UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

RESISTANCE OF SELECTED PROTECTIVE COATINGS FOR CONCRETE TO HIGH-VELOCITY WATER JETS

Report No. Hyd-543

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

April 2, 1965

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ABSTRACT

Tests to determine relative flow resistance of two selected protective coatings showed that an unbroken surface of thermosetting random-glass-filament-reinforced polyester resin applied to an untreated concrete surface was quite resistant to the force of a high-velocity jet. The polyester resin and a flexible neoprene membrane were applied to an 11-1/2-in. square face of concrete test blocks and subjected to a 1-in.-dia, 100-fps jet striking at a 45-deg angle for 4-1/2 hr in all tests. Two resin samples had a homogeneous and unbroken 1/8-in. uniformly thick coating. One resin sample had the coating covering the face but varying uniformly from 1/8 in. to zero in thickness. Two resin and one neoprene sample had the 1/8-in. coatings cut across at right angles to the exposed face near the horizontal centerline and one-half removed, leaving sharp cut edges. One resin sample had the edge protected by an epoxy fillet. Results were: (1) The smooth unbroken surface of the polyester resin remained undamaged. (2) The same coating with the unprotected cut edge was washed from the concrete in 5 min. (3) The same coating with the epoxy-protected cut edge remained intact. (4) The neoprene membrane with the unprotected edge adhered to the concrete during the test, but high-pressure water blisters formed between the membrane and concrete surface about 2-1/2 in. from the point of jet impact. This report is for official use only.

DESCRIPTORS-- *protective coatings/ *plastics/ glass fibers/ reinforcing/ *synthetic rubber/ membranes/ mastics/ surfaces/ concrete structures/ high pressures/ hydraulics/ *jets/ flow resistance/ hydrostatic pressures/ edges/ laboratory tests/ research and development/ thermoplastics/ adhesion/ brittleness/ polymers/ materials testing

IDENTIFIERS-- polyesters/ thermosetting resins/ neoprene// impingement/ hydraulic// impinging flow/ blistering

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RESISTANCE OF SELECTED PROTECTIVE COATINGS FOR CONCRETE TO HIGH-VELOCITY WATER JETS

PURPOSE

Tests were conducted to determine the resistance of selected protective coatings for concrete to a 1-inch-diameter, 100-fps (feet per second) water jet which struck the coatings at an angle of 45°. The materials tested were a random glass-filament reinforced thermosetting polyester resin (plastic) and a flexible neoprene (synthetic rubber) membrane.

CONCLUSIONS

1. With the jet impinging on unbroken surfaces of polyester resin (Figures 3A and 3B) there was no apparent damage after 4-1/2 hours of operation.

2. The jet impinging on the cut edge of an unprotected polyester resin surface (Figure 4A) ripped the sample from the concrete base in less than 5 minutes.

3. A cut polyester resin surface with the cut edge protected by an epoxy fillet (Figure 4B) remained intact throughout a 4-1/2-hour test with the jet directed on the protected edge.

4. With the jet directed at the unprotected cut edge of a flexible neoprene membrane (Figure 5A), no damage was noted after 1 hour of operation. After 1-1/2 hours' operation, blisters were noted on the sample about 2-1/2 inches from the point of jet impingement (Figure 5B). These blisters continued to grow, but the sample remained adhered to the concrete surface for the 4-1/2-hour test.

INTRODUCTION

These hydraulic laboratory tests were performed at the request of the Concrete and Structural Branch of the Division of Research. Prior to the tests reported here, selected protective coatings for concrete had been subjected to mechanical abrasion. It was then desired to subject two of the coatings to a high-velocity water jet to determine the relative resistance of the materials to waterflow. For this study, a jet velocity of 100 fps, a jet diameter of 1 inch, an angle of impingement of 45°, and a maximum test duration of 4-1/2 hours per sample, were arbitrarily selected. These parameters remained unchanged throughout the test program.

A polyester resin coating, reinforced with random glass filaments, was applied to an 11-1/2-inch square face of five concrete test blocks. Two samples had a uniform thickness of about one-eighth inch and were homogeneous and unbroken, completely covering the face of the test block (Figure 3A). The third sample completely covered the face of the test block but was applied in such a manner that the coating thickness varied uniformly from one-eighth inch at one edge of the block to zero thickness at the opposite edge (Figure 3B). The remaining two samples were formed by applying a coating of 1/8-inch uniform thickness to the test face, then cutting through the coating at right angles to the exposed face and across the sample near the horizontal centerline. One-half of each sample was removed mechanically, leaving a sharp cut edge as shown in Figure 4A. One of the cut edge samples was tested without further treatment; the cut edge of the other sample was protected with a fillet of epoxy before testing (Figure 4B).

One sample of 1/8-inch-thick flexible neoprene membrane was bonded to a test block with a mastic. The membrane was cut and half the membrane was removed to leave an exposed cut edge similar to that described above (Figure 5A). This membrane was tested without further preparation or protection of the edge.

No further testing or evaluation was requested by the Concrete and Structural Branch, and all of the high-velocity jet tests performed by the Hydraulics Branch are reported herein.

THE STUDY

Test Apparatus

The test apparatus (Figure 1) consisted of a nozzle to form a 1-inch-diameter jet, and a wooden frame to hold the concrete test specimen at a slope of 45° and allow for vertical and horizontal adjustment to position the sample under the jet. The nozzle was first placed 8 inches above the sample (Figure 2A). However, at this distance the jet tended to entrain air, causing it to ravel and strike the test surface so that a sound like a continuous stream of small explosions occurred. The jet appeared to be solid for a distance of about 2-1/2 inches from the nozzle; therefore, the nozzle was lowered until it was about 2 inches from the test surface. At this distance, the full force of the jet impinged smoothly on the test surface (Figure 2B).

Test Procedure

The approach piping was first purged of all air so that a clean jet emerged from the nozzle. Then, with the velocity through the nozzle reduced to about 1 fps, the specimen to be tested was properly positioned under the jet (Figure 2A). The jet was then increased to the full-test velocity of 100 fps and allowed to impinge on the specimen for 5 minutes. The flow was then decreased to 1 fps and the specimen examined. If no apparent damage resulted, the specimen was allowed to be tested an additional 5 minutes and again examined. Thereafter, examination of the specimen was made at 10-minute intervals for a total elapsed time of 30 minutes, then 30-minute intervals for a total elapsed time of 2-1/2 hours, and finally 1-hour intervals for a total elapsed time of 4-1/2 hours.

Results

(Specimens FP-1X-C and FP-1X-D, polyester resin.) These samples consisted of uniform, unbroken coatings one-eighth inch thick over the entire concrete block (Figure 3A). No damage was noted on either surface after 4-1/2 hours of operation.

(Specimen FP-3W-A, polyester resin.) This specimen consisted of an unbroken coating about one-eighth inch thick at one edge of the concrete block and feathered to 0-inch thickness at the other edge (Figure 3B). The jet impinged at a point where the coating thickness was about 1/32 inch, with the jet directed toward the thick edge of the coating. No damage was noted after 4-1/2 hours of operation.

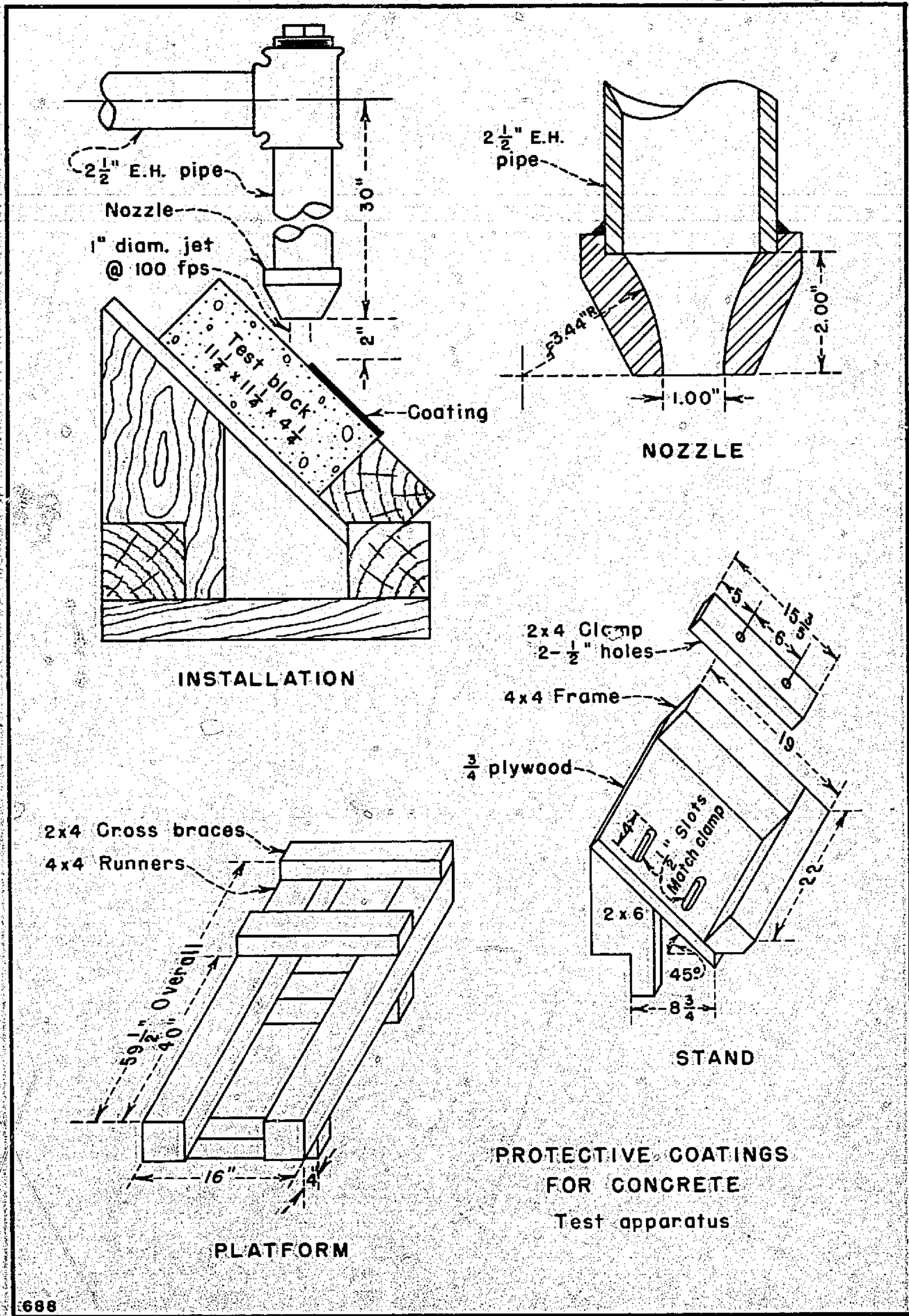
(Specimen FP-1X-A, polyester resin.) This specimen presented a 1/8-inch-thick unprotected cut edge to the jet (Figure 4A). The coating was removed from the concrete sample by jet action in less than 5 minutes of operation.

(Specimen FP-1X-B, polyester resin.) The 1/8-inch-thick cut edge of this specimen was protected with an epoxy fillet (Figure 4B). No damage was noted after 4-1/2 hours of operation.

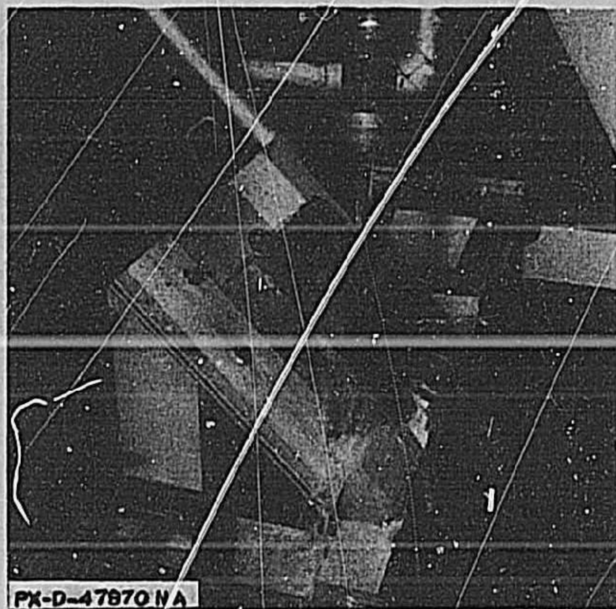
(Specimen Sample No. 35, Lot 4398, flexible neoprene membrane.) This specimen consisted of a 1/8-inch-thick neoprene membrane bonded with a mastic to the concrete base; the membrane was cut with a sharp instrument, and half the membrane was removed mechanically to leave an unprotected square edge (Figure 5A). The jet impinged on this cut edge. An examination made after 1 hour of operation indicated no damage. After 1-1/2 hours of operation, water blisters had started to form downstream from the point of jet impingement (Figure 5B); however, the leading edge of the membrane appeared to be quite tightly bonded throughout its full width. The test continued for the required 4-1/2 hours, at which time the blisters had grown considerably (Figure 6). The leading edge of the membrane still adhered tightly to the concrete surface. One of the blisters was punctured with a sharp-pointed instrument and water under high pressure spurted out. Apparently, the high-pressure water from the jet passed through discontinuities either in the concrete or in the mastic and came to the surface between the membrane and the concrete where it could not escape. Undoubtedly, the specimen would have been forced from the concrete surface by the spreading of the water blisters had the test been permitted to continue.

These tests demonstrated that an unbroken surface of thermosetting, random glass-filament reinforced polyester resin applied to an untreated concrete surface as a protective coating was quite resistant to the forces of a high-velocity water jet. The specimens tested could not be damaged or washed from the concrete surface by a 1-inch-diameter, 100-fps water jet striking the unbroken surface at an angle of 45° for 4-1/2 hours. However, when the jet was directed at an unprotected cut edge (simulating a broken or cracked surface), the coating was removed from the concrete surface in less than 5 minutes. A similar cut edge, protected by a fillet of epoxy, remained undamaged throughout a 4-1/2-hour test run. The coating was quite brittle and could withstand very little bending. If high-pressure water had penetrated under the protected cut coating, the coating would have undoubtedly been forced from the concrete surface and destroyed. There was no evidence that such high-pressure penetration had occurred during the 4-1/2-hour test.

A fexible neoprene membrane bonded to the concrete surface with a special mastic withstood the test jet directed on an unprotected cut edge for 4-1/2 hours. Water did penetrate, however, by some path not readily ascertainable, to form high-pressure water blisters between the neoprene membrane and the concrete (Figures 5B and 6). This membrane would undoubtedly have been forced away from the concrete surface and washed off had the test been continued.



PROTECTIVE COATINGS
FOR CONCRETE
Test apparatus

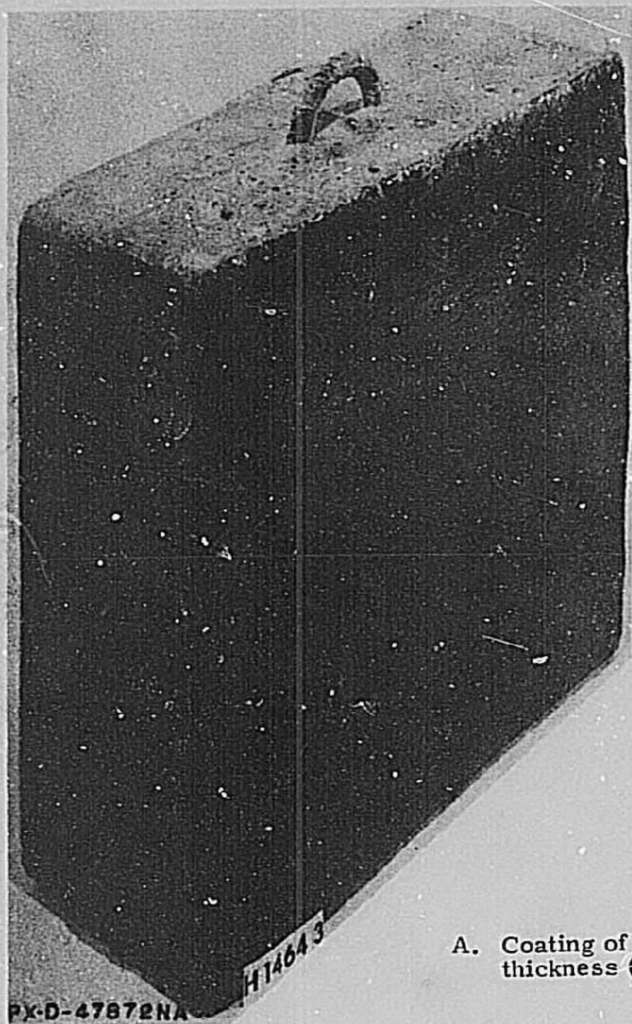


A. Alining a test specimen under the jet

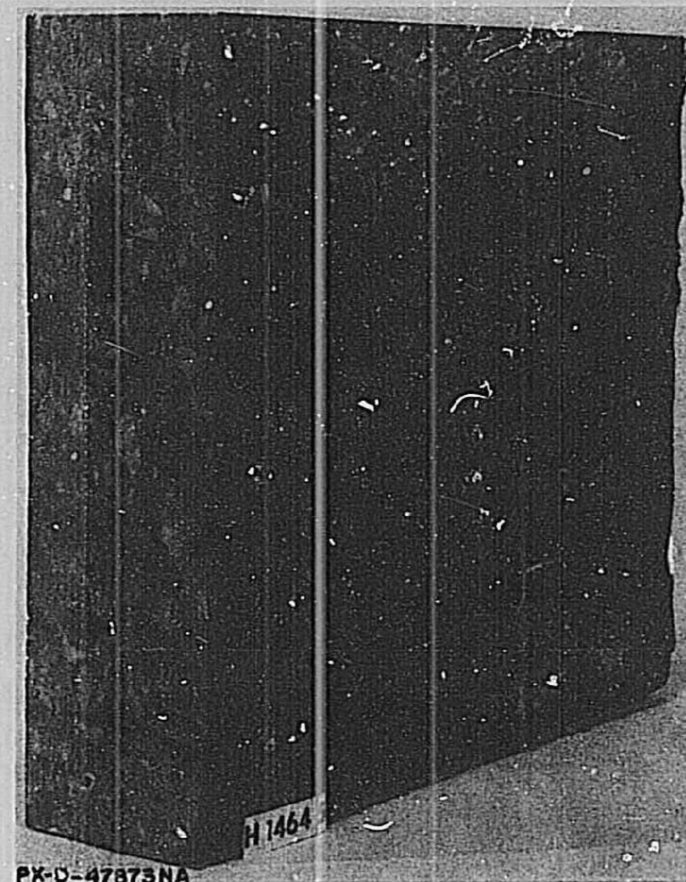
B. Test in progress with a 100-fps, 1-inch-diameter jet

PROTECTIVE COATINGS
for CONCRETE

Test apparatus in operation



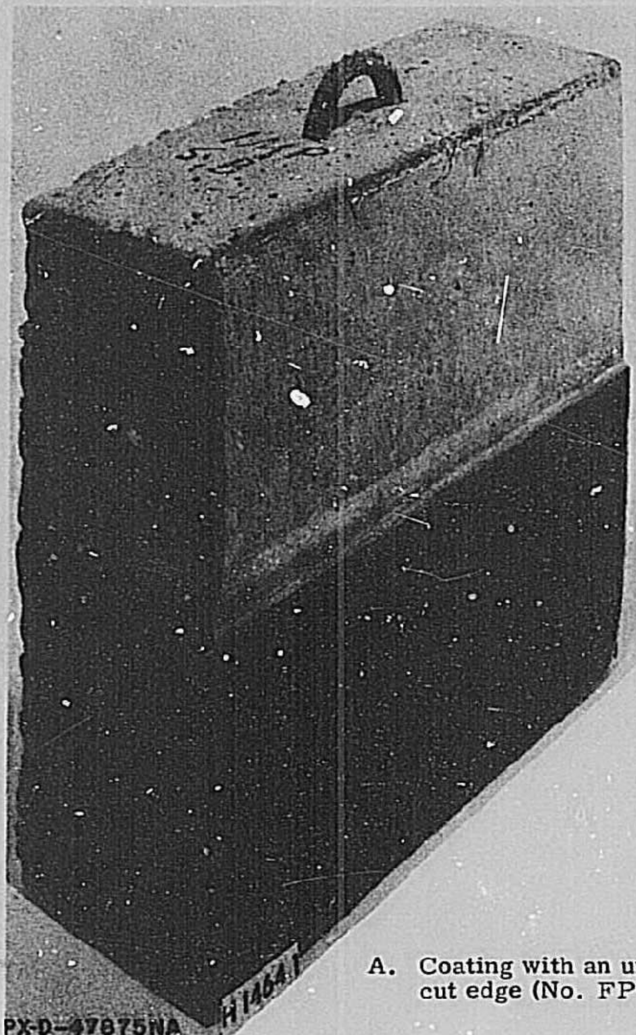
A. Coating of uniform thickness (No. FP-1X-C)



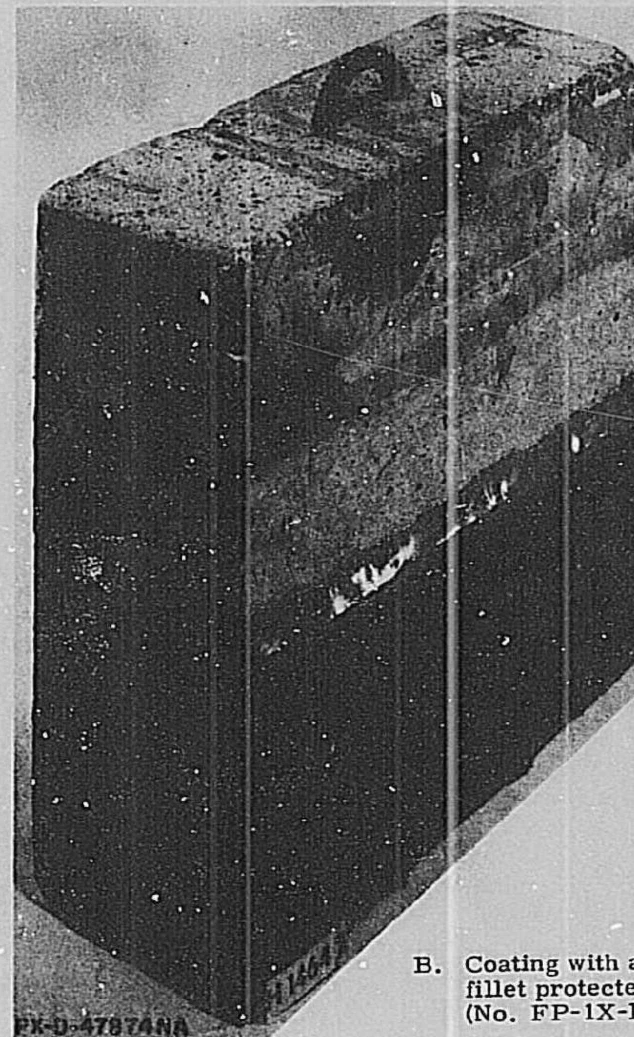
B. Coating varying uniformly from a thickness of one-eighth inch to a feathered edge of zero thickness (No. FP-3W-A)

PROTECTIVE COATINGS for CONCRETE

Continuous polyester resin coatings



A. Coating with an unprotected cut edge (No. FP-1X-A)



B. Coating with an epoxy fillet protected cut edge (No. FP-1X-B)

PROTECTIVE COATINGS for CONCRETE

Polyester resin coating with a cut edge

Figure 5
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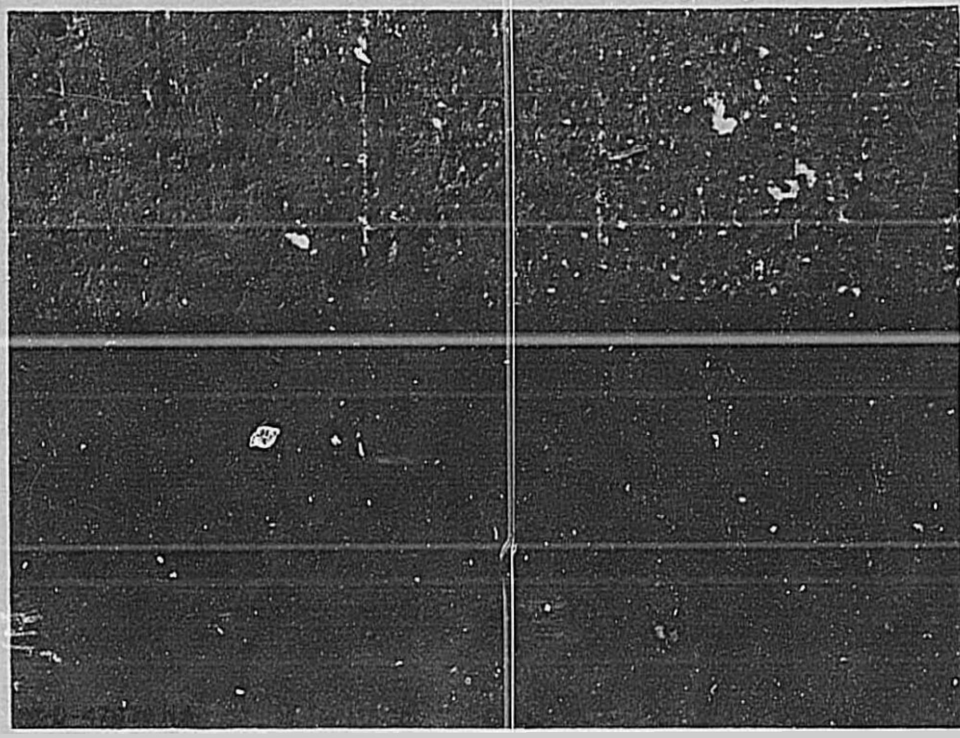
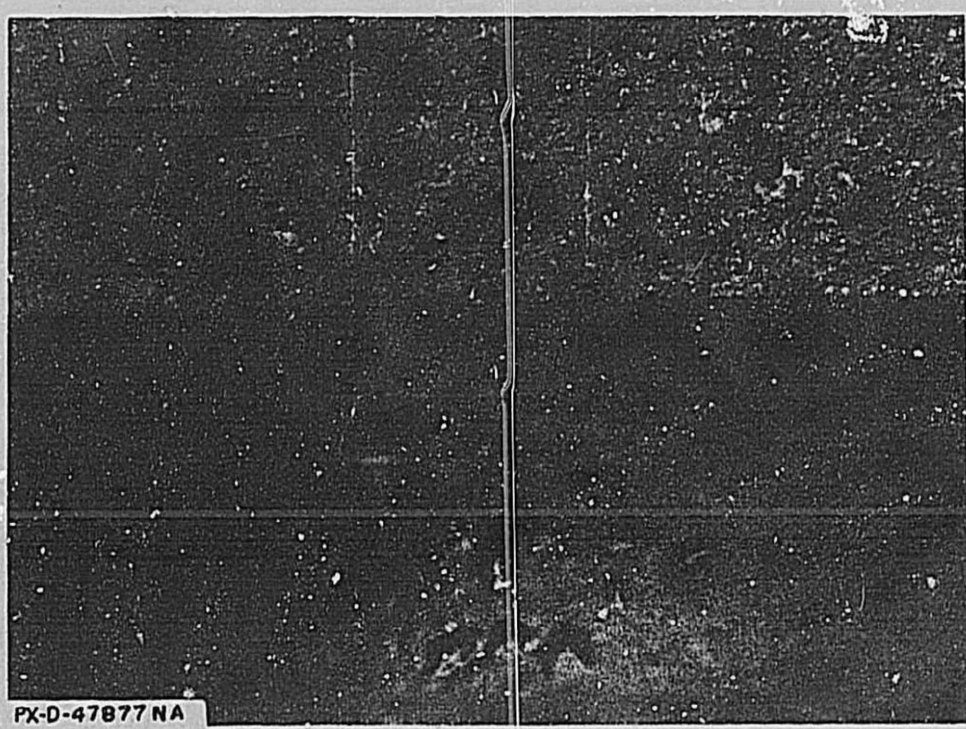


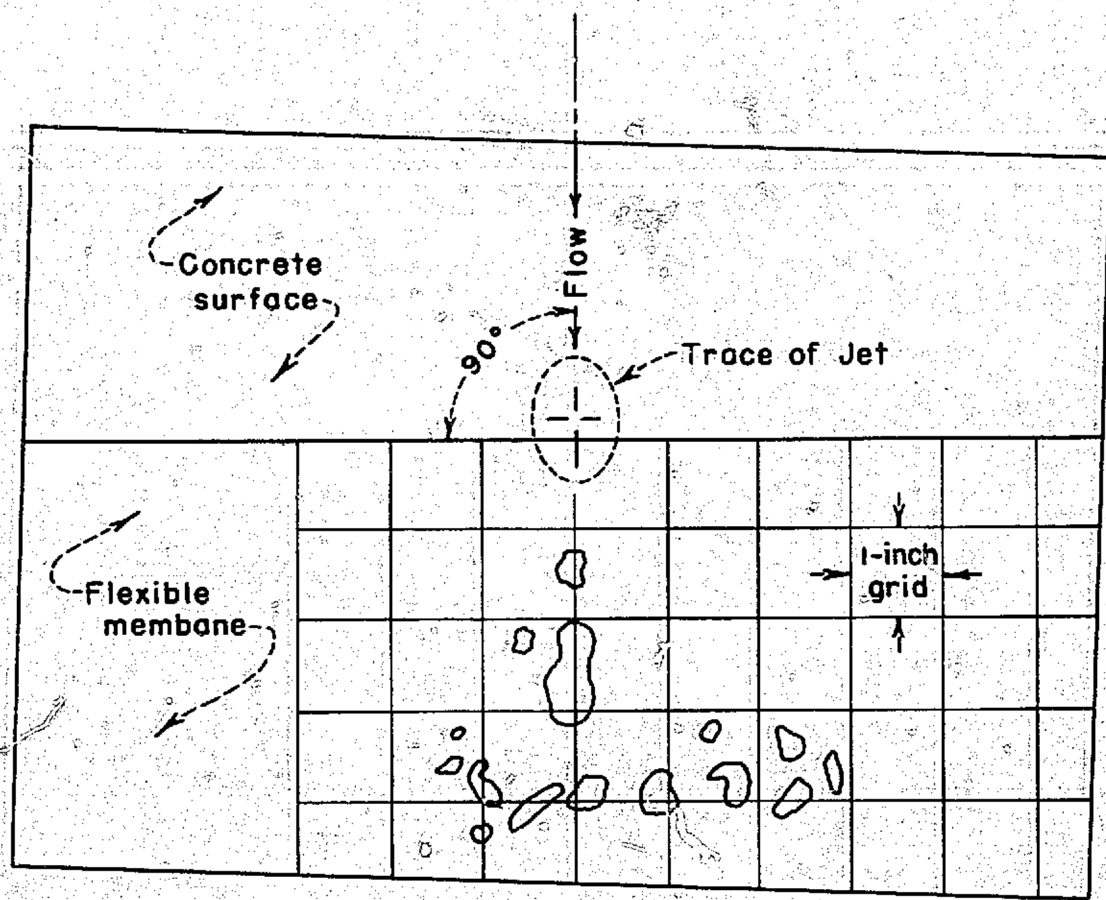
A. Before test



B. Blisters formed after 1-1/2 hours' operation

PROTECTIVE COATINGS for CONCRETE

One-eighth-inch-thick, unprotected cut edge, flexible neoprene membrane bonded to concrete with a mastic (No. 35, Lot 4398)



DISTRIBUTION AND SIZE OF WATER BLISTERS
AFTER $4\frac{1}{4}$ HOURS OPERATION

PROTECTIVE COATINGS FOR CONCRETE
Blistering of flexible neoprene membrane
(No. 35, Lot 4398)

GPO 849-200

7-1750
(10-64)

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.404693	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second

Multiply	By	To obtain
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

Tests to determine relative flow resistance of two selected protective coatings showed that an unbroken surface of thermosetting random-glass-filament-reinforced polyester resin applied to an untreated concrete surface was quite resistant to the force of a high-velocity jet. The polyester resin and a flexible neoprene membrane were applied to an 11-1/2-in. square face of concrete test blocks and subjected to a 1-in.-dia, 100-fps jet striking at a 45-deg angle for 4-1/2 hr in all tests. Two resin samples had a homogeneous and unbroken 1/8-in. uniformly thick coating. One resin sample had the coating covering the face but varying uniformly from 1/8 in. to zero in thickness. Two resin and one neoprene sample had the 1/8-in. coatings cut across at right angles to the exposed face near the horizontal centerline and one-half removed, leaving sharp cut edges. One resin sample had the edge protected by an epoxy fillet. Results were: (1) The smooth unbroken surface of the polyester resin remained undamaged. (2) The same coating with the unprotected cut edge was washed from the concrete in 5 min. (3) The same coating with the epoxy-protected cut edge remained intact. (4) The neoprene membrane with the unprotected edge adhered to the concrete during the test, but high-pressure water blisters formed between the membrane and concrete surface about 2-1/2 in. from the point of jet impact. This report is for official use only.

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IDENTIFIERS-- polyesters/ thermosetting resins/ neoprene// impingement/ hydraulic// impinging flow/ blistering

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