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INVESTIGATION OF MATERIALS FOR WATERPROOFING LEAKY CONCRETE AMM--ETC(U)
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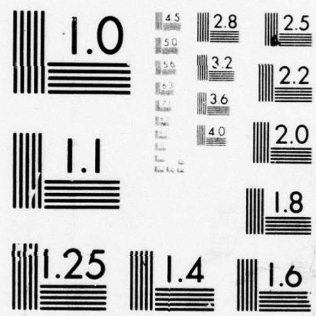

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SPECIAL REPORT M-256
January 1979
Evaluation and Introduction of
New Construction Materials and Techniques

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# INVESTIGATION OF MATERIALS FOR WATERPROOFING LEAKY CONCRETE AMMUNITION-STORAGE BUNKERS FROM THE INSIDE

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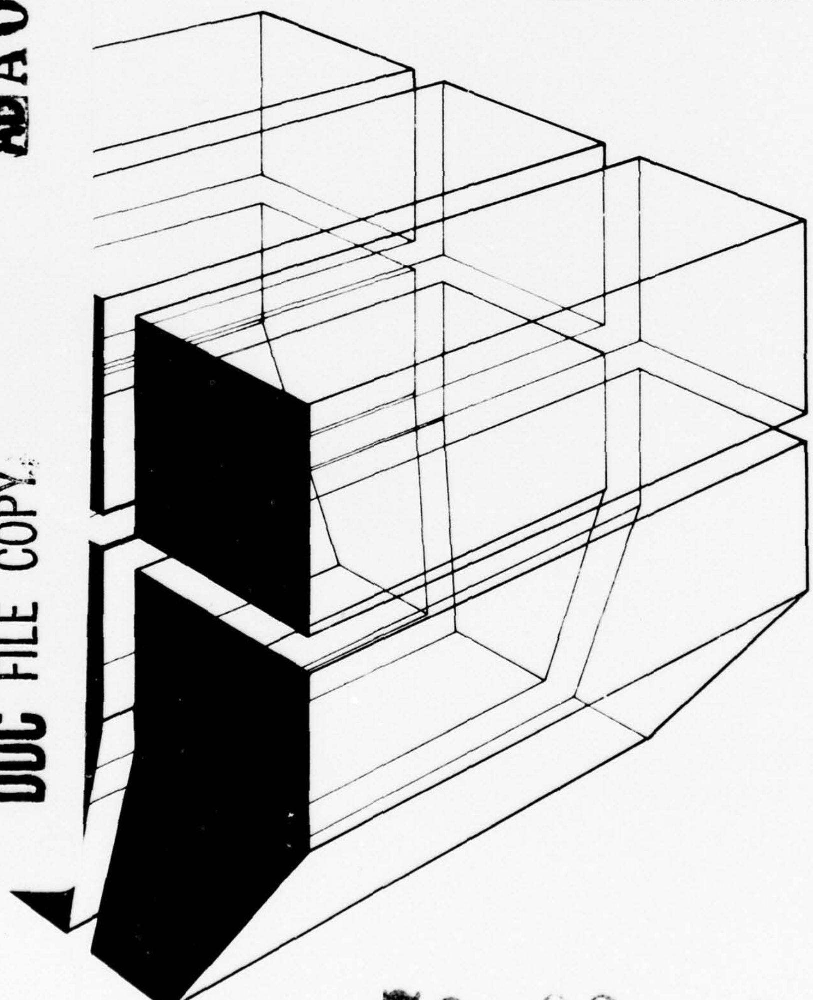

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This investigation is concerned with the problem of water seepage in concrete ammunition-storage bunkers and the findings of an evaluation of crack-waterproofing materials to be used for such repairs inside bunkers. The study included: (1) a survey of military installations to determine the nature of the seepage and remedial methods, (2) a survey of manufacturers for material recommendations and samples, and (3) a testing program involving the waterproofing and hydrostatic testing of cracked concrete slabs.

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Results of the investigation indicate that four types of materials had good resistance to water pressure: 1-component urethane, 2-component tar/urethane, epoxy/polysulfide, and neoprene base.

## FOREWORD

This laboratory investigation was conducted as part of the Facilities Investigation and Studies Program sponsored by the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Operation and Maintenance, Army (OM&A) funding entitled, "Evaluation and Introduction of New Construction Materials and Techniques." The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. Dr. G. R. Williamson is Chief of EM. The OCE Technical Monitors were Mr. W. R. Darnell, DAEN-MPE-S, and Mr. R. L. Wight, DAEN-MPE-T.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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INVESTIGATION OF MATERIALS FOR WATERPROOFING LEAKY CONCRETE AMMUNITION-STORAGE BUNKERS FROM THE INSIDE

# 1 INTRODUCTION

## Background

Earth-covered concrete ammunition-storage bunkers in CONUS and Europe often develop cracks which allow water to seep inside, resulting in the deterioration and corrosion of products stored within the bunker.

The normal procedure for repairing such leaky bunkers is to remove the earth covering and apply ordinary waterproofing materials in a manner similar to built-up roof construction. However, this method is time consuming and costly. A more practical solution would be to apply waterproofing to the cracks on the inside of the bunker. Ideally, the repairs could be made without removing the material stored within the bunker. It is toward this type of solution that this study was directed.

## Objective

The objective of this work is to investigate and evaluate new materials for waterproofing cracks on the inside of concrete bunkers and to provide data for implementing the use of those materials found acceptable.

## Approach

The approach was: (1) review present literature for similar solutions, (2) contact military ammunition-storage installations to investigate water seepage problems in concrete bunkers and identify remedial methods, (3) visit two military installations, (4) contact manufacturers for recommendations on crack-waterproofing materials and obtain samples for inside repairs, and (5) develop laboratory tests and equipment, prepare cracked concrete slab specimens and apply selected materials to evaluate their ability to resist a prolonged hydrostatic load.

## Mode of Technology Transfer

Information contained in this report will impact on Department of the Army (DA) Technical Manual (TM) 5-615, *Repairs and Utilities, Concrete and Masonry*.

# 2 FIELD INVESTIGATION

## Field Investigation of Army, Navy, Marine Corps, and Other Ammunition-Storage Installations

Forty-three Army and 19 Navy, Marine Corps, and other Federal ammunition-storage installations were contacted for information on water seepage in bunkers. Three of the Army and two of the Navy installations had no bunkers. Of the 40 Army installations with ammunition-storage bunkers, 37 had concrete bunkers of which 18 (49 percent) reported seepage due mainly to cracks in the concrete. Of the 17 Navy and other Federal installations with bunkers contacted, 16 had concrete bunkers of which eight reported seepage due mainly to cracks. Although there were fewer corrugated/galvanized steel bunker installations, 50 percent of Army installations and 30 percent of the Navy and other installations reported seepage. Table 1 summarizes these data. Three state highway tunnel departments were also contacted; information obtained from these agencies is listed in Appendix A, Table A3.

Table 1

Seepage Reported

| | Army | Navy and Others |
|---|---|---|
| Active installations | 40 | 17 |
| Installations with concrete bunkers | 37 | 16 |
| Seepage reported (percent) | 49 | 50 |
| Installations with galvanized steel bunkers | 8 | 7 |
| Seepage reported (percent) | 50 | 30 |

Remedial measures for seepage control in concrete bunkers at the installations contacted consisted of either inside or outside repairs or both. Outside repairs required removal and replacement of the earth cover; in some instances, a membrane was used over the concrete bunker or the soil over the bunker was gunited. Materials used for repairing cracks inside the concrete bunkers included epoxy patching grouts and injection types of materials; quick set cement; tar; 1- and 2-component polysulfide; silicone sealant; unknown types of caulking and sealant coating. However, the survey indicated that none of the internal-repair materials in use were successful. For more detailed information, see Appendix A, Tables A1, A2, and A3.

## Installation Visits

The Lexington Blue Grass Army Depot, KY, and the Iowa Army Ammunition Plant in Middletown, IA, were visited. At Lexington, 12 concrete bunkers were investigated that had water seepage caused by horizontal and circumferential cracks. The majority of the cracks were horizontal, occurring about 18 in. (45.7 cm) from the floor in the area of the knee wall joint (cold joint) between the wall and the concrete floor. Circumferential cracks measured from less than 1 yard (0.91 m) in length, beginning near the floor, and extended almost to the center of the ceiling. Cracks varied in width from hairline to as wide as 1 in. (2.54 cm) and the wider cracks appeared to be deep. The bunkers had water troughs located close to the walls below floor level and several were draining water. Small repairs had been made inside the bunker; however, the standard repair method at Lexington consisted of outside repairing. This procedure involves removing the earth cover, cleaning and scraping the concrete surface coatings on the outside, applying hot asphalt to the concrete, and covering the asphalt with a 15-lb (6.8-kg) felt sheet, laminated to an aluminum sheet, with the aluminum as the outside surface. The earth is then replaced over the bunker.

Materiel stored inside bunkers was not removed during outside repair work at Lexington, since damage to the bunkers was not severe. Generally, where the stored materiel is sensitive, the safety department may require its removal from the bunker even though outside repairs will be made. The current procedure (including complete removal of soil and reroofing) is expensive; e.g., about $5000 per bunker for repairing 60 bunkers at Lexington Blue Grass Army Depot, KY.

The Iowa Army Ammunition Plant had both concrete and galvanized steel bunkers. Two concrete bunkers built in 1941 and 1942 and six galvanized steel bunkers built in 1969 and 1973 were investigated. One concrete bunker had hairline cracks in the ceiling and some fine cracks in the walls which were coated with an unknown material. This bunker was at the edge of a hill and was subject to surface water drainage. The galvanized steel bunkers had leaks mainly at the anchor bolts that join the corrugated metal sheets to the anchor plate at the concrete base. (The contractor was called back several times prior to completion of construction to seal leaks, especially around bolts.) Seepage was also noted in some of the longitudinal seams. Corrosion and rust were also present in a few areas. Drainage troughs were not provided in the floor adjacent to each wall since drainage tile is installed on the exterior of the concrete bases. One experimental method used at Iowa to solve the seepage problem in steel bunkers was to strip off the sod cover of the earth embankment and replace it with a 1/2-in. (1.27-cm)-thick, asphalt-impregnated mat liner to seal the surface. This method is successful but requires yearly maintenance similar to roofing. A major difficulty is the settling and movement of the earth, which causes the liner to crack.

This investigation confirmed that outside repairing, though sometimes effective, is expensive and time consuming. Significant maintenance and repair savings are possible if an efficient, reliable inside repair technique can be developed to seal leaking bunkers.

# 3 LABORATORY INVESTIGATIONS

In general, laboratory investigations which resulted in the selection of satisfactory concrete-crack repair materials consisted of: (1) planning and developing a test procedure and technique, (2) designing testing equipment and purchasing materials and parts for tests, (3) building a multiple-sample hydrostatic test assembly for evaluation of in-place crack-waterproofing materials in concrete, (4) obtaining manufacturer-recommended waterproofing materials, (5) preparing concrete slab samples and applying waterproofing material, and (6) assembling the sample unit and subjecting it to a hydrostatic test similar to what would be expected in the field.

## Materials

Eighty manufacturers were contacted regarding material recommendations for waterproofing cracks in concrete bunkers. Thirty-nine manufacturers recommended materials (33 furnished samples) and 41 had no products to recommend.* These materials fell into four general categories:

1. Caulks, sealants, and mastics

2. Epoxies

3. Hydraulic cement types for patching

4. Surface waterproofing coatings.

Only flexible materials were considered for evaluation because of the possibility of movement in the cracks. An additional criterion for consideration was a material's sprayability. Except for two cases, only one test was conducted on any given generic material. Detailed information on the manufacturers and others contacted is contained in Appendix B. Table 2 is a categorized list of generic types of materials and related manufacturers.

## Preparation of Concrete Specimens

To evaluate the performance of materials in sealing cracked concrete, concrete slabs were cast, cured, broken in two, and rebonded after setting a specific crack-opening size between the slab sections.

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* Some manufacturers did not know if any of their products were applicable, some were only raw material suppliers, and some referred to other companies.

These cracks were then waterproofed with materials previously selected for testing. Next, a plastic box was clamped to the slab over the crack on the opposite side of the repair. This watertight unit was then attached to a hydrostatic test system and subjected to a nominal water pressure of 5 ± 0.5 psig (34.5 ± 3.4 kN/$m^2$). Finally, the materials were rated with respect to their ability to resist water seepage under these conditions.

Concrete slabs* used in the test series were 3-in. thick x 16 in. x 16 in. (7.6-cm thick x 40.6 cm x 40.6 cm). The slabs were broken in flexure and the two sections of each slab were rebonded, leaving a crack opening ranging in size from hairline to 0.5 in. (12.7 mm) in width. Each test slab was limited to a single-size crack by grouting** 3 in. (7.62 cm) of the crack at each end to hold the slab together. This left approximately a 10-in. (25.4-cm) crack length in the middle of the slab for testing of the sealant material. Figure 1 shows a slab being cracked in two and Figure 2 shows a cracked concrete slab.

Figure 3 shows a grouted concrete slab with a 3/8-in.- (9.53-mm)-wide crack and overall length of 10 in. (25.4 cm). The sealant material was applied into the crack on the uncoated side of the slab. Figure 4 shows the coated+ side of the same slab. (All test slabs were coated thus, on one side, to seal the concrete surface and prevent absorption of water during the hydrostatic testing.) Figures 5 and 6 are similar examples, except that they have a hairline crack. Figures 7 and 8 illustrate a completed test specimen with a sealed 5/16-in.-(7.94-mm)-wide crack and a clamped-on plastic box ready for the hydrostatic test at nominal water pressure of 5 ± 0.5 psig (34.5 ± 3.4 kN/$m^2$). The water box++ is in the foreground of Figure 8. It can also be seen in Figures 9, 12, and 13. Figures 14 through 20 provide views of specimens 1 through 8.

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* See Appendix C, Table C1 for details on criteria, mix proportions, and resulting strengths of the concrete.

** Code 2388 Epoxtite Resin (W. R. Grace) was used to bond the slab together and retain a hairline crack. For wider cracks, the resin was mixed with dry sand to make a grout.

\+ Coated with ACME HydrEpoxy 300/20, 2-component water-based epoxy, white surface waterproofing coating. Two coats used.

++ The plastic boxes were made from 1/2-in. (12.7-mm) thick Plexiglas. Outside dimensions of the boxes are 5 in. x 12 in. x 12 in. (12.7 cm x 30.48 cm x 30.48 cm), with a 12 in. x 12 in. (12.7 cm x 12.7 cm) open side. The box has a hole on the large side which is used as the water inlet and a hole on top with a plug for bleeding out air. Inside joint seams were sealed with rod-form putty. Most boxes had screws to hold the sides together.

## Test Specimens -- Materials Selected for Tests

Table 3 identifies the trade and generic names of the concrete crack waterproofing materials selected for hydrostatic tests. It also shows the specimen widths and diameter of the polyethylene foam backup rod used in some of the cracks.

## Application of Materials to Concrete Specimens

All materials were applied and cured in accordance with the manufacturer's recommended procedure. The concrete slabs were stored at 30 to 95 percent relative humidity. Some materials required a caulking gun for application (1 and 8 in Table 3), some a trowel or putty knife (2, 3, 4, and 5 in Table 3), some a brush (7 in Table 3), and some could be sprayed (6, 7, and 9 in Table 3). All except 1 and 8 required mixing. Specimen 9 was extremely thin and could not bridge the crack when sprayed over it; this specimen was not used. Detailed application procedures are given for the successful materials in Appendix C, Table C2.

## Discussion and Results

All specimens (Table 3) were then subjected to the hydrostatic tests. Numbers 5, 7, and 8 developed leaks. Number 5 failed on the third day and number 7 in less than 1 day. Number 8 developed some seepage on each side of the crack during the first day and also began to swell. However, since the leak subsided, this specimen was continued in the test; the swelling became larger and spread over a greater area. One area of No. 8 swelled to a height of 11/16 in. (17.5 mm) after 30 days of testing; it failed completely 3 days later.

Figures 9 through 20 show the hydrostatic test system and views of test specimens 1, 2, 3, 4, 6, 7, and 8. (See Appendix D for information concerning the pressure/recorder system.)

Hydrostatic test results for the successful materials--specimens 1, 2, 3, 4, and 6--are listed in Table 4. None of these specimens had leaks at the conclusion of testing. Their costs are listed in Table 5.

## Comparison of Properties of Successful Materials

Of the four successful materials tested, only one was a 1-component type (Mameco Vulkem Sealant 116). The other three required mixing two components prior to use. Cure time was generally the same (3 to 4 days) except for Carboline Caulking Compound 225 (7 days). This material is also the hardest. Pot life must be watched on all materials except Mameco. Only Tremco 50V can be sprayed. For all materials, the bonding surface should be dry, but most materials can be applied to damp surfaces if necessary. Tremco 50V and Neobon Trowel Cement are available in black only. The Mameco material is available in many colors. Although suggested by only one manufacturer, the use of a backup material in cracks over 1/8 in. (3.18 mm) in width is a good procedure for controlling sealant depth. (Backup materials are commonly used in sealing joints.) In the tests, a backup rod was not used with the Tremco 50V sprayed material. The carboline material was applied over a hairline crack without routing. Cost per gallon is the lowest for the Tremco material and highest for the Neobon Trowel Cement. The Mameco material has the longest warranty (5 years). See Table 6 for complete details.

# 4 CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

1. Forty-nine percent of the Army installations and 50 percent of the Navy and other installations contacted reported water seepage in concrete ammunition-storage bunkers.

2. None of the internal repair materials used by the installations were considered generally successful.

3. Four of the seven classes of concrete-crack repair materials selected for laboratory evaluation have withstood hydrostatic tests and have performed well. The materials are: (1) Mameco Vulkem Sealant 116, (2) Tremco-Tremproof 50V, (3) Carboline Caulking Compound 225, and (4) Atlas Neobon Trowel Cement.

## Recommendations

It is recommended that the four laboratory-proven materials be field tested on leaky bunkers.

Table 2

Material Types Recommended by Manufacturers for Waterproofing Cracked Concrete Ammunition-Storage Bunkers From the Inside

Caulks, Sealants, Mastics

| Caulk or Sealant | Components | Manufacturers* |
|---|---|---|
| Acrylic Latex | 1 | Franklin |
| Butyl | 1 | DAP, U.S. Gypsum |
| Epoxy/Polysulfide | 2 | Carboline, Matcote |
| Polysulfide | 1 | DAP, 3M |
| | 2 | Atlas, Grace, Pecora, Std. Dry Wall |
| Polyurethane | 1 | Mameco, Poly Resins, Sika |
| | 2 | Peterson, Tremco |
| Silicone | 1 | General Electric, Dow Corning |
| **Mastic Type** | | |
| Asphalt Extended Polyurethane | 2 | Chevron |
| Asphalt/Inorganic Fillers | 1 | Daubert |
| Asphalt/Urethane | 1 | Tremco |
| Coal Tar/Butyl | 1 | Protecto Wrap |
| Neoprene Trowel Cement | 2 | Atlas |
| Tar/Urethane | 2 | Tremco |

Note: Some of these materials require a primer.

*See Appendix B1 for addresses and phone numbers.

Table 2 (cont'd)

Hydraulic Cement Types for Patching and Surface Waterproofing Coatings

| Hydraulic Cement Types | | Manufacturer |
|---|---|---|
| Drylok Fast Plug | | United Gilsonite |
| Durabond | | U.S. Gypsum |
| Duralith | | Monroe |
| Embeco 167 Mortar (Metallized) | | Master Builders |
| RPM Jet Set | | Republic Powdered Metals |
| Sikaset 517 | Add to cement for quick set patch | Sika |
| Speed Rock | Does not contain cement | Monroe |
| Thorite | Fast set patching mortar | Standard Dry Wall |
| Waterplug | | Standard Dry Wall |

| Surface Waterproofing Coatings | Manufacturer |
|---|---|
| Blockoter Ready-Mixed Waterproof Cement Paint* | Republic Powdered Metals |
| Drylok Ready-Mixer Sealer* | United Gilsonite |
| Durabond Waterproofing Coating Ready-Mixed* | U.S. Gypsum |
| Raylite B-36, clear | Raylite |
| Thoroseal, Cement Base Heavy Duty Waterproofing Coating | Standard Dry Wall |
| Vandex | Vandex |
| Hydr Epoxy 300/20* | ACME |

* These materials meet Federal Specification TT-P-1411-A, *Paint, Copolymer-Resin, Cementitious (For Waterproofing Concrete and Masonry Walls)* (15 November 1973).

Table 2 (cont'd)

Epoxies*

| Flexible | Manufacturer |
|---|---|
| Flexible Epoxybond Paste | Atlas |
| Epi Rez 505, 510, and Epi Cure 872 | Celanese |
| M-12 Flexible Grout-Sealant | Marweld |
| Multi Mortar | Poly Resins |
| **Other Epoxies for Nonmoving Cracks** | |
| Hydr Epoxy 300/20 or 260/23, both water-based | ACME |
| Resiweld CK-109 | Fuller |
| Epoxtite Grout, Code 2388 | Grace |
| 46 X 16 for wide cracks | Mobil |
| 46 X 28 for hairline cracks | Mobil |
| Zelox Crack Filler, for cracks less than 1/4-in. (6.35-mm) wide | Monroe |
| PG-2089 or 1024 | Permagile |
| Sikastix 360 | Sika |
| Wall-Nu | Steelcote |

*All 2-component and for vertical use.

Table 3

Test Specimens -- Materials Selected for Tests

| | Specimen No. | Slab Crack Width, Inches | Crack Sealing Material | Backup Rod* Diameter, Inches | Generic Type |
|---|---|---|---|---|---|
| 1. | 6-1-2 | 1/2 (12.7 mm) | Mameco Vulkem Sealant No. 116 1/2 in. deep No primer | 3/4 (19.1 mm) | Urethane, 1-comp |
| 2. | 6-2-1 | 1/4 (6.35 mm) | Tremco 50V 1/4 in. deep No primer | 3/8 (9.53 mm) | Tar/Urethane, 2-comp |
| 3. | 6-3-8 | Hairline | Carboline 225 Applied on surface No primer | 1/4 (6.35 mm) In one spot | Epoxy/Polysulfide, 2-comp |
| 4. | 6-5-3 | 1/4 (6.35 mm) | Atlas Neobon Trowel Cement and Primer, 1/4 in. deep | 3/8 (9.53 mm) | Neoprene base, 2-comp |
| 5. | 6-4-4 | 1/8 to 3/16 (3.18 - 4.71 mm) | Pecora Synthacalk GC-5 and P-53 Primer, 1/4 in. | 1/4 (6.35 mm) | Polysulfide, 2-comp |
| 6. | 6-9-18 | 5/16 ± 1/8 (1.94 ± 3.18 mm) | Tremco 50 V and Primer Sprayed | None | Tar/Urethane, 2-comp |
| 7. | 6-6-6 | Hairline | Protecto Wrap CA1200 Mastic and Primer 1170 AP, Sprayable | None | Coal Tar/Resin, 1-comp |

Table 3 (cont'd)

| | Specimen No. | Slab Crack Width, Inches | Crack Sealing Material | Backup Rod* Diameter, Inches | Generic Type |
|---|---|---|---|---|---|
| 8. | 6-7-7 | 1/4 (6.35 mm) | G. E. Silicone SCS 2004 and SCP 3154 Primer, 1/4-in. deep | 3/8 (9.53 mm) | Silicone, 1-comp |
| 9. | 6-11-16 | 3/8 (9.53 mm) | Poly Resins Urabond 836-5 Sprayed No primer | None | Urethane, 1-comp |

* Ethafoam SB Polyethylene Backer Rod, Closed Cell, Dow Chemical Co.

Table 4

Hydrostatic Test Performance of Concrete Crack-Waterproofing Materials

| Specimen | Generic Type | Manufacturer's Recommended Cure Time | Hydrostatic Test* Days Without Leaks |
|---|---|---|---|
| 1 (6-1-2) | Urethane, 1-comp | 3 days at $70^{\circ}F$ ($21.1^{\circ}C$) | 165 |
| 2 (6-2-1) | Tar/Urethane, 2-comp | 3-4 days | 165 |
| 3 (6-3-8) | Epoxy/Polysulfide, 2-comp | 7 days at over $75^{\circ}F$ ($23.9^{\circ}C$) | 157 |
| 4 (6-5-3) | Neoprene Base, 2-comp | 3 days at $65^{\circ}$ - $90^{\circ}F$ ($18.3^{\circ}$ - $32.2^{\circ}$ C) | 137 |
| 6 (6-9-18) | Same as No. 2 except with primer and sprayed | 3-4 days | 98 |

See Table 3 and Appendix B, Table B1 for trade names of materials and addresses of manufacturers, respectively.

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*Nominal operating pressure: 5 $\pm$ 0.5 psig (34.5 $\pm$ 3.4 $kN/m^2$) at room temperature and static condition of specimens. The tests were terminated the days listed above without any leaks developing.

Table 5

Cost of Successful Concrete Crack-Waterproofing Materials

| | Materials | | Bulk Cost Per Gallon* |
|---|---|---|---|
| 1. | Mameco Vulkem Sealant 116<br>1-component | | $14.00 (50+Gals); $16.00<br>(1 to 49 Gals) |
| 2. | Tremco 50V<br>2-component | Mixed | $7.50 to 7.75 (For $300+Order)<br>and |
| | Masonry Conditioner (Primer) | | $10.60 to 10.95 |
| 3. | Carboline Caulking Compound 225<br>2-component | Mixed | $26.15 (1 to 100 Gals) |
| 4. | Atlas Neobon Trowel Cement<br>2-component | Mixed | $45.50 (5 Gal); $49.50<br>and |
| | Chloroprime (Primer) | | $14.25 (5 Gal); $14.75 |

*Prices do not include shipping cost.

Table 6

Comparison of Properties of Successful Materials -- Summary*

| Material | Advantages | Disadvantages |
|---|---|---|
| 1. Mameco Vulkem Sealant 116 | No mixing required, 1-component<br>Ready to use<br>Low cost per gallon (higher than Tremco)<br>No primer required<br>Many colors available<br>Long shelf life (1 year) in can<br>No Worry about pot life<br>5-Year material warrantee | Cannot be sprayed<br>One viscosity grade available unless other material is used. |
| 2. Tremco 50V | Sprayable<br>Lowest cost per gallon<br>Longer pot life than #3 and #4<br>Highest elongation (750%)<br>Non-sag and self-leveling grades available | Two components must be mixed before use<br>Available in black color only<br>Use of primer recommended by manufacturer<br>Pot life must be considered (4 hours)<br>Shelf life is lower (6 months) |
| 3. Carboline Caulking Compound 225 | No primer required<br>Gray color<br>Highest tensile, 2700 psi (18616 $kN/m^2$)<br>1-Year shelf life | Two components must be mixed before use<br>Higher cost than #1, #2, and #5<br>Longest cure time (7 days)<br>Low pot life (1½ hours)<br>Lowest elongation (20 to 25%)<br>Cannot be sprayed. |
| 4. Atlas Neobon Trowel Cement and Primer | Trowelled | Two components must be mixed before use<br>Available in black color only<br>Most expensive<br>Primer required<br>Cannot be sprayed |
| 5. Tremco 50V and Primer | Sprayable<br>Second lowest cost<br>Longer pot life than #3 and #4<br>Highest elongation (750%)<br>Non-sag and self-leveling grades available | Same as for No. 2 above |

*From manufacturers' literature and contacts

Table 6 (cont'd)

| | Material | Generic Type | Viscosity | Solids or Non-Volatiles, % By Weight | Application: General Methods | Application: Surface Wetness | Application: Test Crack Width, In. (mm) | Back-Up Rod: Need | Back-Up Rod: Diameter, In. (mm) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Mameco Vulkem Sealant 116 | Urethane 1-Component | Non-Sag only unless use other material | 98 | Pressure equipment or hand operated caulking gun | Should be dry but can be damp, not wet | ½ (12.7) | For back-up and joint fillers | 3/4 (19.1) |
| 2. | Tremco 50V | Tar/Urethane 2-Components | Non-Sag and Self-Leveling Available | 87 | Squeegee, brush or spray | Should be dry but can be damp, not wet | ¼ (6.35) | Not Stated | 3/8 (9.53) |
| 3. | Carboline Caulking Compound 225 | Epoxy/Polysulfide 2-Components | Non-Sag | 100 | Brush, caulking gun, trowel, putty knife | Should be dry but can be damp, not wet | Hairline | Not Stated | ¼ (6.35) in one spot |
| 4. | Atlas Neobon Trowel Cement and Primer | Neoprene Base 2-Components | Non-Sag | 80 to 83 Base Material | Trowel or caulking gun | Should be dry but can be damp, not wet | ¼ (6.35) | Not Stated | 3/8 (9.53) |
| 5. | Tremco 50V and Primer | (Same | Properties | as | No. 2) | | 5/16±1/8 (7.94±3.18) | Not Stated | None |

*From manufacturers' literature and contacts.

Table 6 (cont'd)

| Material | Curing | | | Physical Properties | | | |
|---|---|---|---|---|---|---|---|
| | Cure Time | Pot-Life | Shelf-Life | % Elongation | Tensile, PSI(kN/m²) | Hardness | % Shrinkage |
| 1. Mameco Vulkem Sealant 116 | 3 Days | N/A, 1-Component | 1 Year minimum in can | 330 | 180 (1241) | 28 Shore A | 0 |
| 2. Tremco 50V | 3 to 4 Days | 4 Hours minimum | 6 Months | 750 | 150 (1034) | 30 Shore A | 10 to 13 |
| 3. Carboline Caulking Compound 225 | 7 Days | 1½ Hours | 1 Year minimum | 20 to 25 | 2700 (18616) | 65-70 Shore D | Less than 1 |
| 4. Atlas Neobon Trowel Cement and Primer | 3 Days | 1 to 1½ Hours | 8 Months in cool place | 100 to 150 | 650 to 750 (4482 to 5171) | 55±5 Shore A | 17 to 20 |
| 5. Tremco 50V and Primer | | (Same | Properties | as | No. 2) | | |

*From manufactures' literature and contacts

Table 6 (cont'd)

| Material | Color | Federal Specification Conformance | Packaging | Warrantee |
|---|---|---|---|---|
| 1. Mameco Vulkem Sealant 116 | Gray Six standard colors available and special colors | TT-S-00230c | Standard Cartridges and bulk in 1 gal and 5 gal cans and drums | 5 Years |
| 2. Tremco 50V | Black only | Not stated | Bulk, 4 gal final mix units | 1 Year |
| 3. Carboline Caulking Compound 225 | Gray | Not stated | 1 Gal and 5 gal kits | Time not stated |
| 4. Atlas Neobon Trowel Cement and Primer | Black only | Not stated | 5 to 50-lb can | 1 Year |
| 5. Tremco 50V and Primer | (Same | as | No. 2) | |

* From manufacturers' literature and contacts

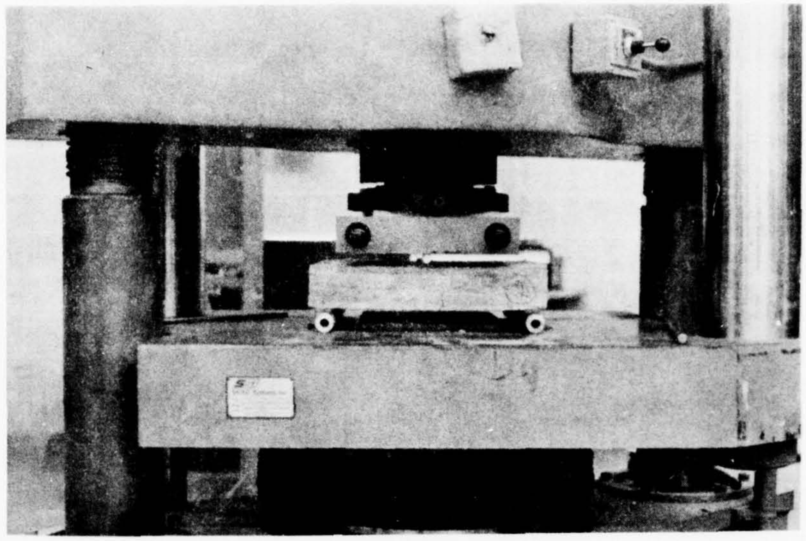

Figure 1. Satec Universal Testing Machine cracking a concrete slab in two.

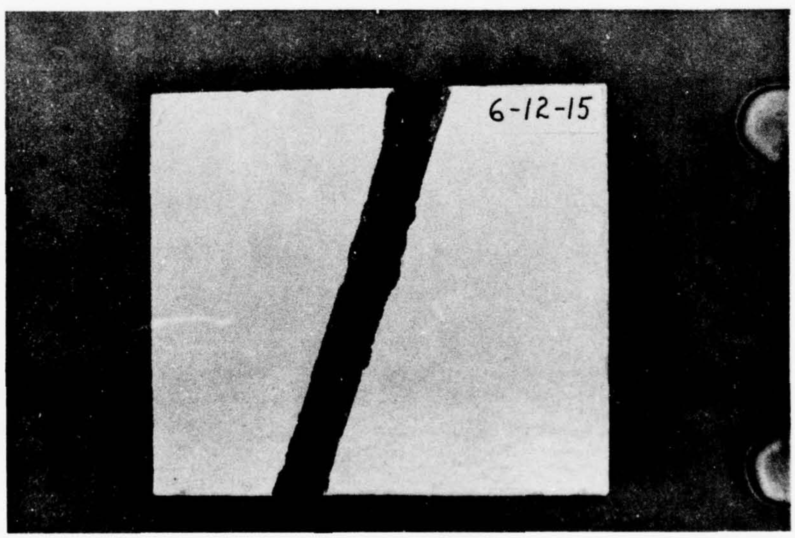


Figure 2. Cracked concrete slab.

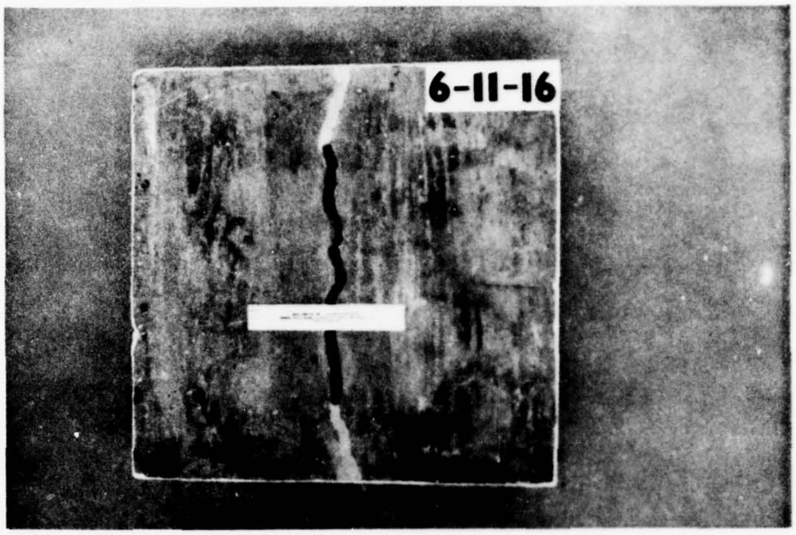


Figure 3. Grouted concrete slab with 3/8-in. (9.53-mm) crack.

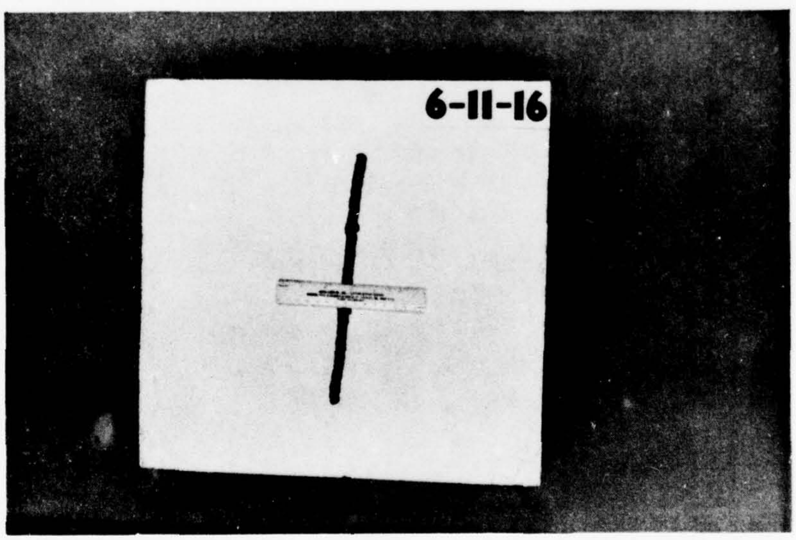


Figure 4. Coated side of grouted concrete slab with 3/8-in. (9.53-mm) crack.

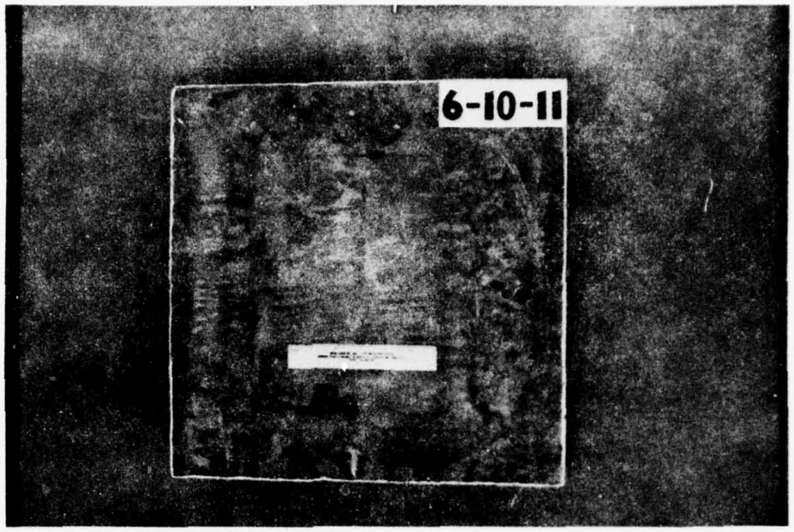


Figure 5. Bonded concrete slab with hairline crack.

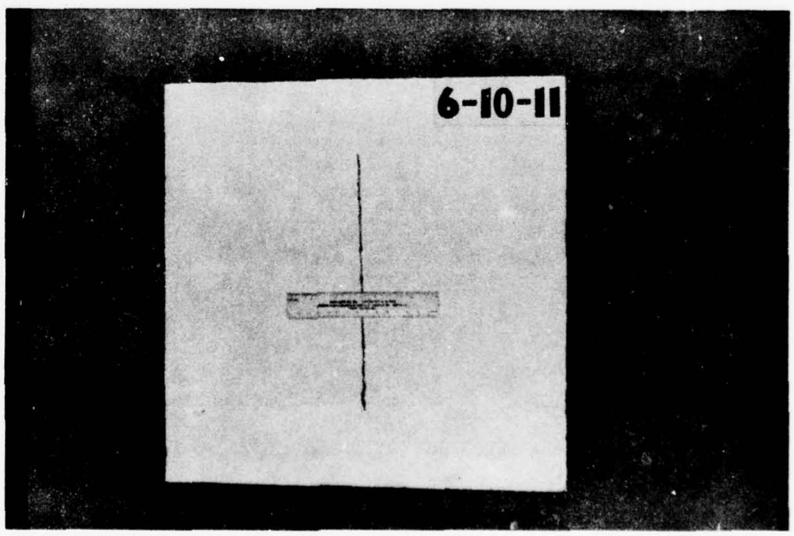


Figure 6. Coated side of bonded concrete slab with hairline crack.

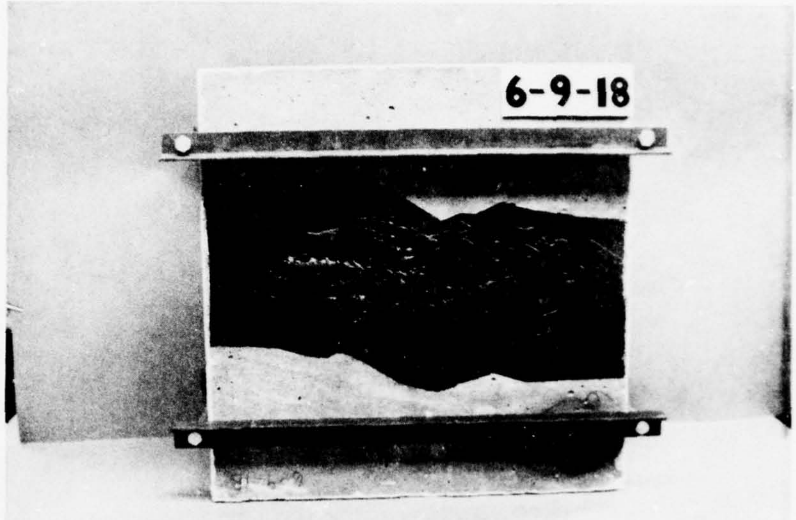


Figure 7. Tremco 50V and primer sprayed in 5/16-in. (7.94-mm) crack (specimen 6).

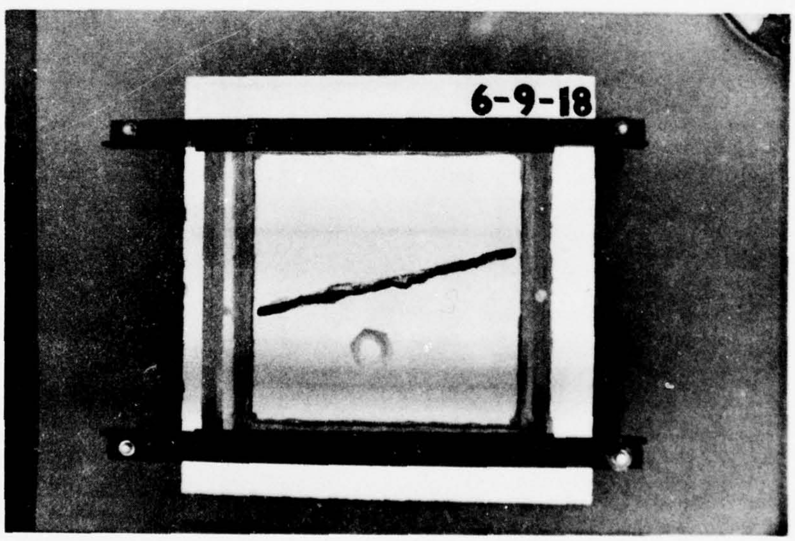


Figure 8. Plastic water box clamped on reverse side of specimen 6.

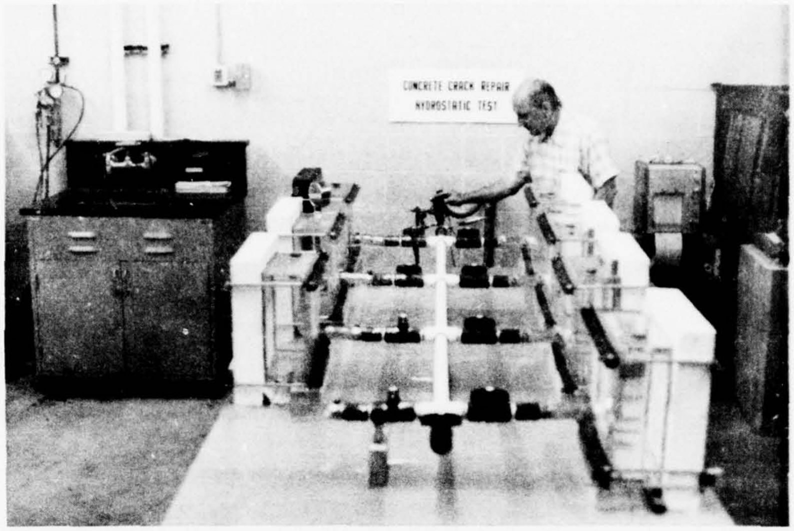


Figure 9. Overview of hydrostatic test system.

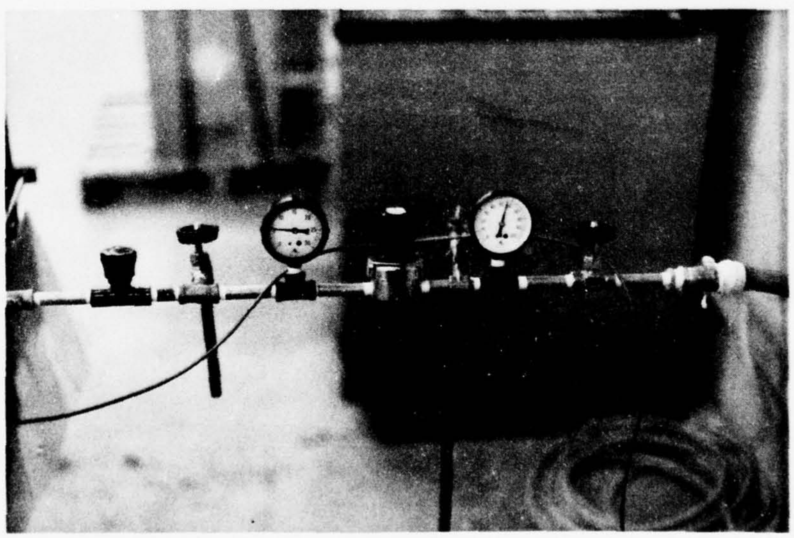

Figure 10. Pressure control equipment and water inlet -- right side.

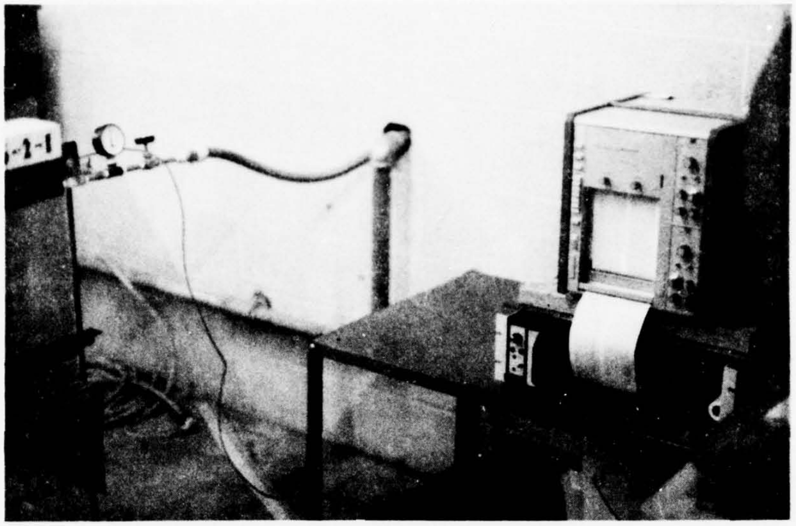

Figure 11. Hydrostatic pressure recorder -- Gould (Brush 2200).

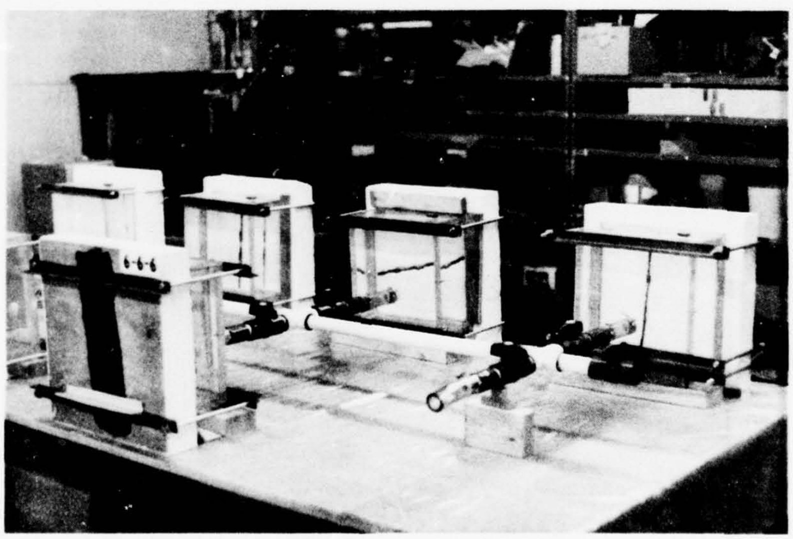

Figure 12. Surface of test specimens 2, 4, 6, and 8 exposed to hydrostatic pressure -- note severity of cracks.

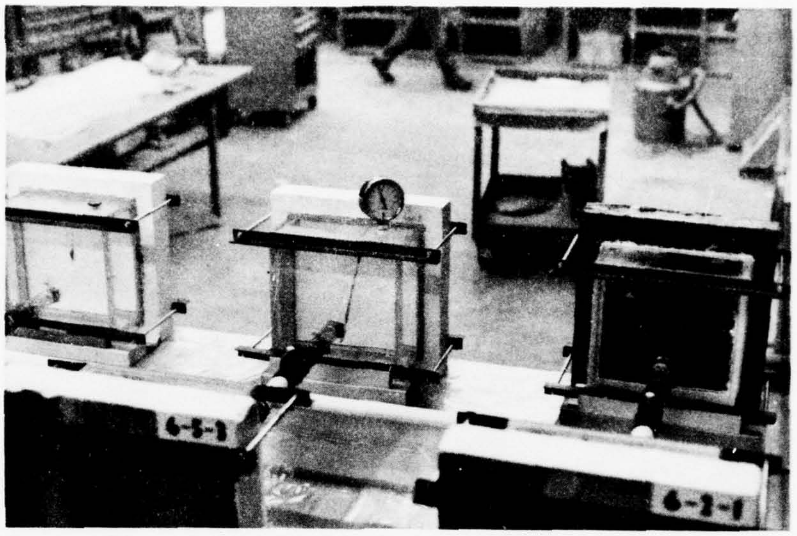

Figure 13. Surface of test specimens 7 and 3 (left and center) which were exposed to hydrostatic pressure -- hairline cracks.

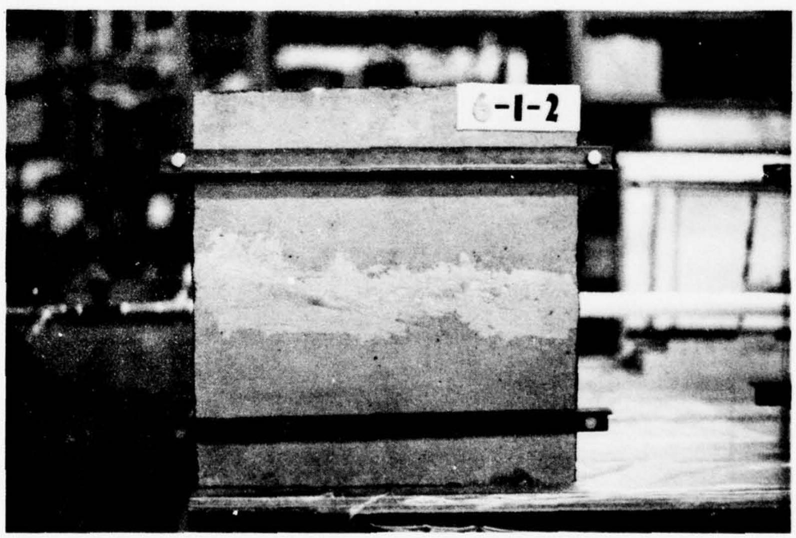

Figure 14. Specimen 1 -- Mameco Vulkem Sealant No. 116 (urethane, 1-comp).

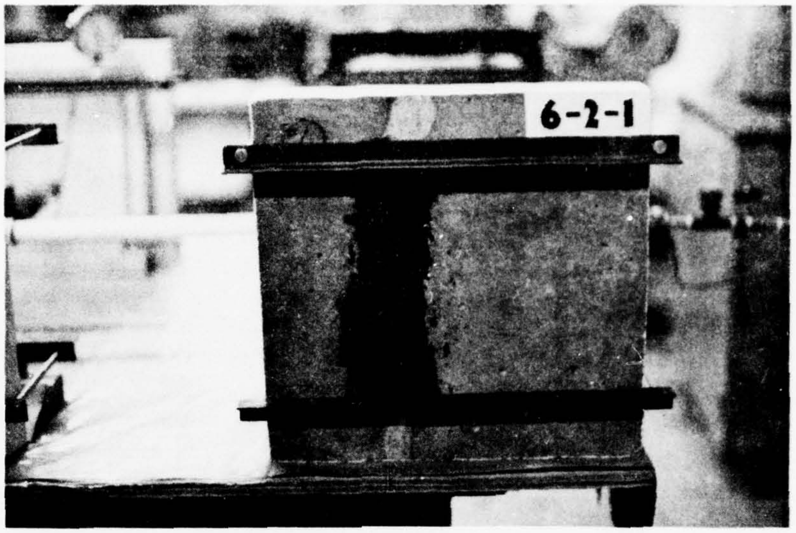


Figure 15. Specimen 2 -- Tremco 50V, no primer (tar/urethane, 2-comp).

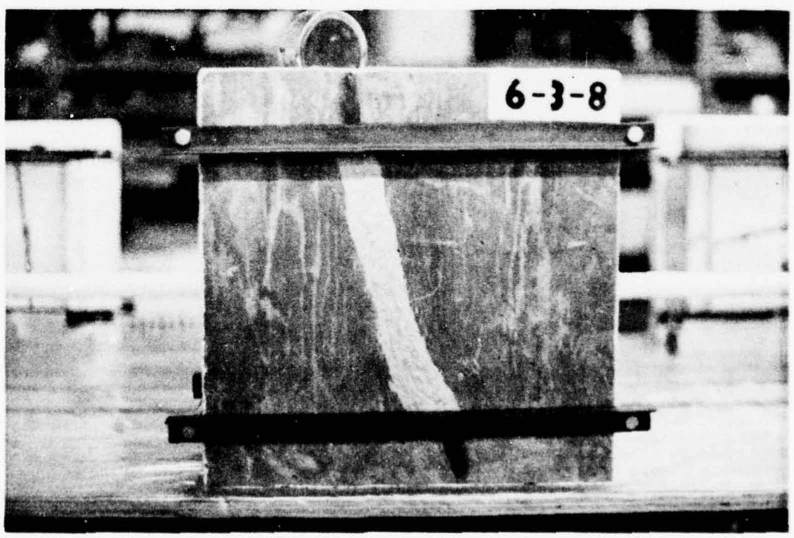


Figure 16. Specimen 3 -- Carboline 225 (epoxy/polysulfide, 2-comp).

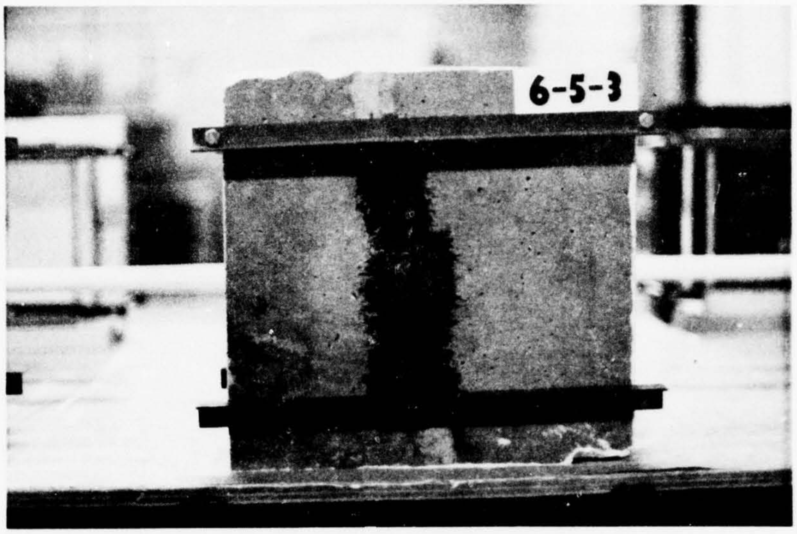


Figure 17. Specimen 4 -- Atlas Neobon Trowel Cement and primer (neoprene base, 2-comp).

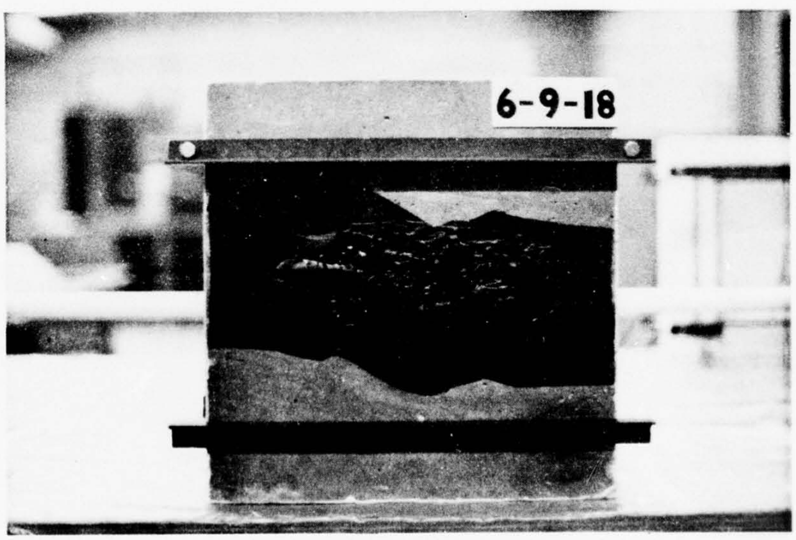


Figure 18. Specimen 6 -- Tremco 50V and primer, sprayed (tar/urethane, 2-comp).

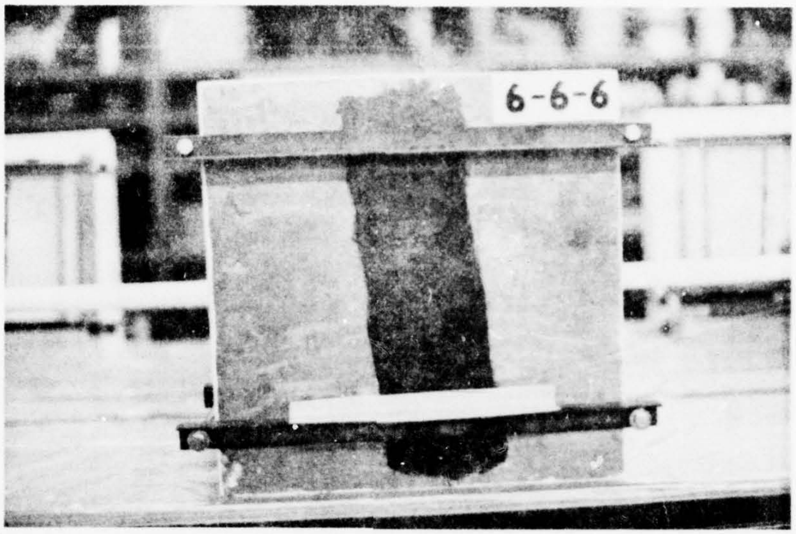


Figure 19. Specimen 7 -- Protecto Wrap CA1200 Mastic and primer (coal tar/resin, 1-comp).

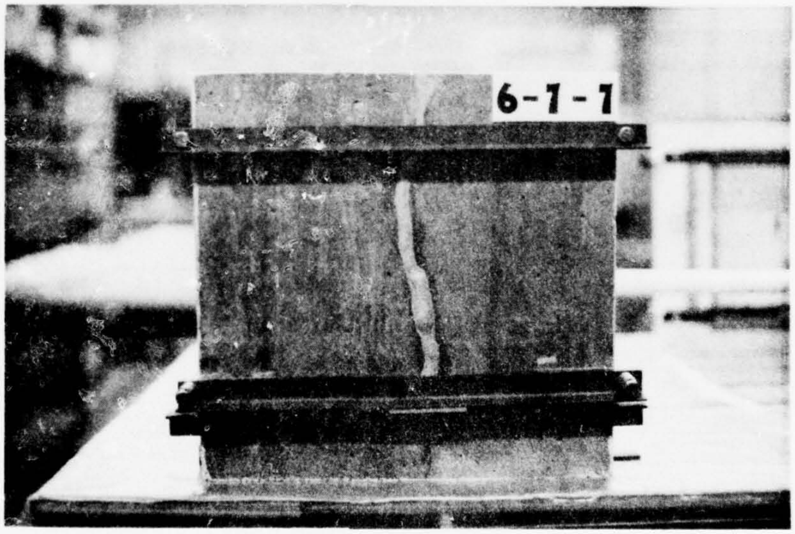


Figure 20. Specimen 8 -- GE Silicone SCS2004 and primer (silicone, 1-comp).

APPENDIX A:

DATA FROM FIELD INVESTIGATIONS

Table A1

Ammunition-Storage Installations Contacted (U.S. Army)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 1. Aberdeen Proving Ground | Aberdeen Proving Ground, MD | Yes | - | - | Some seepage around front wall. Some floors cracked. Repaired one on outside and inside, using sealant. No big problems. They like epoxy patching cement for inside crack repairs. |
| 2. Anniston Army Depot | Anniston, AL | Yes | - | Four, small, for temporary storage | Have cracks in concrete but no serious problems. Repairs can be made on outside only. Use plastic cement and fiberglass, slip sheet and roofing cement. Galv. steel have some leakage at anchor base. |
| 3. Badger Army Ammunition Plant | Baraboo, WI | Yes | - | - | Have condensation on walls during humid weather. No cracks or water seepage. Floors in good condition. |
| 4. Cornhusker Army Ammunition Plant (Inactive) | Grand Island, NE | Yes, with blow-away roof | - | - | No leakage since maintained. Water can get in. Repair outside with roll roofing, 3-ply, and mop on asphalt. Roof construction is 1-1/2-in. (3.8-cm) planks with asbestos. |
| 5. Edgewood Arsenal | Aberdeen Proving Ground, MD | Yes | - | - | Concrete in good condition. Repair work on some igloos, early in 1976, required ventilation, lightning protection and doors. |
| 6. Fort Carson | Fort Carson, CO | Yes | - | Yes New, erected in Jan 1976 | Concrete igloos are only 12-14 years old. No water seepage yet. Have ventilation at front and back and have a drain. No problems yet with the galv. steel igloos. |
| 7. Fort Leonard Wood | Fort Leonard Wood, MO | - | - | Yes | Have 25 World War II galvanized steel igloos. These were resealed in the 1950's. Earth was removed and hot asphalt applied. No work done inside. No leakage or corrosion. Now in process of building 8 new galvanized steel igloos. |
| 8. Fort Polk | Fort Polk, LA | - | Yes Wood arch, rear & front head wall & door | Yes Galv. metal arch, rear & front walls & door | Many galv. metal igloos leaked during rainy season. Source of leakage unknown. Tried to stop leakage. Floor is concrete but too weak for fork lift trucks. New construction proposed. |

Table A1 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 9. Frankford Arsenal | Philadelphia, PA | - | - | - | No igloo storage. Operation phasing out by Sep 77. |
| 10. Gateway Army Ammunition Plant | St. Louis, MO | - | - | - | No igloos. Inactive 5 years. |
| 11. Holston Army Ammunition Plant | Kingsport, TN | Yes | - | - | Water seeps in at base (seams) at foundation joint. Seams are level with floor. Drainage ditch takes care of water. They excavated earth at base & installed outside drain tiles with holes in them. Water is thus caught and removed before it reaches base of igloos. Hydraulic cement used inside. Seepage occurred during rainy season in Spring. Do not have ceiling cracks. |
| 12. Indiana Army Ammunition Plant | Charlestown, IN | Yes | - | Have 4 to 6 on grade, quonset type | No problems with galv. steel type. Concrete igloos have water seepage. There are cracks in the ceiling. Repairs made on outside as well as inside using caulking materials. |
| 13. Iowa Army Ammunition Plant | Middletown, IA | Yes | - | Yes | No problems with concrete igloos. Had seepage in galvanized steel igloos almost immediately after construction. Bolts tightened on inside but still had leakage. Used mopped-on bituminous material on roof. Polysulfide caulking used inside around seams, bolts, and bottom where the steel sheet is joined to the anchor plate on the concrete base. |
| 14. Jefferson Proving Ground | Madison, IN | Yes | - | - | No leaks. Rainfall is heavy. |
| 15. Joliet Army Ammunition Plant | Joliet, IL | Yes | - | - | Seepage has started. Plan on sealing 26 igloos in March or April 1977. Most cracks are in ceiling. Plan to use G.E.1200 Sealant. Will make inside repairs. |
| 16. Kansas Army Ammunition Plant | Parsons. KS | Yes | - | - | Not much seepage. Have a few cracks. Climate is dryer. Used epoxy grout (SWEPCO). Rodents and animals would dig to concrete and make holes. |
| 17. Lake City Army Ammunition Plant | Independence, MO | Yes | - | - | Have cracks in concrete. Floor settled. No problems with roofs. |
| 18. Letterkenney Army Depot | Chambersburg, PA | Yes | - | - | Have seepage in 5% of igloos. Cracks are in the ceiling. They will make another survey during the last half of the year. They remove earth & apply fresh tar over the whole igloo. Small trees or plants grow & cause leaks. |

## Table A1 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 19. Lexington Blue Grass Army Depot | Richmond, KY | Yes | - | - | Have seepage in many. Cracks are in walls and ceiling. They usually re-cover the outside of the roof using an aluminum sheet laminated to a 15 lb. (6.8 kg) felt sheet. |
| 20. Lone Star Army Ammunition Plant | Texarkana, TX | Yes | - | - | Floor cracks. Mud jacking used to even the floors. Have little seepage problems. They repair on inside as well as outside. Rainfall is not severe. |
| 21. Longhorn Army Ammunition Plant | Marshall, TX | Yes but with wood roof and asphalt shingles, not earth covered, roof has gutters | Roof | Three earth covered and inactive | No seepage problems. Have heavy rains in Spring and Fall. |
| 22. Louisiana Army Ammunition Plant | Shreveport, LA | Yes | - | Yes | Repairs made on 25 concrete igloos in 1952. Removed earth off top and poured tar into cracks. Some inside repairs made with coal tar. Have 25 galvanized steel igloos and no seepage but a white rust. |
| 23. Milan Army Ammunition Plant | Milan, TN | Yes | - | - | Have seepage in ceiling. Repairs made on outside only. Top earth cleared away and top of igloos scraped, cleaned, coated with tar and covered with a 6 mil (0.015 cm) polyethylene sheet. |
| 24. Navajo Depot Activity | Flagstaff, AZ | Yes | - | - | Have cracks and minor seepage. Soil has good drainage-cinder base-volcanic ash. Climate is drier. Make inside repairs using 1-component caulking material. |

Table A1 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 25. New Cumberland Army Depot | New Cumberland, PA | Masonry Block. Roof: Wood, built-up felt, slag | Roof | - | A few of these bunkers constructed in 1967 on grade. No seepage problems as yet. Rainfall is heavy. |
| 26. Newport Army Ammunition Plant | Newport, IN | Yes, walls and floors. Roof: "A" frame, 2 in. x 4 in. (5.08 cm x 10.2 cm) rafters, hot tar | Roof | - | Have cracked walls and floor and water seepage. Magazines covered with earth to roof line, no earth on roof. Trying many materials for repairing. Thorospan and primer for inside crack repair good (1 year old now). |
| 27. Picatinny Arsenal | Dover, NJ | Concrete Cinder block on grade. | - | - | Holding up well. No major problems. |
| 28. Pine Bluff Arsenal | Pine Bluff, AR | Yes | - | - | Have water seepage. Major repairs made on 2 to 3 igloos per year. Some repaired on inside with "Water-stop" and caulking and others on outside with caulking, asphaltic mastic, and fiberglass. Cracks routed out primarily on outside but sometimes on inside. Also use roofing felt and sheet of polyethylene on top. Trying Sika materials now on inside (5 months old). |
| 29. Pueblo Army Depot | Pueblo, CO | Yes | - | - | Hairline cracks prevalent but no major problems. Climate is dry except for condensation. Ground is solid and there is no shifting. |
| 30. Ravenna Army Ammunition Plant | Ravenna, OH | Yes | - | - | Have separation of head wall from barrel and barrel cracks. In repairing, the igloo is uncovered and mastic applied. The head wall is bolted to the barrel. |

Table A1 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 31. Red River Army Depot | Texarkana, TX | Yes | - | - | During last 20 to 25 years, 98% of igloos were patched and cracks sealed. Most cracks were in the ceiling and work was done mainly on the inside. Many cracks were less than 1/16in. (16. mm) wide. Some 2-part epoxies tried were satisfactory and others not. Going back to outside repairing. |
| 32. Rocky Mountain Arsenal | Denver, CO | Yes | - | - | Not very many igloos. No problems. Not much rain and area is dry. |
| 33. St. Louis Army Ammunition Plant | St. Louis, MO | - | - | - | No igloos. Inactive for about 5 years. |
| 34. Savanna Army Depot | Savanna, IL | Yes | - | - | Have no cracks. Rainfall is heavy but soil is light and sandy. |
| 35. Seneca Army Depot | Romulus, NY | Yes | - | - | Had water seepage. Cracks were hairline in width up to over 1/4 in. (0.64 cm) in ceilings and walls. Repaired 20 igloos in 1973 and 61 in 1974 and have no leaks. Used epoxy injection method on inside of igloos. More igloos will be repaired in 1977 and same specification will be used. Cost was $10 per linear ft (0.30 m) or $2,700 for 20 igloos. This is much less than the $4,000 to $5,000 required per igloo when all the earth cover is removed and repairs are made on the outside. |
| 36. Sierra Army Depot | Herlong, CA | Yes | - | - | No problems. Cracks present but climate is dry and soil is sandy. |
| 37. Sunflower Army Ammunition Plant | Lawrence, KS | - | Yes | - | Inactive but a 1980 project is anticipated. |
| 38. Tobyhanna Army Depot | Tobyhanna, PA | Yes | - | - | Have only two igloos and they are new. There is dampness but no seepage. |

Table A1 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 39. Tooele Army Depot | Tooele, UT | Yes | - | - | No seepage problems. Located 5,000 ft (1.524 km) above sea level and climate is dry. |
| 40. Twin Cities Army Ammunition Plant | Minneapolis, MN | Yes | Yes | - | Have only two concrete igloos and no problems. There are also 22 wood buildings on grade that they want to replace. These only require painting. Anticipating construction of six concrete type igloos with a steel arch in about 1980 to replace the wood buildings. The latter will be earth covered. |
| 41. Volunteer Army Ammunition Plant | Chattanooga, TN | Yes | - | - | Have hairline cracks and water seepage. Repairs are made inside the igloos and outside. A 1-component paint-on sealer is used. |
| 42. Wingate Depot Activity | Gallup, NM | Yes | - | - | No seepage. Location is dry and a desert. Repaired *a hairline crack in one igloo. They get erosion from* winds in April or May. |
| 43. Yuma Proving Ground | Yuma, AZ | Yes | - | Yes | No problem with concrete igloos. Have both old and new (15 new) galvanized steel igloos. Climate is dry. The two and five year old steel igloos are corroded on the inside, mostly 3 or 4 ft (0.914 - 1.22 m) above the concrete floor. This corrosion probably reaches from the outside to the inner surface and may be caused by the soil. The steel igloos are coated with asphalt on the outside and cathodic protection is provided. Some of the older steel igloos (10 - 15 years old) have water seepage in the ceiling or roof. |

Table A2

Ammunition-Storage Installations Contacted
(U.S. Navy, Marine Corps, and Others)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 1. Marine Corps Air Station | Yuma, AZ | Yes | - | Yes | No cracks or seepage on both types of igloos. Climate is dry and soil is sandy. Galvanized steel igloos are new and were completed in July 1976. There is evidence of salt corrosion. |
| 2. Naval Weapons Center | China Lake, CA | Yes | - | Yes | No major problems. Very little rainfall. Have corrosion in galvanized steel igloos. Soil is alkaline. Three were repaired by hanging a screen inside, 2 in. (5.08 cm) away from the metal. This was then united with a new type cement to a 4 in. (10.2 cm) thickness. Expect to treat more this way if cost is not high. Have gunited the soil over concrete and galvanized steel igloos. |
| 3. Naval Weapons Station | Concord, CA | Yes | - | - | Have seepage from defective flashing at roof joint in front of igloo. No cracking problems. Had some floor failures near doorway due to fork lift trucks. |
| 4. Naval Weapons Station | Seal Beach, CA | Yes | - | - | No cracks or water seepage. Very little rainfall. Only problem is that of animals burrowing in. Floors are 3-1/2 ft (1.07 m) above grade level and earth cover is 3 ft (0.91 m) deep. |
| 5. Navy Submarine Base, New London | Groton, CT | Yes | - | Yes | No cracks or water seepage in concrete igloos. Problem with galvanized steel igloos was not in roof seepage but due to sinking of igloos and high water table. Igloos were constructed on a glacier lake. |
| 6. Naval Ordnance Station | Forest Park, IL | - | - | - | No igloos. |

Table A2 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 7. Naval Ammunition Depot | Crane, IN | Yes | - | - | Have some moisture seepage. In 1975, used Sika IGAS for deep cracks and Thoroseal with Acryl 60 as a coating. Deep cracks are chipped out first. Most repairs are made inside. |
| 8. Naval Ordnance Station | Louisville, KY | - | - | - | No magazines or igloos. |
| 9. Naval Ordnance Station | Indian Head, MD | Yes | - | Yes (Few) | Occasionally have seepage in concrete igloos. Rains are heavy. Outside repairs: Uncover and apply coal tar pitch and membrane. On inside (small spots) use Pecora P-53 Primer and Synthacalk and GC-5 two-part Synthacalk (Nonsag) Polysulfide Rubber Sealant. There are no problems on the few galvanized steel igloos. |
| 10. Naval Ammunition Depot | Hawthorne, NV | Yes | - | - | No problems, desert area, little rain. Soil is high in alkali. Earth cover contains 50% gravel and oil spray used. Had some initial cracking due to differential settlement. |
| 11. Naval Ammunition Depot | Earle, NJ | Yes | - | - | Have very few cracks. Rain is heavy. |
| 12. Naval Ammunition Depot | McAlester, OK | Yes | - | - | Have water seepage. Some cracks are as wide as a pencil. Use epoxy grout. Remove earth on outside and use a membrane. |
| 13. Naval Weapons Station | Charleston, SC | Yes | - | - | Get some seepage. Use sealants. Grout and repair on outside using epoxy grout. Get occasional cracks due to resettlement. |
| 14. Naval Torpedo Station Bangor | Bremerton, WA | Yes | - | - | Have cracks in roof. Sometimes make inside repairs using quick set cement. |

Table A2 (cont'd)

| Installation | Location | Type of Igloo or Magazine | | | Water Seepage Problems |
|---|---|---|---|---|---|
| | | Concrete | Wood | Galv. Steel | |
| 15. Naval Torpedo Station | Keyport, WA | Yes | - | - | Have cracks in concrete. They are not severe and no attempt has been made to repair them. |
| 16. Blytheville AF Base | Arkansas | ? | - | Yes | Seepage in anchor base and at bolts. Tried injection with AM-9 and leaks moved to another location. A promising method is to gunite the outside, using a wire screen. This method may be tried. |
| 17. Richards-Gebauer AF Base | Kansas City, MO | Yes | - | - | No seepage. |
| 18. ERDA (formerly Pantex Ordnance Plant) | Amarillo, TX | Yes | - | Yes | No cases of leakage. |
| 19. Warren AF Base | Wyoming | Yes | - | Yes | Have two concrete and three steel igloos. No seepage problems. |

Table A3

State Highway Tunnel Installations

| Installation | Authority | | Water Seepage Problems |
|---|---|---|---|
| 1. Holland & Lincoln Tunnels New York, NY | Port of New York-New Jersey Authority New York, NY | Joseph Zitelli & Robert Foote 212-466-7405 | Have success with American Cyanamid AM-9 for leaks in land section. Drill holes and pump material inside. Dye tracer is used. Sometimes also use Metalcoat like Embeco (Master Builders Co.). Contractor is Penetryn Systems, Inc., Latham, NY 12110. |
| 2. Battery Tunnel Toll Plazas New York, NY | Tri-Borough Bridge+Tunnel Authority New York, NY | Robert Martin 212-876-9700 | Use AM-9 and pump under pressure in smaller areas. Hydraulic cement also used. Bentonite clay slurry used for large areas. AM-9 is sometimes followed up with epoxy. |
| 3. Tunnels State of Pennsylvania | Pennsylvania Dept. of Transportation | Terry Matuszak 412-381-1815 | No success with materials. Epoxies eventually blister and come off. Injection never used, can't block water since it will come out in another place. They usually remove the area and do a new job. Need good drainage system behind concrete or above tunnel. Their problem is not quite the same as with bunkers since the tunnel is surrounded by rock and there are many streams going through mountains. |

APPENDIX B:

MANUFACTURERS AND OTHERS CONTACTED

Table B1

Manufacturers Recommending Products for Waterproofing Cracked Concrete Ammunition-Storage Bunkers from the Inside

Caulks, Sealants

1. DAP Inc.
   Subsidiary of Plough, Inc.
   Dayton, OH 45401
   513-253-7151

2. Devcon Corp.
   59 Endicott St.
   Danvers, MA 01923
   617-777-1100

3. Dow Corning Corporation
   Midland, MI 48640
   517-496-4000
   800-248-2345 (Watts No.)

4. Franklin Chemical Industries
   2020 Bruck St.
   Columbus, OH 43207
   614-443-0241

5. Silicone Products Department
   General Electric Company
   Waterford, NY 12188
   518-237-3330

6. Mameco International
   Vulkem Sealants Div.
   4475 E. 175th St.
   Cleveland, OH 44128
   216-752-4400

7. 3M Company
   Adhesives, Coatings & Sealers Div
   3M Center
   St. Paul, MN 55101
   612-733-1110

8. Norton Sealants
   835 New York Ave.
   Trenton, NJ 08638
   609-695-6194
   Formerly Novagard Corp.

9. Harry S. Peterson Co.
   4150 South Lapeer Road
   Pontiac, MI 48057
   313-373-8100

10. Poly Resins
    11655 Wicks St.
    Sun Valley, CA 91352
    213-875-0820

11. Standard Dry Wall Products
    7800 N.W. 38th St.
    Miami, FL 33166
    305-592-2081
    317-332-2733 (Straughan, IN)

12. Tremco
    10701 Shaker Blvd.
    Cleveland, OH 44104
    216-229-3000
    other manufacturers are:
    13, 21, 24, 26, 30, 34, and 43.

Table B1 (cont'd)

**Mastics**

13. Atlas Minerals & Chemicals Div.
    EBS Incorporated
    Farmington Road
    Mertztown, PA 19539
    215-682-7171

14. Chevron USA, Inc.
    575 Market St.
    San Francisco, CA 94105
    415-894-3295

15. Daubert Chemical Co.
    1200 Jorie Blvd.
    Oak Brook, IL 60521
    312-582-1000

16. Porter Paint Co.
    400 South 13 St.
    Louisville, KY 40201
    502-589-6250

17. Protecto Wrap Company
    2255 South Delaware St.
    Denver, CO 80223
    303-777-3001

18. Tremco, See 12

Table B1 (cont'd)

Epoxies

19. ACME Chemicals & Insulation Co.
Div. of Allied Products Corp.
P. O. Box 1404
New Haven, CT 06505
203-562-2171

20. Atlas Minerals & Chemicals Div.
ESB Incorporated
Farmington Road
Mertztown, PA 19539
215-682-7171

21. Carboline Co.
350 Hanley Industrial Court
St. Louis, MO 63144
314-644-1000

22. Celanese Resin Systems
Div. of Celanese Coatings & Spec. Co.
Louisville, KY 40208
502-585-8011

23. H. B. Fuller Company
315 South Hicks Road
Palatine, IL 60067
312-358-9500

24. W. R. Grace & Co.
Construction Products Division
6051 West 65th St.
Chicago, IL 60638
312-767-4282

25. Marweld Epoxy Industries, Inc.
P. O. Box 6902
San Antonio, TX 78209
512-224-6914

26. Matcote Company, Inc.
P. O. Box 10762
6001 Antoine
Houston, TX 77018
713-682-1711

27. Missouri Paint & Varnish Co.
5129 N. 2nd St.
St. Louis, MO 63147
314-241-6370

28. Mobil Chemical Company
Maintenance & Marine Coatings Dept
901 N. Greenwood Ave.
Kankakee, IL 60901
815-933-5561

Table B1 (cont'd)

Epoxies

29. The Monroe Company, Inc.
30801 Carter St.
Cleveland, OH 44139
216-248-7890

30. Pecora Corporation
165 Wambold Road
Harleysville, PA 19438
215-723-6051

31. Permagile Corp. of America
101 Commercial St.
Plainview, NY 11803
516-433-1100

32. Poly Resins
11655 Wicks St.
Sun Valley, CA 91352
213-875-0820

33. Rocky Mountain Chemical Co.
Kimball St.
Casper, WY 82601
307-265-3227

34. Sika Chemical Corp.
Box 297
Lyndhurst, NJ 07071
201-933-8801

35. Steelcote Manufacturing Co.
3418 Gratiot St.
St. Louis, MO 63103
314-771-8053

36. George W. Whitesides Co., Inc.
31st & Michigan Drive
Louisville, KY 40212
502-778-4492

Table B1 (cont'd)

## Hydraulic Cement Types for Patching

37. Master Builders
Div. of Martin Marietta Corp.
Cleveland, OH 44118
216-371-5000 Cleve., OH
314-962-6646 St. Louis, MO

Other hydraulic cement type product manufacturers are:
11, 29, 34, 37, 40, 42, and 43.

## Surface Waterproofing Coatings

38. ACME Chemicals & Insulation Co.
Div. of Allied Products Corp.
P. O. Box 1404
New Haven, CT 06505
203-562-2171

39. Raylite Company
P. O. Box 7218
Wilmington, DE 19803
302-652-3904

40. Republic Powdered Metals
2628 Pearl Road
Medina, OH 44256
216-225-3192

41. Standard Dry Wall Products
7800 N.W. 38th St.
Miami, FL 33166
305-592-2081
317-332-2733 (Straughan, IN)

42. United Gilsonite Laboratories
Scranton, PA 18501
717-344-1202

43. United States Gypsum Co.
101 South Wacker Drive
Chicago, IL 60606
312-299-3381

44. Vandex (USA) Inc.
1200 High Ridge Road
Stamford, CT 06905
202-322-7020

## Table B2

### Federal Agencies and Private Organizations Contacted

Bureau of Mines
Pittsburgh Mining & Safety Research Center
Bruceton, PA

Bureau of Mines
Spokane Mining Research Center
Spokane, WA

Prof. J. D. Kriegh
University of Arizona
Tucson, AZ

National Bureau of Standards
Gaithersburg, MD.

Portland Cement Association
Skokie, IL

The Sulfur Institute
1725 K Street, N. W.
Washington, D. C. 20006

## Table B3

### Chemical And/Or Epoxy Grouting Contractors

| | | |
|---|---|---|
| ABC Services<br>205 22nd St.<br>Sacramento, CA 95816 | 916-448-2982 | Chemical mainly |
| Adhesive Engineering Co.<br>1411 Industrial Rd.<br>San Carlos, CA 94070 | 415-592-7900 | Epoxy |
| Halliburton Services<br>Duncan, OK 73533 | 405-255-3760 | Chemical |
| Penetryn System, Inc.<br>424 Old Niskayuna Road<br>Latham, NY 12110 | 518-783-2958 | Chemical & Epoxy |
| Structa-Bond, Inc.<br>Jones & Elm Streets<br>Conshohocken, PA 19428 | 215-828-3222 | Epoxy |
| T J K Inc.<br>7407 Fulton Ave.<br>N. Hollywood, CA 91605 | 213-875-0410 | Chemical |

APPENDIX C:

LABORATORY INVESTIGATIONS

Table C1

Concrete Mix Design Used for Test Slabs

Criteria:

a. 3000 psi (20.68 $MN/m^2$) at 28 days

b. Nonair-entrained

c. 3-in. (7.6-cm) slump

d. 3/4 in. (19.1-mm) coarse aggregate

e. Fineness modulus of sand: 2.6

f. Dry rodded unit weight of agg: 104 $lb/ft^3$ (1666 $kg/m^3$)

Air content was 1.4%, actual slump was 4 1/8 in. (10.5 cm), and unit weight was 146.0 $lb/ft^3$ (2339 $kg/m^3$).

Mix Design:

W/C = 0.68 (Table 5.2.4* [a])
Mixing Water = 340 lb (154 kg) (Table 5.2.3*)
(Cement content = 340/.68 = 500 lb (227 kg)

Coarse aggregate content = 0.64 (Table 5.2.6*)
(0.64 x 27 = 17.28 $ft^3$ (0.489 $m^3$), 17.28 x 104 = 1797 lb (815 kg)
2% air content (Table 5.2.3*)

Volume Calculations:

| Component | $Lb/yd^3$ | | ($kg/m^3$) |
|---|---|---|---|
| Cement | 500 | (SG: 3.15) | 297 |
| Water | 340 | (SG: 1.0) | 202 |
| Coarse Agg. | 1797 | (SG: 2.67) | 1066 |
| Sub Total | 2637 | | 1565 |
| Sand | 1256 | (SG: 2.65) | 745 |
| Total | 3893 | | 2310 |

*_Recommended Practice for Selecting Proportions for Normal Weight Concrete_, ACI Publication 613.54 (ACI, 1974).

Table C1 (cont'd)

Specimens:

Sixteen concrete slabs were cured at 28 days and 4 at 23, at a temperature of 75°F (23.9°C) and 100 percent relative humidity. The average 28-day compressive strength of three cylinders from this mix design was 4005 psi (27.61 $MN/m^2$). Slabs were later allowed to dry and were cracked in two by using a 500,000 lb (226,796 kg) Satec Universal Testing Machine. Each slab was placed on two 1-5/16-in. (33.3-mm) diameter parallel steel rods located 1 in. (25.4 mm) from the edge of the slab on each side. A 5/8-in. (15.9-mm) diameter steel rod was placed on top of the slab in the center for the ram pressure application to break the slab. Figure 1 illustrates the Satec testing machine cracking a slab in two. Four slabs were cracked after a 23-day cure and maximum load was an average of 5100 lb (2313 kg). This results in a flexural cracking stress of 743.7 psi (5128 $kN/m^2$). The remaining slabs were cracked after the 28-day cure and maximum load was an average of 5270 lb (2390 kg). Flexural cracking stress was 768.5 psi (5300 $kN/m^2$).

Table C2

Application Procedures Used for Successful Materials

| Sealant Material | Application Procedure |
| --- | --- |
| 1. Mameco Vulkem Sealant 116<br>Urethane, 1-component<br>Gray color. In cartridge.<br>Specimen No. 1 (6-1-2)*<br><br>Not Sprayable | -Crack was 1/2 in. (12.7 mm) wide<br>-Crack cleaned with air hose and loose concrete blown out<br>-Ethafoam backup rod, 3/4-in. (19.1-mm) diameter applied into crack to depth of 1/2 in. (12.7 mm)<br>-Sealant applied into crack over backup rod with caulking gun and smoothened with putty knife, leaving a 1-in. (25.4-mm) feather edge on each side of crack. |
| 2. Tremco Tremproof-50V<br>Tar/Urethane, 2-component<br>Black. Mixing required.<br>Specimen No. 2 (6-2-1)*<br><br>Sprayable | -Crack was 1/4 in. (6.35 mm) wide<br>-Crack cleaned with air hose and loose concrete blown out<br>-Ethafoam backup rod, 3/8-in. (9.53-mm) diameter applied into crack to depth of 1/4 in. (6.35 mm)<br>-Sealant was mixed and applied over backup rod using putty knife, leaving a 1-1/2-in. (38.1-mm) feather edge on each side of crack. |
| 3. Carboline Caulking Compound 225<br>Epoxy/Polysulfide, 2-component<br>Gray. Mixing required.<br>Specimen No. 3 (6-3-8)*<br><br>Not Sprayable | -Crack was hairline in width<br>-Crack not routed<br>-Surface adjacent to crack (12.7 mm) on each side, sanded and wire brushed to remove form release coating<br>-Surface cleaned with air hose.<br>-Sealant mixed and applied with paint mixing paddle, leaving a 3/4- to 1-in. (19.1- to 25.4-mm) feather edge on each side of crack. |

Note: All sealant materials were applied to slabs in a vertical position beginning at the bottom of the crack and ending at the top and from the inside out except on Specimen No. 5 which was sprayed from the top down. All specimens were allowed time for cure before testing.

*From Table 3.

Table C2 (cont'd)

| Sealant Material | Application Procedure |
|---|---|
| 4. Atlas Neobon Trowel Cement Neoprene Base, 2-component Black. Mixing required. | -Crack was 1/4 in. (6.35 mm) wide<br>-Sandpaper the area on each side of crack to remove form release coating |
| Chloroprime Primer, 1-component<br>Specimen No. 4 (6-5-3)* | -Crack and surface cleaned with air hose<br>-Ethafoam backup rod 3/8 in. (9.53 mm) in diameter applied into crack to depth of 1/4 in. (6.35 mm) |
| <u>Not Sprayable</u> | -Chloroprime primer applied on inside walls of crack and on slab surface adjacent to crack, and allowed to dry for 20 minutes<br>-The trowel cement was mixed and applied in two layers over backup rod using a putty knife and leaving a 1-1/4-to 1-1/2-in. (31.8-to 38.1-mm) feather edge on each side of crack. |
| 5. Same as (2) except a primer | -Crack was 5/16 ± 1/8 in. (7.94 ± 3.18 mm) wide |
| (Tremproof Masonry Conditioner) was also used and sealant was sprayed using conventional DeVilbiss equipment.<br>Specimen No. 6 (6-9-18)* | -Sandpaper the area adjacent to the crack, 3 in. (76.2 mm) on each side to remove form release coating and can apply masking tape at edge.<br>-Spray primer into crack and on surface, avoiding puddles, and let dry at least 2 hours |
| <u>Sprayable</u> | -Mix the sealant and spray on the crack and adjacent area (total of 6 in. (15.2 cm) beginning at the top of the crack in the slab. The rough textured surface was improved by troweling. Sealant penetration into crack varied from 7/8 in. (22.2 mm) at the top of the crack to over 1 in. (25.4 mm) at the bottom of the crack. No backup rod was used. |

Note: All of the above materials (1 to 5) should normally be applied to dry concrete, however, they can be applied to damp but not wet concrete.

*From Table 3.

## APPENDIX D:

## EQUIPMENT

A Bell and Howell Pressure Transducer (Type No. 4-326-0031, range 0 to 20 psig, 30 mv at 20 psig) is connected to the water line and an Endevco unit.

The signal from the transducer is conditioned by the Endevco Model 4470 (Master Box) Universal Signal Conditioner Module (with a 4471.1A Card).

The conditioned signal is recorded on a Gould (Brush 2200) Recorder, Model 2007-2202-00.

Initial calibration of the system is for 12.5 psig full scale deflection.

---

12.5 psig = 86.2 $kN/m^2$

20 psig = 137.9 $kN/m^2$

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Kanarowski, Stanley M
Investigation of materials from waterproofing leaky concrete ammunition-storage bunkers from the inside. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : available from NTIS, 1979.
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1. Waterproofing. 2. Concrete construction-deterioration. 3. Bunkers. I. Title. II. Series: U.S. Construction Engineering Research Laboratory. Special report ; M-256.