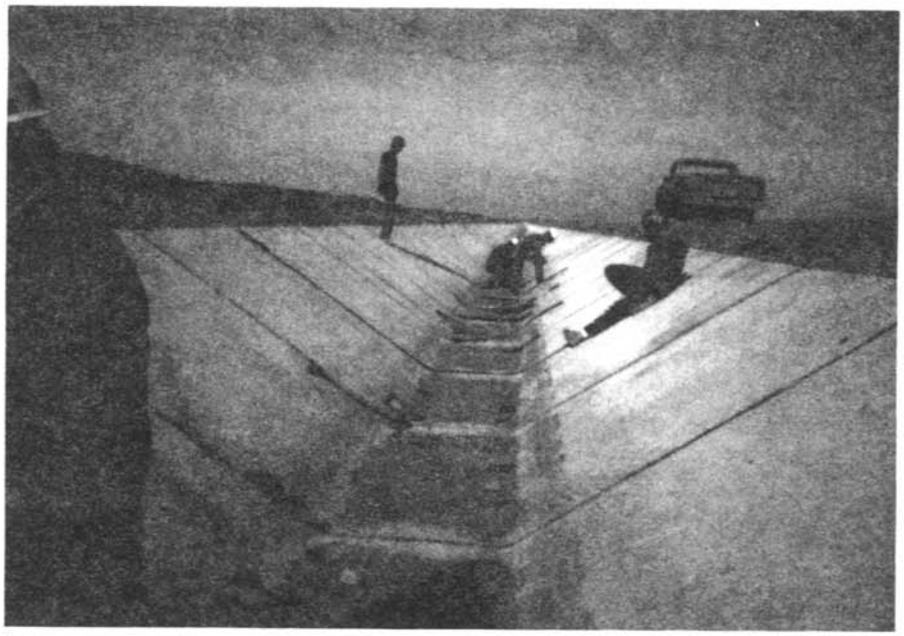

Figure 14. – Sealant is removed from the joint and replaced because of poor bond.

Table 1. – Comparison of elastomeric sealants

Generic description	Underwater durability (years)	Cost per gallon	USBR experience	Cure time	Size of jobs	Application equipment
Two-part rapid-set polysulfide or polyurethane	20	$15	High	1 hour	Large jobs only	Machine applied
Two-part slow-set polysulfide or polyurethane	15-20	$20	Medium	24 hours	Small jobs only	Hand applied
One-part polysulfide or polyurethane	15-20	[4]	Medium-high	21 days	Any size	[6]
One-part hot-applied coal-tar PVC	[2]	$7-$10	Low	1 day	Large only	Machine applied
One-part hot-applied asphalt	5-10	$5	Medium	1 day	Large only	Machine applied
Reinforced asphalt mastic tape[1]	5-10	[5]	Medium	0	Small only	Hand applied
One-part silicone	[3]	[4]	Medium	21 days	Any size	Either

[1] This material can only be used as a cap-seal.
[2] Use of this material in canals is relatively new. Underwater durability is not yet known, but components are highly durable.
[3] Silicones are excellent for use above grade, but quickly lose bond under water. Use in canals and related structures should be limited to areas above the waterline.
[4] These materials are available in almost any quantity, but the price varies accordingly ($20 to $60 per gallon).
[5] Roll of 3-inch tape with coverage equivalent to l gallon of elastomeric sealant costs approximately $15.
[6] Wide variety of available application equipment makes these materials excellent candidates for remedial repair work.

Specific information about particular products or application techniques can be obtained by contacting the author of this article.

STUDIES OF ANTIFOULING PAINTS ON BUREAU SYSTEMS

By Victor S. Miyahara[7]

INTRODUCTION

A major objective of the Bureau of Reclamation is the timely distribution of water to agricultural areas in the arid Western States. To help accomplish this mission in an environmentally safe and efficient manner, the Environmental Sciences Section conducts many studies aimed at controlling the biological problems in these irrigation systems. This report describes chemical control studies using antifouling paints to inhibit algae and aquatic organisms from attaching to irrigation system structures.

An antifouling paint is a paint containing a pesticide, and when applied to the surface which is submersed in water, the pesticide is released slowly to prevent the attachment of algae and aquatic organisms. These paints were first developed for use on bottoms of boats and ships to prevent attachment of aquatic organisms. This is still the main use for the paints; however, studies conducted on irrigation system structures with antifouling paints showed excellent results in inhibiting algae attachment.

The initial study by the Bureau with the use of antifouling paints on irrigation system structures was in 1958. The Bureau continued to test paints ranging from coal-tar to copper-bearing paints until 1970. In 1970, there was an amendment to FIFRA (Federal Insecticide Fungicide Rodenticide Act) which required a tolerance for a pesticide if applied to feed or food. This meant that the antifouling paints had to be registered for use in irrigation systems; and at this time, there was not enough interest from the paint companies and users to warrant continuation of the studies.

In the mid-to-late 1970's, it was determined that a real need existed for a good antifouling paint to be used on irrigation system structures. Interest from Bureau regional and project offices prompted personnel to contact paint companies to ask if they were interested in going through the process of having one of their paints registered for use in irrigation systems. There were a few paint companies that were interested in amending the label of their antifouling paint for use in irrigation systems, and this report will cover studies conducted on these paints plus one formulated at the Bureau's laboratory.

The studies were conducted with the antifouling paints to obtain data on the amount of copper or tin residue that was released in the irrigation water, the effectiveness for preventing attachment of algae and other aquatic organisms to painted surfaces, and the durability of the paint.

[7] Victor S. Miyahara is a botanist in the Environmental Sciences Section, Division of Research and Laboratory Services, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

Table 1 shows the paints which were tested. Each was assigned a number which is used for identification throughout the report.

METHODS AND MATERIALS

The sites in the study where algae usually present a problem in delivering water, the antifouling paints tested, and the amount of paint applied at each site are shown in table 2 and discussed in the following paragraphs.

a. The St. Vrain Supply Canal delivers water from Carter Lake west of Berthoud, Colorado, to St. Vrain River and Boulder Feeder Canal in Lyons, Colorado. The upper end of the canal is concrete lined and the lower section is earthen. This canal is approximately 9.8 miles in length. The St. Vrain supplies water to farms adjacent to the canal, the St. Vrain River, and Boulder Reservoir. The water delivery capacity is approximately 625 ft^3/s through this canal. This portion of the canal that is painted has a history of algae problems, which will reduce the canal's water-carrying capacity by 20 percent. A total area of 8,873 ft^2 was painted with 44 gallons of a soluble matrix-type paint containing 15 percent copper flakes (paint No. 1) (fig. 1).

b. The aquatic weed test station was established just east of dam No. 1 on Carter Lake, part of the Colorado-Big Thompson Project. This station was constructed to provide a flowing-water research facility to represent field conditions similar to those in irrigation canals for studies on aquatic pest control methods. Key features of the facility include a diversion dam, warming pond, water control structure, flumes, drop structures, terminal structures, and holding pond (fig. 2). Various studies, including evaluation of promising new algicidal and herbicidal materials are being conducted at this site.

Two antifouling paint studies were conducted at the aquatic weed research station. Black metal panels were treated with a paint containing 25 percent cuprous oxide (paint No. 2), a paint containing 33.6 percent cuprous oxide and 3.65 percent TBTO (tributyltin oxide) (paint No. 3), and a paint containing 45 percent cuprous oxide and 1.6 percent TBTO (paint No. 4) (fig. 3). In another study, 1.94 ft^2 strips were painted on the concrete canal walls with vinyl resin paint containing 95 percent, by weight, cuprous oxide (paint No. 5). Detached concrete panels with an area of 0.97 ft^2 were painted with a thin layer polymer overlay (protective coating) containing 10 percent, by weight, TBTO (paint No. 8), and a thin layer polymer overlay (protective coating) containing 20 percent, by weight, cuprous oxide (paint No. 7) (fig. 4).

c. The Steinaker Canal is located north of Vernal, Utah, and supplies water for irrigating agricultural crops. Algal growth in the Steinaker Service Canal not only restricts waterflow, but affects the accuracy of Parshall flume delivery measurement. The flume is a trapezoidal bench Parshall concrete flume, and the total area painted was 239.9 ft^2 (fig. 5). The paint used in this study for both efficacy and copper residue data was a soluble matrix paint containing 25 percent cuprous oxide (paint No. 2). The data are to be used to support registration of this product for use in irrigation systems.

d. Pilot Chute Canal near Riverton, Wyoming, is 1.25 miles long by 7 feet wide with 4-foot walls. The water-carrying capacity of this chute is 565 ft^3/s. However, the rate of water delivery during the peak period of algae (*Cladophora*) and caddis fly (*Hydropsyome spp.*) attachment to the chute is decreased to approximately half the original rate. Three 2.5-foot test strips were painted with a soluble matrix paint containing 25 percent cuprous oxide (paint No. 2) as shown on figure 6.

e. Charles Hansen Canal is a large concrete-lined canal, between Flatiron and Horsetooth Reservoirs, Loveland, Colorado. This canal is divided into two sections with the upper end which is 5.6 miles in length with a carrying capacity of 1,400 ft^3/s. The lower section of the canal is approximately 13.2 miles in length with a water-carrying capacity of 930 ft^3/s. This canal is used to supply water to the Big Thompson River and Horsetooth Reservoir. Test strips measuring approximately 2 feet by 8 feet were painted on the side of the canal with the following antifouling paints (fig. 7):

(1) Soluble matrix paint containing 25 percent cuprous oxide (paint No. 2)

(2) Vinyl resin (insoluble matrix) containing 20 percent cuprous oxide (paint No. 6)

(3) A chlorinated rubber paint containing 20 percent cuprous oxide (paint No. 9)

The water sampling schedule set up for a test that required copper residue data was as follows: (a) the day of first water delivery, (b) second day, (c) two times a week for next 3 weeks, (d) once a week for next 4 weeks, and (e) once a month until canal was dewatered. To determine background copper found in the water, three 1-quart check water samples were collected at a station before the water reached the painted area. There were four 1-quart canal water samples collected approximately 15 inches below the painted area to determine the copper residue released from treated area. One ounce of concentrated nitric acid was added to each water sample immediately after samples were collected as a preservative to maintain copper in solution. The water samples were analyzed for copper, using an atomic absorption spectrophotometer with a carbon graphite furnace attachment.

The painted area was inspected each water-sampling date for effectiveness in preventing algae attachment. The tests that required only efficacy and durability data were observed twice a month throughout the season.

In preparing the surface to be painted, a wire brush or sandblasting was used to remove all loose soil, rust, scale, or paint. The paints were usually applied with a brush. The only test where a spray gun was used to apply the paint was the large area in St. Vrain Canal. The soluble matrix-type paints were applied directly to the concrete without a primer coat; however, a primer is needed when these paints are applied to metals or wood. A primer was used before applying all insoluble matrix-type antifouling paints. The polymer thin layer overlay coating is a three-component system with each component applied in two coats with a 1-day cure between coats. The paints were allowed to dry at least over night before resuming water delivery.

The antifouling paints used in most of the studies conducted in this report were made up either in soluble or insoluble matrix. The soluble matrix usually consists of a rosin, a binder, and plasticizer. The insoluble matrix consists of vinyl resin binder containing a copolymer of vinyl chloride-vinyl acetate. The matrix in antifouling paints dissolves at a slower rate than the algaecide, making it the controlling factor of leaching rate of cuprous oxide or TBTO. The permeability of the matrix is therefore very important. If it is too readily permeable, the algaecide will find its way to the paint interface too quickly and wash away in a relatively short time. On the other hand, if the matrix is not permeable enough, the concentration at the interface may be too low to be toxic to the algae and aquatic organisms.

Cuprous oxide and TBTO were used as the algaecides in most of the antifouling paints tested. The solubility of these algaecides is high enough to be effective but not so high that leaching rate from the antifouling paints is difficult to control. Bis (tributyltin) oxide is equal or at times superior to cuprous oxide for effectiveness in antifouling paints. However, environmental concerns for tributyltin residue in water and possible effects on aquatic organisms will likely make it very difficult to register for use in irrigation systems.

The primer is very important, especially with the insoluble matrix antifouling paints. It prevents the paints from blistering and flaking off. An anticorrosive primer is essential when the antifouling paints are applied to a metal surface. Whether a primer is needed or not, a very clean surface is required for adhesion of any type of coating.

RESULTS AND DISCUSSIONS

There were six studies from 1977 to 1984 covered in this report and the results were as follows:

a. *Copper residue and efficacy study of paint No. 1* (used on a concrete-lined irrigation canal for attached algae control conducted at the St. Vrain Canal).–Copper residue contained in the water at first delivery was 1.3 p/b (parts per billion) copper. As the rate of water delivery increased and with a larger painted area submersed in water, the copper residue found in the water increased to a high of 1.9 p/b when all the painted area was finally under water (table 3) (fig. 8). The copper levels gradually decreased to an undetectable amount in the next 2 months. The copper residue levels followed a similar pattern the following year (table 4) (fig. 8). The test conditions of this study, with the very large painted area, very high-quality water as shown in table 5, and using a soluble matrix antifouling paint, probably gave the maximum amount of copper residue to be found in water from this type of treatment. The effectiveness of this antifouling paint in inhibiting algae attachment was excellent up to the last part of the season. Early in November, there were painted areas showing some attachment of algae.

b. *Copper residue and efficacy study of paints No. 2, 3, and 4* (tested at aquatic weed field station). - From the water samples collected throughout the season, the amount of copper residue detected was from 1.0 p/b to undetectable levels. The amount of copper detected varied throughout the season. The amount of tin found in water samples collected from the flumes was less than the concentration that can be detected with the analytical method used for this study (<0.5 p/b). Panels painted with paints No. 3 and 4 had no algae attached to them at the end of the season, but the test panel with paint No. 2 had some algae attachment.

c. *Efficacy and durability study of paints No. 5, 7, and 8* (tested at aquatic weed field station). — The effectiveness of paints No. 7 and 8 was very good but only for one-half season. The same thing happened the next season when the test panels were submersed in water. This indicates that when the algaecide is depleted from the interface, the matrix of this coating is not permeable enough for the algaecide from the lower layers to leach to the interface at a rate that would be toxic to algae. The algaecide seemed to work its way to the surface during the months the panels were not exposed to water. So, the coatings were effective in inhibiting algae attachment for the first part of the next season. Efficacy for algae control using paint No. 5, which was formulated in the Bureau of Reclamation laboratory, was very good. The test area was still inhibiting algae attachment at the end of the season. The durability of this paint is very good; however, the proper primer must be used and the area to be painted must be adequately prepared.

d. *Copper residue and efficacy study of paint No. 2* (tested at the Steinaker Supply Canal in Vernal, Utah). - These data are needed to amend the label of this antifouling paint for use in irrigation systems. Copper residue released from the antifouling test area was very low throughout the irrigation season, ranging from undetectable amounts most of the season to levels less than 2.0 p/b (table 6). The efficacy in inhibiting algae attachment to the concrete-lined flume was excellent for most of the season. However, by the end of the season, there were spots in the test area where the paint had eroded away. The higher alkalinity of the Steinaker Canal water, as shown in table 7, seemed to have no bearing on the effectiveness of this treatment.

e. *Efficacy study of paint No. 2* (tested at Pilot Chute Canal in Riverton, Wyoming, for control of algae and caddis fly population). — This treatment kept all organisms from attaching to the flume for most of the season.

f. *Efficacy study of paints No. 2, 6, and 9* (tested at the Charles Hansen Canal, Loveland, Colorado). -Paints No. 2 and 6 gave excellent results in inhibiting algae attachment the first season, and paint No. 6 continued to give very good control the second season after the paint was applied. Paint No. 9 may have inhibited algae attachment at the beginning of the first season, but no control was observed after this short period. From a durability standpoint, paint No. 9 held up very well; however, it was not releasing a high enough level of copper to be toxic to algae.

The data collected from these studies conducted with antifouling paints were sufficient to meet all EPA (Environmental Protection Agency) requirements necessary to obtain a registration of paint No. 2 for use in irrigation systems. Paint No. 2 is soluble matrix plus 25 percent cuprous oxide antifouling paint that gives excellent control of algae attachment but only for one season. Lack of durability would be the only drawback to this paint. It should preferably last for at least two seasons. The addition of a second coat did not extend the durability of paint No. 2 when applied to concrete irrigation structures. The price of this paint has been greatly reduced within the last year making it more attractive to use in irrigation systems despite the fact it is effective for only one season.

CONCLUSIONS

The soluble matrix and vinyl resin paints containing TBTO or cuprous oxide as the algaecidal additive performed very well for inhibiting algae and aquatic organism attachment. This was true in previous studies with antifouling coatings in irrigation systems. For durability, the vinyl resin coatings having an insoluble matrix were superior to soluble matrix-type antifouling paints. The vinyl ester thin layer overlay coating and the chlorinated rubber coating were superior to the vinyl resin paint for durability. However, after the copper was released from the surface layer, these coatings would not release enough copper to inhibit algae from attaching. Results of these tests show that a vinyl resin matrix with cuprous oxide or TBTO as the algaecide rated at the top for overall performance.

So far, paint No. 2 is the only antifouling paint registered for use in irrigation systems. This paint gives excellent results for inhibiting algae and aquatic organism attachment. However, with its soluble matrix, it is effective only for one season. The plans for the future are to attempt obtaining a registration for the vinyl resin antifouling coatings and to extend the durability of paint No. 2.

Table 1. - Identification, description, and composition of paint materials under test

Paint No.	Description and composition of paint materials
1	Soluble matrix, 15 percent copper flakes
2	Soluble matrix, 25 percent cuprous oxide
3	Insoluble matrix, unepoxy, 33.6 percent copper powder, 3.65 percent Bis (tributyltin) oxide
4	Insoluble matrix, unepoxy, 45 percent cuprous oxide, 1.6 percent Bis (tributyltin) oxide
5	Insoluble matrix, vinyl resin, 95 percent cuprous oxide
6	Insoluble matrix, vinyl resin, 20 percent cuprous oxide
7	Insoluble matrix, vinyl ester resin, silica, 20 percent cuprous oxide
8	Insoluble matrix, vinyl ester resin, silica, 10 percent Bis (tributyltin) oxide
9	Insoluble matrix, chlorinated rubber, 20 percent cuprous oxide

Table 2. – Study sites and amount of paint applied per treatment

Antifouling paints	St. Vrain Supply Canal		Aquatic weed field station		Steinaker Canal (Utah)		Pilot Chute flume (Wyoming)		Charles Hansen Canal (Colorado)	
	Area painted (ft^2)	Amount used (quart)	Area painted (ft^2)	Amount used (quart)	Area painted (ft^2)	Amount used (quart)	Area painted (ft^2)	Amount used (quart)	Area painted (ft^2)	Amount used (quart)
No. 1	8,873	177								
No. 2			7.75	0.80	239.9 387.4	8.0 16.0	29	1.6	16.14	0.53
No. 3			7.75	0.80						
No. 4			7.75	0.80						
No. 5			0.97	0.21						
No. 6									16.14	1.0
No. 7			0.97	0.21						
No. 8			0.97	0.21						
No. 9									16.14	1.0

Table 3. – Copper found in St. Vrain Canal water

Average waterflow in 1977

Sampling date	Background copper (p/b)*	Copper 0.25 mile down-stream of treated area (p/b)	Copper residue (p/b)	Monthly average water delivered (ft³/s)
03-14-77	1.0	2.3	1.3	50.0
03-15-77	0.5	3.23	1.73	100.0
03-18-77	1.07	1.98	0.91	
03-23-77	0.97	2.03	1.06	
03-28-77	0.88	1.20	0.32	47.5
04-01-77	0.97	1.29	0.32	
04-07-77	1.05	1.43	0.38	
04-14-77	0.93	1.62	0.69	
04-21-77	0.93	1.38	0.45	32.0
05-06-77	0.75	0.99	0.24	
05-11-77	0.98	1.00	0.02	207.7
06-02-77	2.00	3.90	1.90	421.4
07-07-77	2.00	2.50	0.50	387.0
08-02-77	1.20	2.00	0.80	291.5
09-07-77	2.00	2.00	0**	168.0
10-03-77	3.00	3.00	0	123.2

* Parts per billion.
** Less than detectable limit of 0.5 p/b.

Table 4. – Copper found in St. Vrain Canal water

Average waterflow in 1978

Sampling date	Background copper (p/b)*	Copper 0.25 mile down-stream of treated area (p/b)	Copper residue (p/b)	Daily average water delivered (ft^3/s)
04-21-78	4.5	4.5	0**	
04-26-78	4.3	3.7	0	
04-28-78	2.4	3.1	0.7	216.3
05-03-78	3.20	3.25	0.05	
05-19-78	3.5	4.5	1.0	
05-23-78	1.4	3.1	1.7	84.08
06-08-78	0	0	0	
06-20-78	0	0	0	84.3
07-12-78	0	0	0	
07-31-78	1.3	2.0	0.7	291.5
08-15-78	1.0	1.5	0.5	
08-29-78	1.0	2.0	1.0	798.9
09-12-78	1.0	1.5	0.5	
09-26-78	1.17	1.55	0.38	418.9
10-11-78	1.13	1.20	0.07	181.4

* Parts per billion.
** Less than detectable limit of 0.5 p/b.

Table 5. – Complete chemical analyses of St. Vrain Canal water

Laboratory No. D-7709		
Conductivity	μ siemens/cm	8.80E+01
pH		8.10E+00
TDS/105C	p/m	8.80E+01
Calcium	p/m	1.12E+01
Magnesium	p/m	9.76E-01
Sodium	p/m	2.53E+00
Potassium	p/m	1.17E+00
Carbonate	p/m	0.00E+00
Bicarbonate	p/m	4.39E+01
Sulfate	p/m	1.20E+01
Chloride	p/m	0.00E+00
Anions & cations	p/m	7.18E+01

Table 6. – Copper found in Steinaker Canal water

Sampling date	Background copper (p/b)*	Copper downstream of treated area (p/b)	Copper residue (p/b)
06-30-80	3.93	3.93	0**
07-10-80	1.97	3.80	1.83
07-16-80	1.20	1.00	0
07-24-80	2.76	1.94	0
07-31-80	1.32	2.49	1.17
08-18-80	2.90	2.90	0
09-09-80	9.00	9.00	0

* Parts per billion.
** Less than detectable limit of 0.5 p/b.