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CHEMICAL STABILIZATION OF SOILS

Laboratory and field evaluation of several petrochemical liquids for soil stabilization

W. R. Morrison
Engineering and Research Center
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Laboratory and field evaluations of several petrochemical, liquid soil stabilizers were conducted. Laboratory tests indicated that a sprayable liquid vinyl polymer has excellent properties for stabilizing sandy soil. Initial observations showed that a deep penetrating liquid cutback asphalt was performing satisfactorily in stabilizing dune sand around transmission tower sites along the Fort Thompson-Grand Island 345-kv Transmission Line. A water-base acrylic copolymer is providing satisfactory erosion control on test sections of spoil banks at the Tehama-Colusa and Putah South Canals in California. However, the high cost would limit the use of the material to minimum wind and water erosion control. None of 5 protective coatings applied to shale seams at Paonia Dam, Colorado, were effective in reducing air-slaking.

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Laboratory and field evaluation of several petrochemical liquids for soil stabilization

by

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Applied Sciences Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
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INTRODUCTION

In slope excavation and embankment construction on Bureau projects, unstable or erodible soils are often encountered. Economic stabilization of these soils is highly desirable, making it important that various petrochemical materials be evaluated for stabilizing applications. Methods are also needed for sealing clay and shale areas in slope or tunnel excavation to prevent air slaking, i.e., the sloughing of soil material due to moisture loss.

This report summarizes laboratory tests conducted under Water Resources Engineering Research (WRER) Program No. DR-11 to evaluate various petrochemical soil stabilizers. Also described in the report are several experimental field applications. These include:

(1) Application of a liquid asphalt prime material to stabilize dune sand at transmission tower sites located along the Fort Thompson-Grand Island 345-kv Transmission Line.

(2) Application of a water-base acrylic copolymer on spoil banks to prevent erosion. The test sites for this application were on the Tehama-Colusa Canal, Central Valley Project, California, and the Putah South Canal, Solano Project, California.

(3) Application of protective coatings on shale seams to prevent air-slaking. This work was performed near Paonia Dam during the rehabilitation of Colorado Highway No. 133.

STABILIZING MATERIALS

Water-Base Stabilizers

In recent years a number of petrochemical polymer materials have been formulated in liquid-applied systems for various construction uses. Several of these materials were investigated for soil stabilization work. They are in a water-base form requiring only dilution for specific application. All stabilizers discussed in this report are identified by laboratory sample number.

a. Sample No. B-5800.—This material is a sprayable liquid vinyl polymer supplied at 60 percent solids in water. Depending upon dilution ratios, it can be used as either a soil stabilizer or dust control agent. At higher concentrations, 2 parts or more of B-5800 per part of water, a continuous film is obtained when applied to substrates that are highly compacted. The Bureau is evaluating such a film for use in brine disposal ponds to control seepage.[1]

The Bureau of Mines at the Salt Lake City Metallurgy Research Center is evaluating B-5800 for stabilizing fine particles of troublesome mineral processing wastes.[2] These wastes, known as tailings, are a potential source of pollution when exposed to erosion by winds. The Corps of Engineers, Vicksburg, Mississippi, is also evaluating B-5800 for various military applications such as airport aprons, helicopter pads, and temporary beach and road stabilization. The approximate cost of this material is $1.75 per gallon ($0.46 per liter), or about $0.09 to $0.18 per square yard ($0.11 per m^2 to $0.22 per m^2) depending upon stabilization requirements.

b. Sample No. B-5778.—A water soluble acrylic copolymer supplied as a concentrate (50 percent solids) for dilution with water. Material cost is about $6 per gallon ($1.58 per liter). This material was used on the experimental field application for erosion control of spoil banks discussed later. For most stabilization work, the manufacturer recommends 90 gallons of concentrate in use with 3,000 gallons of water over 1 acre. The material cost for such an application is $0.11 per yd^2 ($0.13 per m^2).

c. Sample No. B-5856.—An elastomeric emulsion supplied as a concentrate (48 percent solids) for dilution with water. The elastomer is a high-strength synthetic rubber material. The emulsion was used on an experimental basis at the Ontario Motor Speedway in California. The track apron, comprised of the dirt area between the paved track and spectators fence, required stabilization to keep it free from dust. Cost of the emulsion is about $1.50 per gallon ($0.40 per liter), or about $0.10 to $0.15 per square yard ($0.12 per m^2 to $0.18 per m^2) depending upon stabilization requirements.

d. Sample No. B-5551.—An epoxized-silicone material supplied as a concentrate for dilution with water. The supplier reported this material was developed in Israel for stabilization work. The cost of this stabilizer is $10 per gallon ($2.64 per liter). Suggested coverage is 1 gallon per 300 sq ft (0.11

[1] Refer to reference at end of report.

l/m^2), or on a cost basis about \$0.30 per yd^2 (\$0.36 per m^2).

Solvent-Base Stabilizers

Three newly developed liquid asphalt prime materials were evaluated. These materials: B-4645, B-4646, and B-4647 were compared to a liquid asphalt B-5494, specially formulated for deep soil penetration; and a conventional, medium curing (MC-70) liquid cutback asphalt B-5040. Physical properties tests were conducted on the liquid asphalt materials, B-4645, B-4646, B-4647, and B-5494. These results were compared to tentative Bureau of Reclamation specifications requirements for deep penetrating liquid asphalt prime materials, Table 1.

In addition to the above materials, two petroleum resins, B-5089 and B-5090, were evaluated for use as soil stabilizers. The cost for solvent-base materials is about \$0.40 per gallon (\$0.11 per liter), or about \$0.20 to \$0.40 per square yard (\$0.24 per m^2 to \$0.48 per m^2) depending upon stabilization requirements.

CONCLUSIONS

1. Laboratory test results indicate the vinyl polymer formulation, Sample No. B-5800, has excellent properties for stabilizing sandy soils. Soils treated with this material exhibited a significant increase in bearing strength, resistance to wind and water erosion, and resistance to weathering. The study showed that the vinyl polymer applied at a 10 percent mixture strength would be adequate for most stabilization requirements.

2. The acrylic-copolymer, Sample No. B-5778, is providing satisfactory erosion control on spoil banks at the Tehama-Colusa Canal, and the Putah South Canal, California. After 1 year's service all treated areas were generally in good condition. However, the high cost of the material would limit its use. In order to be economical the acrylic material would require application at low mixture strengths, thus reducing its possible uses to minimum wind and water erosion control.

3. In laboratory tests, soils treated with the elastomeric emulsion, Sample No. B-5856, demonstrated a high resistance to water erosion and an increase in cohesive properties of the soils. However, as a result of the degree of erosion occurring to outdoor exposure samples, the weathering characteristics of the elastomeric material is questionable. Therefore, the use of elastomeric emulsion should be limited to applications requiring only temporary service.

4. Visual observations and laboratory tests indicated the epoxized-silicone formulation, Sample No. B-5551, was generally ineffective as a soil stabilizer. Also, based on cost data available to the Bureau of Reclamation, the use of the material at application rates for effective stabilization would be uneconomical.

5. The three newly developed liquid asphalt prime materials were generally adequate as soil stabilizers. However, on comparing their physical properties with current Bureau of Reclamation specifications for deep penetrating asphalt prime materials, each sample was out of specification in one or more requirements. These deficiencies were not serious though, and the manufacturer reported that with slight changes in the distillation processes they could produce materials meeting the current specifications.

6. Although the two petroleum resin materials demonstrated excellent soil penetrating characteristics, their slow-curing properties would not be satisfactory in soil stabilization work. Treated areas would be susceptible to weathering or mechanical damage during the long curing period.

7. Initial observations indicate the deep pentrating liquid asphalt material, Sample No. B-5494, was performing satisfactorily in stabilizing the dune sand around the transmission tower sites along the Fort Thompson-Grand Island 345-kv Transmission Line. After 6 months' service several sites were examined and the asphalt treated soil was in excellent condition with no signs of erosion.

8. None of the five protective coatings applied to the shale seams at Paonia Dam were effective in reducing air slaking. After 1 year's service there was no indication of any of the coatings adhering to the shale seams previously treated. There was evidence of some coatings on the rock surfaces adjoining the shale seams. For protective coatings to be effective under such conditions, a substantial increase in the amount of material applied would be required. Also, the materials should be applied as quickly as possible to the newly excavated surfaces to obtain maximum bonding.

APPLICATIONS

Several potential applications of petrochemical stabilizers are listed below:

1. Stabilization of stockpiled earth materials to control environmental pollution.

2. Control of wind and water erosion on croplands.

Table 1

PHYSICAL PROPERTIES OF LIQUID ASPHALT PRIME MATERIALS

Physical property test	ASTM test method	Tentative USBR specifications requirements		Test results			
		minimum	maximum	Sample No. B-4645	Sample No. B-4646	Sample No. B-4647	Sample No. B-5494
Flashpoint $^{\circ}$ F ($^{\circ}$ C)	D-92	150 (65.6)	–	*135 (57.2)	180 (82.2)	155 (68.3)	165 (73.9)
Viscosity S.S.F.:							
At 122° F (50° C)		50	100	52	78	56	69
At 140° F (60° C)	D-88	35	60	36	45	36	42
Distillation:							
Distillate, (Percent of total distillate to 680° F (360° C):							
To 374° F (190° C)		0	0	0	0	0	0
To 437° F (225° C)		15	30	*32.2	*6.8	*32.2	30
To 500° F (260° C)	D-402	50	75	66.7	57.4	66.7	75
To 600° F (315° C)		75	95	90.4	88.1	90.2	95
Residue from distillation to 680° F, (360° C), volume percent by difference		50	–	55.8	56.2	56.5	56.4
Tests on residue:							
Penetration, 77° F (25° C) 100 grams, 5 seconds	D-5	7	20	16	19	*36	18
Ductility, 77° F (25° C), centimeters	D-113	3	–	3.0	3.2	24	27
Softening point $^{\circ}$ F ($^{\circ}$ C) (ring and ball)	D-36	150 (65.6)	–	163 (72.8)	161 (71.7)	*140 (60.0)	154 (67.8)

*Out of specifications

3. Temporary stabilization to prevent erosion during seed germination in the establishment of vegetation cover.

4. Stabilization and erosion control of access roads on construction projects.

5. Stabilization of erodible soils exposed in canals and reservoirs during low operating levels.

6. Stabilization of clay and shale areas in slope or tunnel excavation to prevent air slaking.

LABORATORY TESTS

General

Laboratory tests were conducted on treated soil samples to determine the following properties of the stabilizers:

1. Binding strength.
2. Curing characteristics.
3. Soil penetration characteristics.
4. Water-erosion resistance.
5. Weathering characteristics.

Gradations of the two soils used in the study are shown in Figure 1. These soils were a sandy material from Cawker City, Kansas (B-4433), and a Clear Creek sand (B-4433A).

Fabrication of Test Cylinders

Soil samples used in the laboratory evaluation were 2 inches (5.08 cm) in diameter by 2 inches (5.08 cm) high. The cylinders were fabricated using double-plunger-type molds and a compactive effort of 715 psi (50 kg/cm^2) held for 1 minute. For tests where the stabilizer was mixed into the soil, the mixing was accomplished in a mechanical mixer prior to cylinder fabrication.

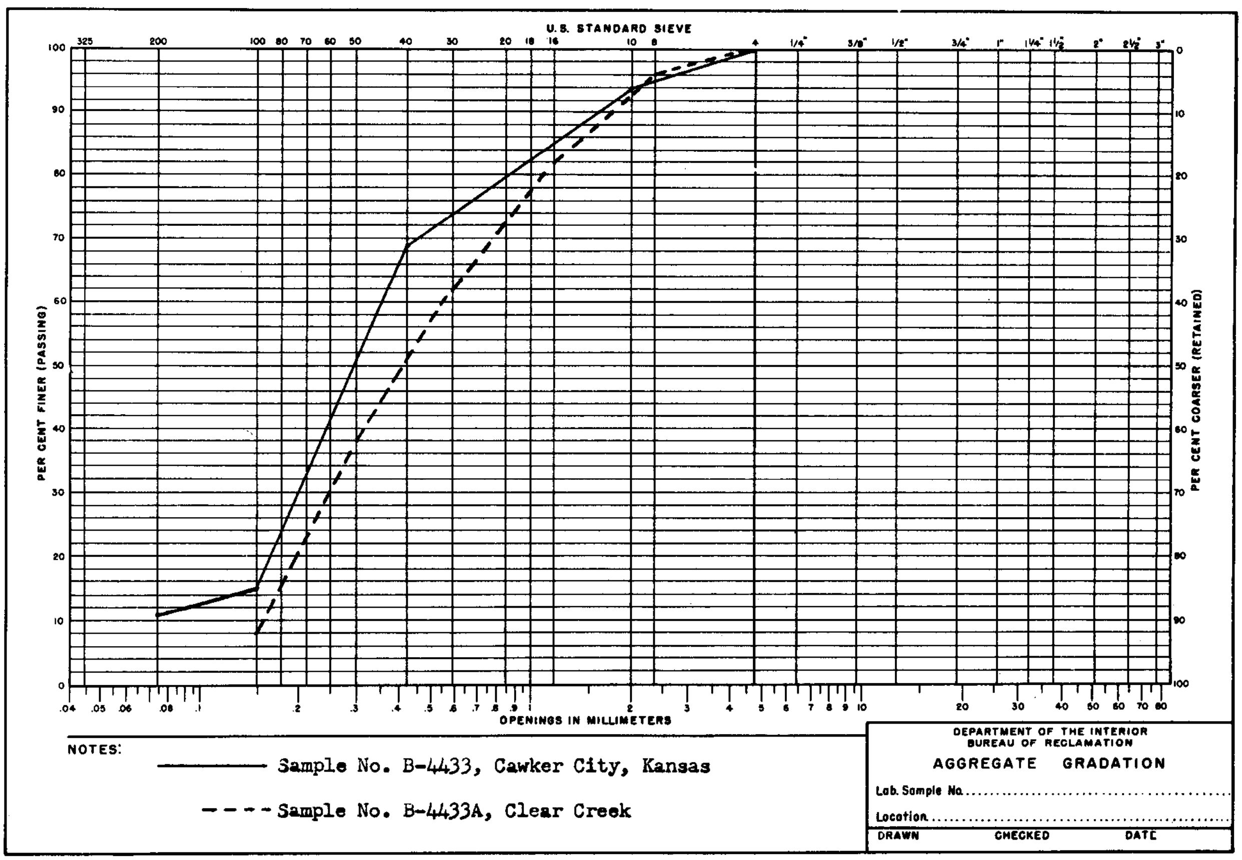


Figure 1. Gradation of soils used in laboratory investigation.

Binding Strength and Curing Characteristics

Compressive strength development of the treated soil samples was used to evaluate the relative binding and curing characteristics of the stabilizers. The treated soil samples were loaded until failure in a universal testing machine operated at a head rate of 0.2 inch (0.5 cm) per minute. The tests involved either of two curing conditions: 140° F (60° C) oven; or 50 percent relative humidity at 73.4° F (23° C). Samples were tested after curing ages of 3, 7, 14, and 28 days. The stabilizers were applied in mixture strengths ranging from 2.5 to 50 percent for the water-base materials, and at full strength for the solvent-base materials.

Soil Penetration

To determine the penetrating capabilities of the stabilizers, standard test cylinders were compacted in 4-inch (10.16-cm) high molds. A 2-inch (5.08-cm) portion of the mold extending above the soil cylinder provided a reservoir for applying the liquid stabilizer. The materials were poured into the top of the molds in quantitites to produce application rates of 0.5, 1.0, and 2.0 gsy* (2.3, 4.6, and 9.2 l/m^2). Where required, the stabilizers were heated prior to application.

Water-Erosion Resistance

Water jet tests were conducted on treated and untreated soil samples to determine their water-erosion resistance. The laboratory apparatus used in the test is shown in Photograph 1. This equipment consists of a metal trough approximately 35 inches (89 cm) long, divided into 10 compartments for holding the test cylinders. A pressure pipe located above the specimens is fitted with jet nozzles, each having an opening of 3/64-inch (0.12-cm) diameter. Each jet nozzle is centered directly above the specimen at a distance of 2.5 inches (6.4 cm) from the top surface. The jet equipment was operated at 5 psi (0.35 kg/cm^2) for either 6- or 8-hour periods. Untreated samples were tested for less than 1 minute due to the rapid rate of erosion. Two groups of samples were cured for 7 days in the 140° F (60° C) oven. One group of samples was tested immediately after the 7 days' oven curing. The second group was immersed in water for 7 days before testing.

Weathering Characteristics

Eleven outdoor exposure samples of sandy soil (B-4433A) measuring 12 by 12 by 2 inches (30.5 by 30.5 by 5.1 cm) were prepared. The four water-base stabilizers were applied at both 2.5- and 10-percent mixture strengths, each at a rate of 1 gsy (4.6 l/m^2). The liquid asphalt prime material, B-5494, was applied at full strength in quantities to produce application rates of 0.5 and 1.0 gsy (2.3 and 4.6 l/m^2). In addition an untreated sample was evaluated for comparative purposes.

*gsy—gallons per square yard.

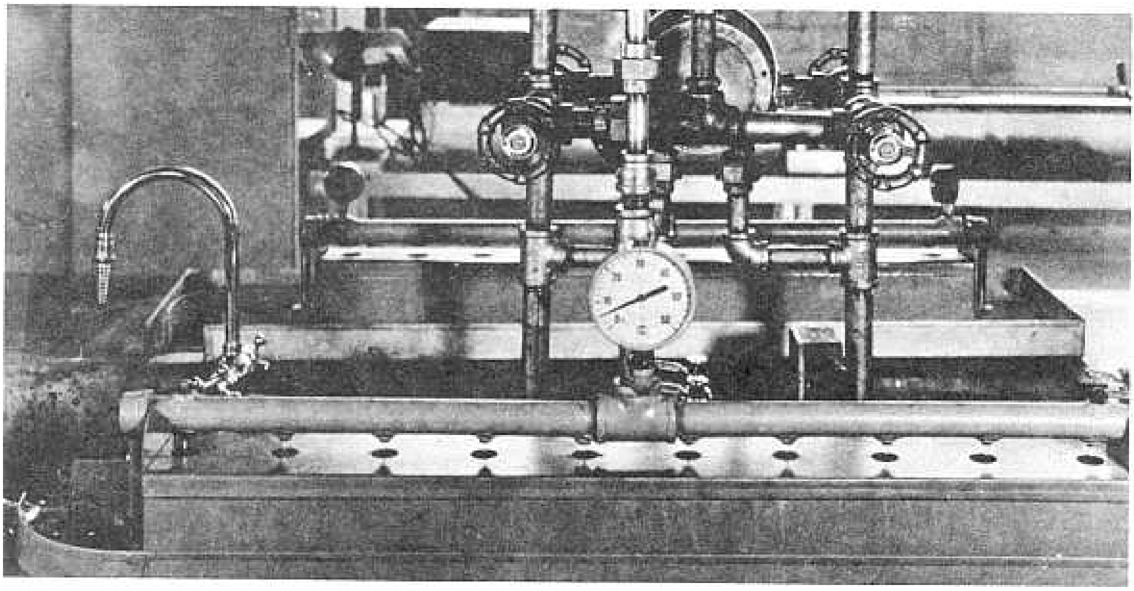
DISCUSSION OF LABORATORY TEST RESULTS

Binding Strength and Curing Characteristics

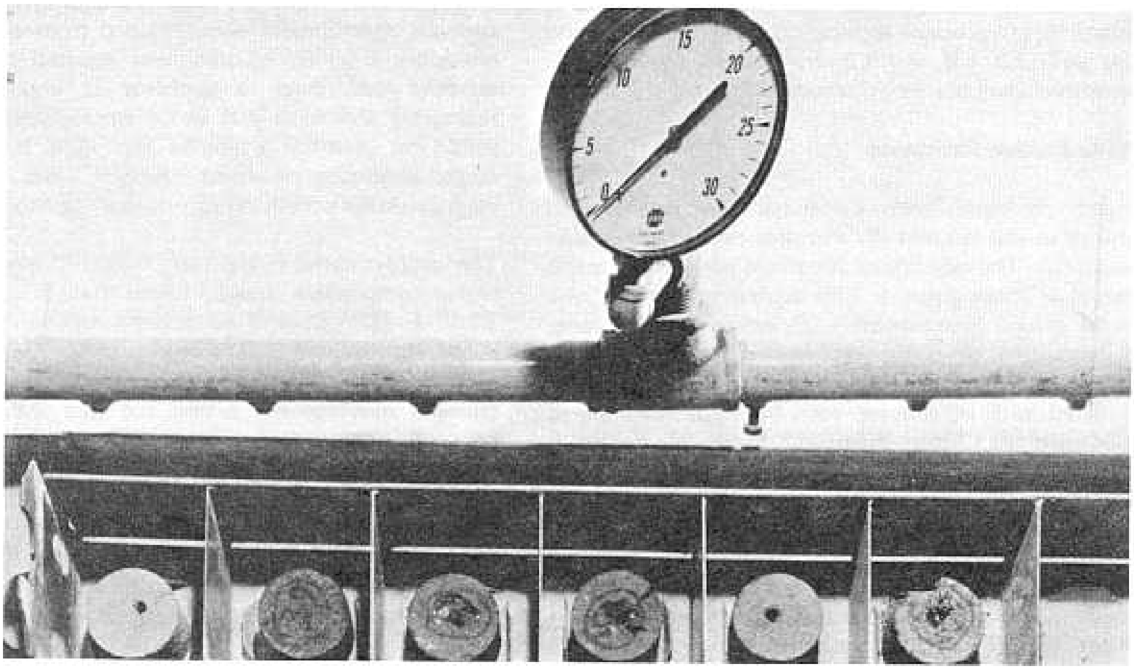
a. Water-base stabilizers.—Compressive strength test results are summarized in Table 2, and comparison of relative binding strength between the stabilizers is shown graphically in Figure 2. At practical field application mixtures, 10 percent or less, vinyl polymer B-5800 and acrylic copolymer B-5778 produced satisfactory strength development. Within these tests B-5800 provided compressive strengths nearly twice that obtained from B-5778. Although no apparent strength development was obtained from elastomeric emulsion, B-5856, its treatment resulted in a more cohesive soil. Such a property is important for increasing the wind and water erosion resistance of soils. For mixture strengths less than 10 percent, epoxized-silicone material, B-5551, was generally inadequate for producing soil strength development.

The samples cured in the 140° F (60° C) oven showed higher compressive strength values than those cured at 73.4° F (23° C) and 50 percent relative humidity. Also, the treated soil samples under both curing conditions obtained over 75 percent of their average strength development within the first 3-day curing period.

b. Solvent-base stabilizers.—Compressive strength test results are summarized in Table 3, and comparison of relative binding strength between the stabilizers is shown graphically in Figure 3. No significant increase in compressive strength was noted for the treated soil samples cured at 73.4° F (23° C) and 50 percent relative humidity. In some cases the values were lower than those obtained for the untreated soil samples. This was true for the soil samples treated with conventional cutback asphalt B-5040; asphalt prime material B-4646; and the two petroleum resins B-5089 and B-5090. For soil samples treated with asphaltic materials and cured at 140° F (60° C), an increase in strength development was noted. Within these data liquid asphalt B-5494 produced the highest values; they



a. Water jet erosion testing equipment in operation. Photo PX-D-44586 NA



b. Interior view of the jetting equipment showing appearance of test cylinders subjected to water jetting. Photo PX-D-44596 NA

Photograph 1. Laboratory apparatus used to determine water erosion resistance of stabilized soil samples.

Table 2

COMPRESSIVE STRENGTH TEST RESULTS

Water-Base Stabilizers

Application rate of mixture: 2 gsy (9.2 l/m^2)

Soil—B-4433A

Stabilizer-laboratory No.	Mixture strength percent	Curing conditions air, 23° C and 50 percent relative humidity oven, 60° C	Compressive strength							
			3 days		7 days		14 days		28 days	
			psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2
Control	0	Air	37.7	2.6	42.2	3.0	35.8	2.5	38.4	2.7
		Oven	25.8	1.8	30.8	2.2	23.8	1.7	23.9	1.7
B-5800	2.5	Air	136.6	9.6	92.0	6.4	84.4	5.9	80.2	5.6
		Oven	149.9	10.5	163.8	11.5	115.0	8.0	109.7	7.7
B-5800	5.0	Air	240.0	16.8	241.0	16.9	160.4	11.2	179.5	12.6
		Oven	283.0	19.8	283.4	19.8	244.5	17.1	248.3	17.4
B-5800	10.0	Air	439.0	30.7	438.0	30.7	343.8	24.1	398.8	27.9
		Oven	478.0	33.5	500.0	35.0	454.5	31.8	427.8	29.9
B-5800	25.0	Air	686.0	48.0	720.0	50.4	675.4	47.3	732.0	51.2
		Oven	829.0	58.0	1,074.0	75.2	907.0	63.5	980.0	68.6
B-5800	50.0	Air	962.0	67.3	1,094.0	76.6	1,129.0	79.0	1,096.0	76.7
		Oven	1,148.0	80.4	1,554.0	108.8	1,566.0	109.6	1,595.0	111.6
B-5778	5.0	Air	95.5	6.7	84.4	5.9	104.6	7.3	91.7	6.4
		Oven	123.2	8.6	123.6	8.6	119.9	8.4	114.2	8.0
B-5778	10.0	Air	182.4	12.8	196.0	13.7	191.3	13.4	181.4	12.7
		Oven	199.4	14.0	199.4	14.0	256.4	17.9	228.2	16.0
B-5778	25.0	Air	554.0	38.8	529.0	37.0	572.0	40.0	577.0	40.4
		Oven	625.0	43.8	606.0	42.4	668.0	46.8	649.0	45.4
B-5551	5.0	Air	19.5	1.4	20.4	1.4	20.5	1.4	18.8	1.3
		Oven	23.6	1.6	27.7	1.9	21.0	1.5	21.8	1.5
B-5551	10.0	Air	77.4	5.4	77.6	5.4	53.4	3.7	61.5	4.3
		Oven	86.0	6.0	95.5	6.7	81.9	5.7	86.2	6.0
B-5551	25.0	Air	331.0	23.2	370.5	25.9	394.2	27.6	408.7	28.6
		Oven	410.2	28.7	460.0	32.2	472.8	33.1	460.0	32.2
B-5856	20.0	Air	13.2	0.9	15.4	1.1	13.8	1.0	14.8	1.0
		Oven	19.5	1.4	20.6	1.4	20.4	1.4	12.2	0.8
B-5856	50.0	Air	36.7	2.6	38.4	2.7	39.9	2.8	41.4	2.9
		Oven	48.0	3.4	45.4	3.2	41.8	2.9	53.4	4.3

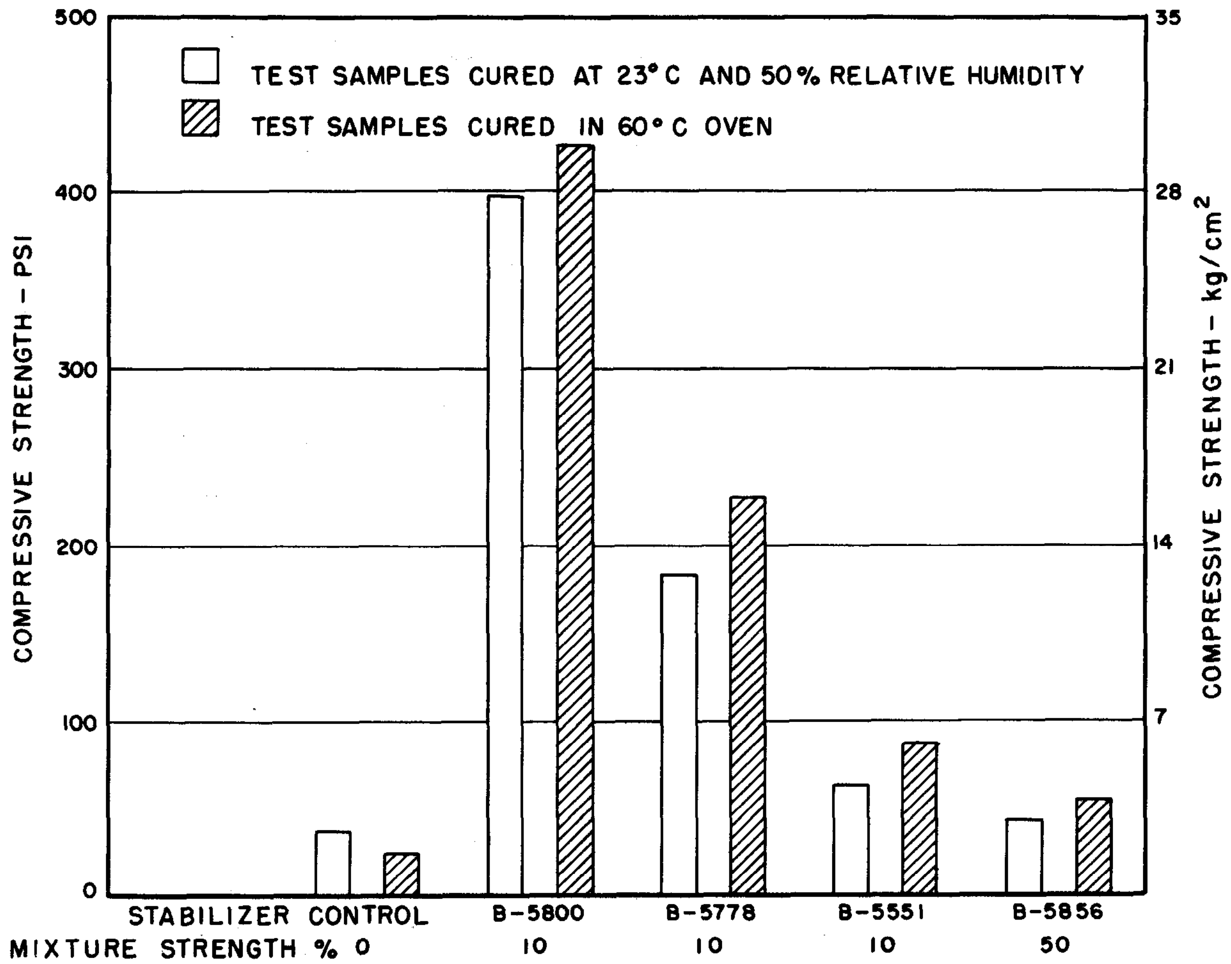


Figure 2. Compressive strength development after 28 days for sandy soil B-4433A treated with various water-base stabilizers. Application rate of water mixture was 2 gsy (9.2 l/m^2).

were nearly twice that obtainable with the other liquid asphalt prime materials.

The test results indicated that the petroleum resins were slow curing and produced compressive strengths lower than the asphalt prime materials. The slow curing was most evident for the 140° F (60° C) oven-cured test cylinders. Examination of the treated soil samples after 28 days' curing showed the residues of both petroleum resins were still tacky. Because of the slow-curing properties, these materials would not be too satisfactory for use in soil stabilization. Treated areas would be susceptible to weathering or mechanical damage during the long curing period.

Soil Penetration

a. Water-base stabilizers.—Penetration test results for the stabilizers applied at 10 percent mixture strength, are summarized in Table 4. Although these materials penetrated deeper than the depths shown in Table 4, the values reported are based on effective stabilizaton depth. This value was determined by immersing treated, cured soil samples in water and measuring the retained, stabilized depth. Acrylic copolymer B-5778 and vinyl polymer B-5800 provided the most effective penetration. All stabilizers, however, penetrated quite rapidly in the sandy soil with complete penetration occurring in less than 1 minute. This period was much less than that required for the solvent-base materials.

b. Solvent-base stabilizers.—Penetration test results are summarized in Table 5. With the exception of conventional cutback asphalt B-5040, good penetration was obtained with these stabilizers. Within these tests the two petroleum resins B-5089 and B-5090 produced the deepest penetration, as shown in Photograph 2.

Water-Erosion Resistance

a. Water-base stabilizers.—Water-jet test results are summarized in Table 6 and shown visually in

Table 3

COMPRESSIVE STRENGTH TEST RESULTS

Solvent-Base Stabilizers

Soil—B-4433

Stabilizer-laboratory No.	Application rate		Curing conditions air, 23° C and 50 percent relative humidity oven, 60° C	Compressive strength							
				3 days		7 days		14 days		28 days	
	gsy	l/m^2		psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2	psi	kg/cm^2
Control	–	–	Air	107.8	7.5	108.4	7.6	108.3	7.6	116.0	8.2
			Oven	132.1	9.2	133.5	9.3	136.1	9.5	143.6	10.0
B-5494	1.0	4.5	Air	41.6	2.9	68.4	4.8	89.3	6.3	127.0	8.9
			Oven	180.8	12.7	255.0	17.8	337.6	23.6	370.2	26.5
B-5040	0.5	2.3	Air	48.1	3.4	55.5	3.9	62.1	4.3	86.0	6.0
			Oven	77.9	5.5	85.2	6.0	124.8	8.7	136.4	9.5
B-5040	1.0	4.5	Air	54.1	3.8	59.4	4.2	75.8	5.3	105.3	7.4
			Oven	95.1	6.7	103.4	7.2	154.3	10.8	168.1	11.8
B-4645	0.5	2.3	Air	30.9	2.2	52.1	3.6	67.1	4.7	102.2	7.2
			Oven	90.5	6.3	144.9	10.1	158.4	11.1	160.6	11.2
B-4645	1.0	4.5	Air	39.6	2.8	62.9	4.4	76.9	5.4	115.2	8.1
			Oven	99.3	7.0	160.2	11.2	167.9	11.8	198.8	13.9
B-4646	0.5	2.3	Air	54.1	3.8	55.7	3.9	67.8	4.7	79.1	5.5
			Oven	60.9	4.3	100.1	7.0	122.4	8.6	133.2	9.3
B-4646	1.0	4.5	Air	63.4	4.4	70.2	4.9	73.4	5.1	89.4	6.3
			Oven	85.2	6.0	118.6	8.3	155.9	10.9	174.9	12.2
B-4647	0.5	2.3	Air	45.5	3.2	71.1	5.0	75.1	5.3	110.8	7.8
			Oven	100.9	7.1	119.4	8.4	152.8	10.7	159.9	11.1
B-4647	1.0	4.5	Air	50.8	3.6	77.6	5.4	90.4	6.3	114.4	8.0
			Oven	106.0	7.4	164.7	11.5	175.7	12.3	183.5	12.8
B-5089	1.0	4.5	Air	52.9	3.7	71.6	5.0	80.0	5.6	86.2	6.0
			Oven	99.8	7.0	105.6	7.4	111.3	7.8	124.9	8.7
B-5090	1.0	4.5	Air	38.2	2.7	67.2	4.7	79.0	5.5	88.0	6.2
			Oven	92.6	6.5	123.3	8.6	104.2	7.3	108.1	7.6

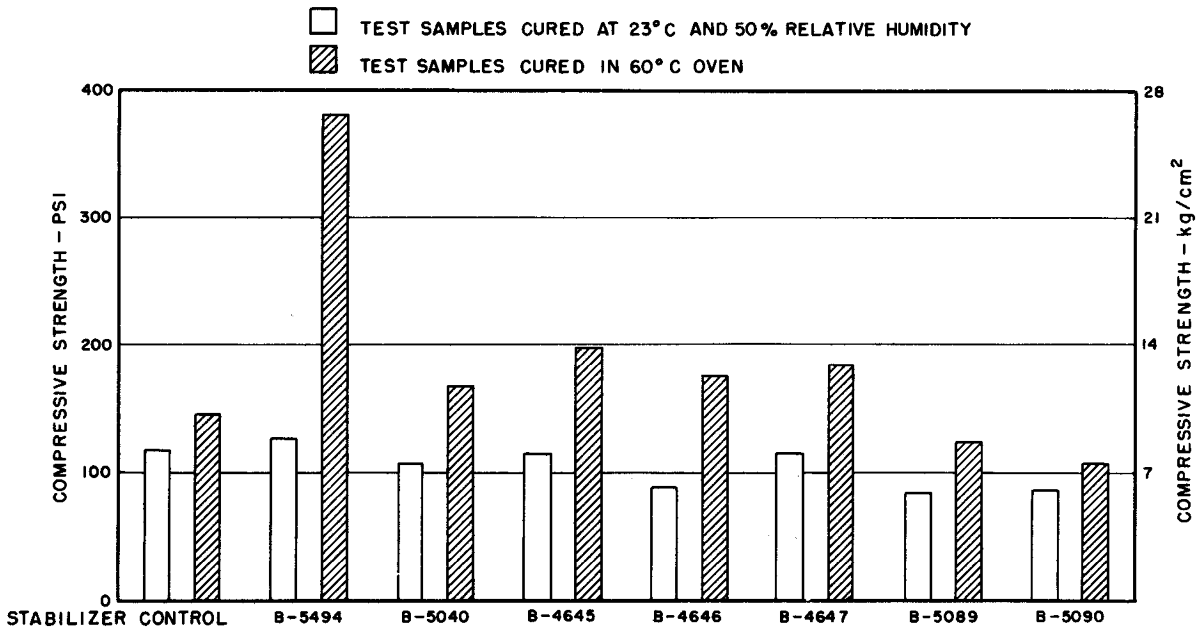


Figure 3. Compressive strength development after 28 days for sandy soil B-4433 treated with various solvent-base stabilizers. Application rate of stabilizer was 1 gsy (4.6 l/m^2)

Table 4

PENETRATION TEST RESULTS

Water-Base Stabilizers—10 Percent Mixture Strength

Stabilizer, laboratory Sample No.	Application rate		Penetration into 2-inch (5.1-cm) high cylinders		Time for material to penetrate hours
	gsy	l/m^2	in.	cm	
B-5800	0.5	2.3	0.65	1.65	Less than 1 minute
	1.0	4.5	0.95	2.41	Less than 1 minute
	2.0	9.1	1.75	4.44	Less than 1 minute
B-5778	0.5	2.3	0.70	1.78	Less than 1 minute
	1.0	4.5	1.00	2.54	Less than 1 minute
	2.0	9.1	2.00	5.08	Less than 1 minute
B-5856	0.5	2.3	0.50	1.27	Less than 1 minute
	1.0	4.5	0.75	1.90	Less than 1 minute
	2.0	9.1	1.45	3.68	Less than 1 minute
B-5551	0.5	2.3	0.50	1.27	Less than 1 minute
	1.0	4.5	0.80	2.03	Less than 1 minute
	2.0	9.1	1.45	3.68	Less than 1 minute

Test cylinders were 2-inch (5.1-cm) diameter by 2-inch-high (5.1-cm) sandy soil (B-4433A) compacted by 715 psi (50 kg/cm^2) loading for 1 minute.

Table 5

PENETRATION TEST RESULTS
Solvent-Base Stabilizers

Stabilizer, laboratory Sample No.	Application rate		Penetration into 2-inch (5.1-cm) high cylinders		Time for material to penetrate, hours
	gsy	l/m^2	in.	cm	
B-4645	0.5	2.3	0.94	2.39	1.0
	1.0	4.5	1.62	4.11	4.0
	2.0	9.1	*2.00	5.08	6.0
B-4646	0.5	2.3	0.88	2.24	1.0
	1.0	4.5	1.62	4.11	4.0
	2.0	9.1	*2.00	5.08	6.0
B-4647	0.5	2.3	0.50	1.27	2.0
	1.0	4.5	0.75	1.90	4.0
	2.0	9.1	1.38	3.51	6.0
B-5040	0.5	2.3	0.38	0.97	1.0
	1.0	4.5	0.69	1.75	2.0
	2.0	9.1	1.44	3.66	4.0
B-5494	0.5	2.3	0.80	2.03	1.5
	1.0	4.5	1.20	3.05	3.0
	2.0	9.1	1.90	4.83	5.0
B-5089	0.5	2.3	1.20	3.05	1.5
	1.0	4.5	1.90	4.83	3.0
	2.0	9.1	*2.00	5.08	5.5
B-5090	0.5	2.3	1.40	3.56	1.5
	1.0	4.5	*2.00	5.08	3.5
	2.0	9.1	*2.00	5.08	5.5

Test cylinders were 2-inch (5.1-cm) diameter by 2-inch (5.1-cm) high sandy soil (B-4433) compacted by 715 psi (50 kg/cm^2) loading for 1 minute.
*Some exudation of stabilizer.

Photographs 3 and 4. Results indicated that treatment with elastomeric emulsion B-5856 and vinyl polymer material B-5800 produced the most effective soil surfaces for resistance to water erosion. The results also showed that the samples immersed in water for 7 days before testing were more susceptible to erosion.

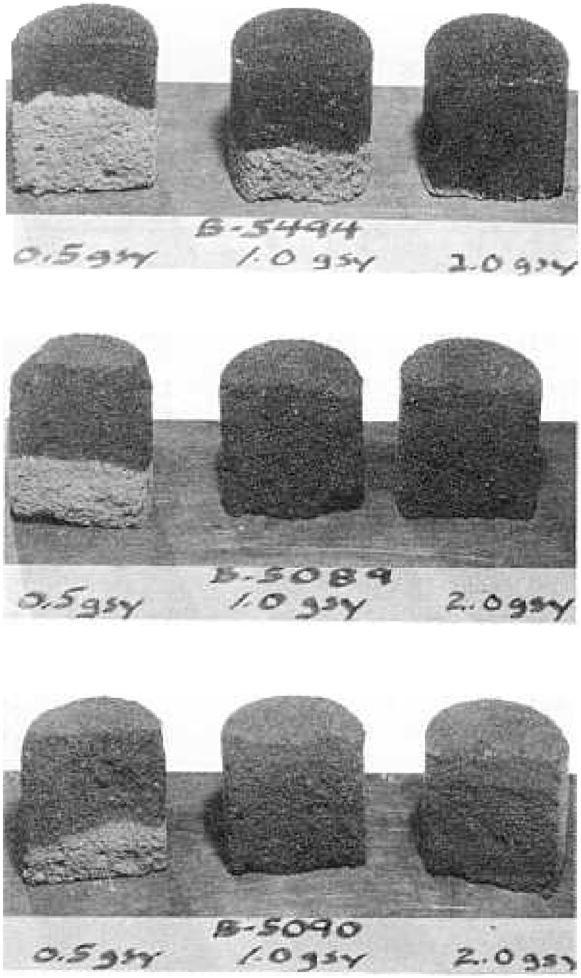
b. Solvent-base stabilizers.—Test results are summarized in Tables 7 and 8 and shown visually in Photograph 5. With the exception of the two petroleum resins B-5089 and B-5090, treatment with solvent-base stabilizers produced excellent surfaces for resistance to water erosion. The slow-curing properties of the petroleum resins resulted in poor water erosion characteristics, as shown in Photograph 5.

Weathering Characteristics

The 1-foot (0.3-m) square test samples were placed outside in February 1970, and they were observed and photographed periodically as shown in Photographs 6 through 16. After 1 year's exposure the soil samples treated with the following stabilizers were in good to excellent condition:

1. Vinyl polymer, B-5800, applied at 10 percent mixture strength—1 gsy (4.6 l/m^2) application.

2. Acrylic copolymer, B-5778, applied at 10 percent mixture strength—1 gsy (4.6 l/m^2) application.

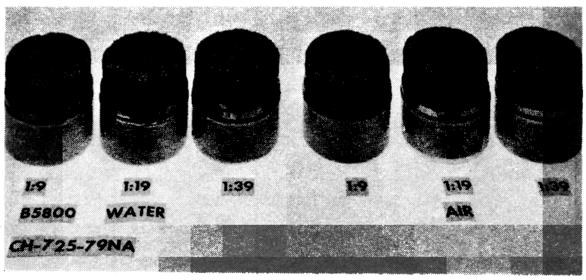


Photograph 2. Penetration of solvent-base stabilizers into 2- by 2-inch (5.1- by 5.1-cm) test cylinders at various application rates.

3. Liquid asphalt prime, B-5494, applied at both 0.5 and 1.0 gsy (2.3 and (4.6 l/m^2).

Of the stabilizers applied at 2.5 percent mixture strengths, the vinyl polymer material B-5800 provided the most effective stabilization. The untreated soil sample showed considerable erosion after only 2 months, Photograph 16.

a. Untreated samples before (left) and after (right) water jet erosion testing. Sample at left was tested for less than 1 minute. Photo PX-D-69209



b. The two groups of samples were cured for 7 days in the 140° F (60° C) oven. The three samples on the right were tested immediately after oven curing; the three samples on the left were immersed in water for 7 days prior to the water jet test. Ratio indicates the amount of B-5800 to water. Samples were surface treated at an application rate of 2 gsy (9.2 l/m^2). Test was conducted for 6 hours. Photo PX-D-69210

Photograph 3. Results of water jet erosion testing at 5 psi water pressure (0.35 Kg/cm^2) of soil samples with and without treatment.

EXPERIMENTAL FIELD APPLICATIONS

Dune Sand Stabilization

In the construction of the Fort Thompson-Grand Island 345-kv Transmission Line, Figure 4, a number of tower sites in dune sand areas required soil stabilization. The stablization was necessary primarily for two reasons: wind erosion control to prevent blow holes in the dune sand; and to increase the bearing strength of the soil around the tower footings to

Table 6

WATER-JET EROSION TEST RESULTS

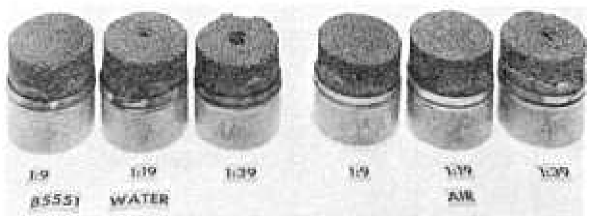
Water-Base Stabilizers
Application Rate of Stabilizers, 2 gsy (9.2 l/m^2)
Soil—B-4433A
Water-jetting conducted at 5 psi (0.35 kg/cm^2) for 6 hours

Stabilizer and dilution ratio of mixture	Immersion in water before testing, (days)	Volume of erosion, percent	Depth of erosion in.	Depth of erosion cm	Remarks
None (control)*	0	50	2.0	5.08	Failure
1 Part B-5800	0	0	0	0	No change
9 parts water	7	Less than 1	0.10	0.25	Slight erosion
1 part B-5800	0	0	0	0	No change
19 parts water	7	Less than 1	0.25	0.63	Slight erosion
1 part B-5800	0	Less than 1	0.04	0.10	Slight erosion
39 parts water	7	Less than 1	0.24	0.62	Some erosion
1 part B-5778	0	Less than 1	0.65	1.65	Erosion
9 parts water	7	1	0.90	2.30	Erosion
1 part B-5778	0	Less than 1	0.38	0.96	Erosion
19 parts water	7	Less than 1	0.60	1.52	Erosion
1 part B-5778	0	2	1.0	2.54	Erosion, sample cracked
39 parts water	7	2	1.0	2.54	Erosion, sample cracked
1 part B-5551	0	0	0	0	No change
9 parts water	7	0	0	0	No change
1 part B-5551	0	0	0	0	No change
19 parts water	7	Less than 1	0.6	1.52	Erosion
1 part B-5551	0	1	1.1	2.79	Erosion
39 parts water	7	1.5	1.25	3.18	Erosion
1 part B-5856	0	Less than 1	0.02	0.05	Trace of erosion
9 parts water	7	Less than 1	0.06	0.15	Trace of erosion
1 part B-5856	0	Less than 1	0.02	0.05	Trace of erosion
19 parts water	7	Less than 1	0.06	0.15	Very slight erosion
1 part B-5856	0	Less than 1	0.20	0.51	Slight erosion
39 parts water	7	Less than 1	0.28	0.71	Slight erosion

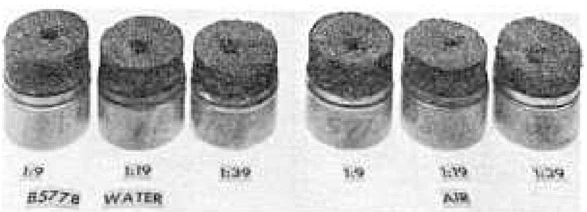
Samples were 2- by 2-inch (5.1- by 5.1-cm) cylinders of sandy soil compacted by 715 psi (50 kg/cm^2) loading for 1 minute. After topical application, samples were cured in 60^{o} C oven for 1 week before water-jetting tests.

*Control sample was tested for only 30 seconds due to rapid erosion rate.

Soil samples treated with Stabilizer B-5856



b. Soil samples treated with Stabilizer B-5551

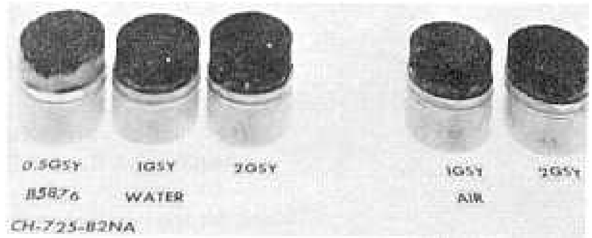


c. Soil samples treated with Stabilizer B-5778

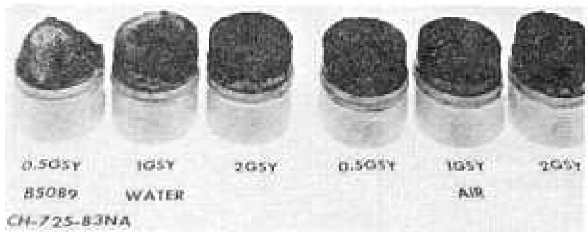
Photograph 4. Results of water jet erosion testing for 6 hours of soil samples treated with various water-base stabilizers. The samples were cured for 7 days in the 140° F (60° C) oven. The samples on the right were tested immediately after curing while samples on the left were immersed in water for 7 days prior to the water jet test. Ratio indicates the dilution factor. Samples were surface treated at an application rate of 2 gsy (9.1 l/m^2).

prevent damage due to animal traffic. Cattle, especially in hot weather, like to use the tower legs as rubbing posts.

Based upon the ease of application, minimum ground surface preparation, and low cost, a special liquid asphalt prime material represented by Sample No. B-5494 was selected for stabilizing the dune sand. Earlier laboratory studies[3] indicated this material was superior to standard emulsified or cutback asphalts for stablizing sandy soils. Laboratory tests were conducted on samples of local dune sand to determine the rate of



a. Soil samples treated with a liquid prime material B-5494. Photo PX-D-69214



b. Soil samples treated with a liquid petroleum resin B-5089. Photo PX-D-69215

Photograph 5. Results of water jet erosion testing for 6 hours of soil samples treated with various solvent-base stabilizers. The samples were cured for 7 days in the 140° F (60° C) oven. The samples on the right were tested immediately after curing while samples on the left were immersed in water for 7 days prior to the water jet test. The numbers indicate the application rate for the materials.

application for the asphalt prime material. Penetration tests results are summarized in Table 9.

Results of these tests indicated that an application rate of 2 gsy (9.1 l/m^2) was the most economical for the desired stabilization requirements. Strength development similar to that shown for Sample No. B-5494 in Table 3, could be expected for the treated dune sand.

Forty-seven tower sites were treated in June and July of 1970 under Bureau of Reclamation Specifications No. DC-6634. Physical property requirements for the liquid asphalt material is listed in Table 1. The total area of coverage was about 18,500 square yards (15,460 m^2). The contractor, after experimenting with several sequences of application, settled on the following procedure:

1. Level and shape the site area to drain.

Table 7

WATER-JET EROSION TEST RESULTS
Solvent-Base Stabilizers
Soil—B-4433A
Water-Jetting conducted at 5 psi (0.35 kg/cm^2) for 6 hours

Stabilizers laboratory No.	Application rate		Immersion in water before testing, (days)	Volume of erosion, percent	Depth of erosion		Remarks
	gsy	l/m^2			in.	cm	
None (control)*	0	0	0	50	2.00	5.08	Failure
B-5494	0.5	2.3	0	0	0	0	No change
			7	0	0	0	No change
B-5494	1.0	4.5	0	0	0	0	No change
			7	0	0	0	No change
B-5494	2.0	9.0	0	0	0	0	No change
			7	0	0	0	No change
B-5089	0.5	2.3	0	10	0.65	1.65	Erosion, sample cracked
			7	50	2.00	5.08	Erosion, sample cracked
B-5089	1.0	4.5	0	5	0.65	1.65	Erosion
			7	5	2.00	5.08	Erosion, sample cracked
B-5089	2.0	9.0	0	2	1.50	3.71	Erosion, sample cracked
			7	2	1.30	3.30	Erosion, sample cracked
B-5090	0.5	2.3	0	5	0.36	0.91	Erosion, sample cracked
			7	50	2.00	5.08	Erosion, sample cracked
B-5090	1.0	4.5	0	2	1.50	3.71	Erosion, sample cracked
			7	5	2.00	5.08	Erosion, sample cracked
B-5090	2.0	9.0	0	2	1.50	3.71	Erosion, sample cracked
			7	5	2.00	5.08	Erosion, sample cracked

*Control sample was tested for only 30 seconds due to rapid rate of erosion.

2. Scarify and loosen the sand with a harrow.

3. Apply a one-coat coverage of liquid asphalt at the rate of 1 gsy (4.6 l/m^2).

4. Rescarify the area with a harrow.

5. Apply a second coat of liquid asphalt at the rate of 1 gsy (4.6 l/m^2).

The above sequence, shown in Photograph 17 through 20, provided good results with penetration varying from 2 to 3 inches (5.1 to 7.6 cms). The contractor generally worked two tower sites at a time, each a different step in the sequence, thus allowing his men and equipment to be continually working back and forth with no waiting time.

It was noted the liquid asphalt penetrated better following a rain when the sand was slightly damp or moist. However, a 3-inch (7.2-cm) penetration could not be obtained unless the harrowing was performed.

In January of 1971, personnel from the Bureau's Project Manager's Office, Huron, South Dakota, inspected several treated tower sites. All sites examined appeared to be in excellent condition after 6 months' service, as shown in Photographs 21 and 22. Additional

Table 8

WATER-JET EROSION TEST RESULTS
Solvent-Base Stabilizers
Soil—B-4433
Water-Jetting Conducted at 5 psi (0.35 kg/cm^2) for 8 Hours

Stabilizer laboratory No.	Application rate		Immersion in water before testing, (days)	Volume of erosion percent	Depth of erosion		Remarks
	gsy	l/m^2			in.	cm	
None (control)*	0	0	0	40	2.0	5.08	Failure
B-4645	0.5	2.3	1	0	0	0	No change
			7	Less than 1	0.05	0.13	Very slight erosion
B-4645	1.0	4.5	1	0	0	0	No change
			7	0	0	0	No change
B-4646	0.5	2.3	1	Less than 1	0.05	0.13	Very slight erosion
			7	Less than 1	0.07	0.18	Very slight erosion
B-4646	1.0	4.5	1	0	0	0	No change
			7	0	0	0	No change
B-4647	0.5	2.3	1	0	0	0	No change
			7	Less than 1	0.05	0.13	Slight trace of erosion
B-4647	1.0	4.5	1	0	0	0	No change
			7	Less than 1	0.05	0.13	Slight trace of erosion
B-5040	0.5	2.3	1	Less than 1	0.07	0.18	Slight trace of erosion
			7	Less than 1	0.09	0.23	Slight trace of erosion
B-5040	1.0	4.5	1	0	0	0	No change
			7	0	0	0	No change

*Control sample was tested for only 30 seconds due to rapid rate of erosion.

inspection of these sites will be made periodically to determine the performance of the asphalt protection.

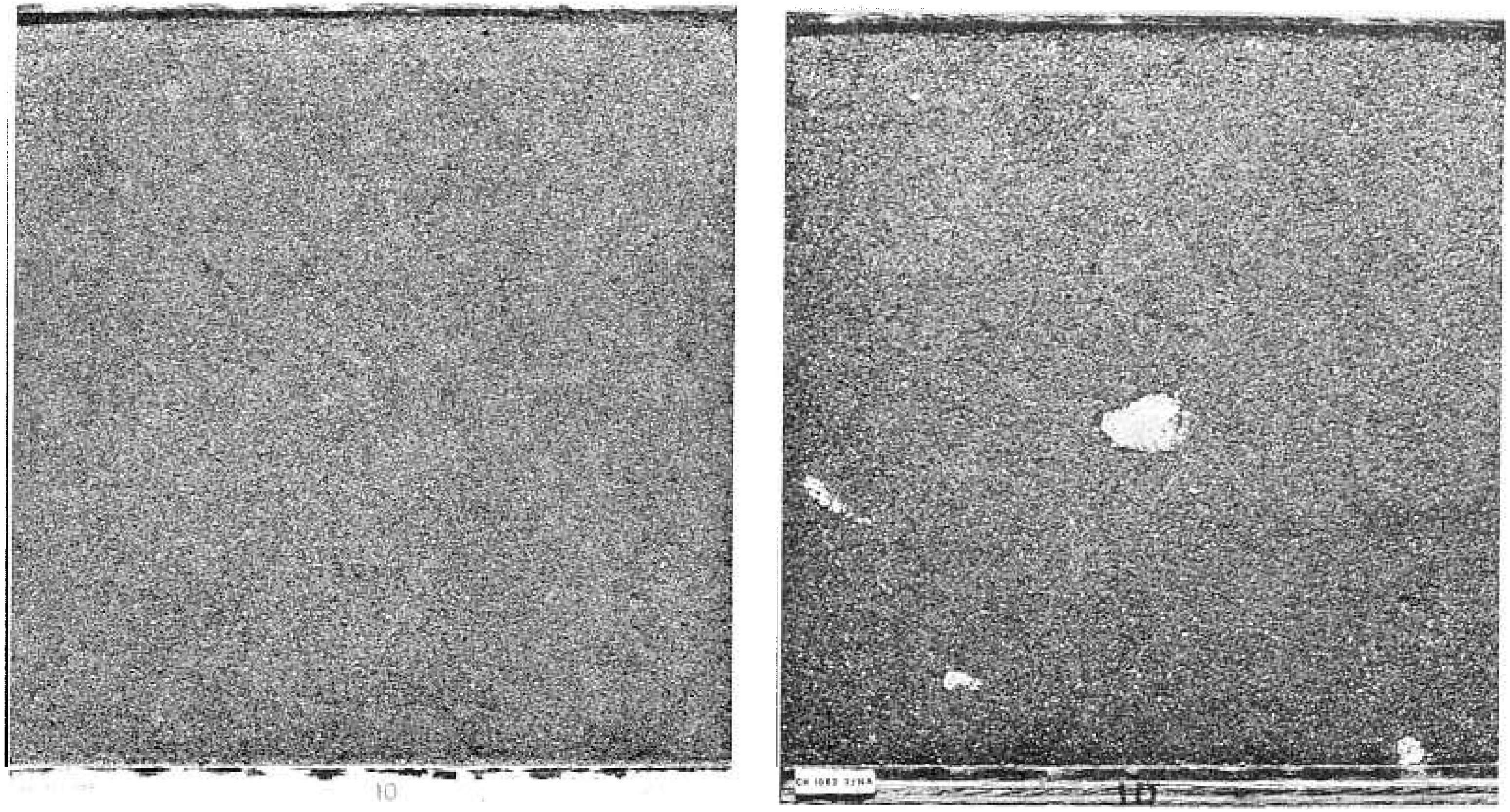
Erosion Control of Spoil Banks

Personnel from the Bureau's Regional Office at Sacramento, California, provided the following information:

On May 5-6, 1970, approximately 6,000 square feet (560 m^2) of spoils banks on the Tehama-Colusa Canal, Central Valley Project, California; and the Putah South Canal, Solano Project, California, were treated with the water-base stabilizer represented by Sample No. B-5778. The spoil banks required treatment to reduce sloughing, Photograph 23. The stabilizer was applied in a 3 percent mixture strength at a rate of 0.64 gsy (2.9 l/m^2).

The experimental treated areas are located at Miles 19.6 and 25.0 on the Tehama-Colusa Canal and near Mile 0.09 on the Putah South Canal. Treatment at Mile 25.0 on the Tehama-Colusa Canal is shown in Photograph 24. For some areas a herbicide mixture (dalapon and simazine) at a rate of 10 pounds per acre (11.2 kg per ha) was added to the application. The addition of the herbicide to the stabilizer mixture was an attempt to determine if this combination would increase the life of the herbicide.

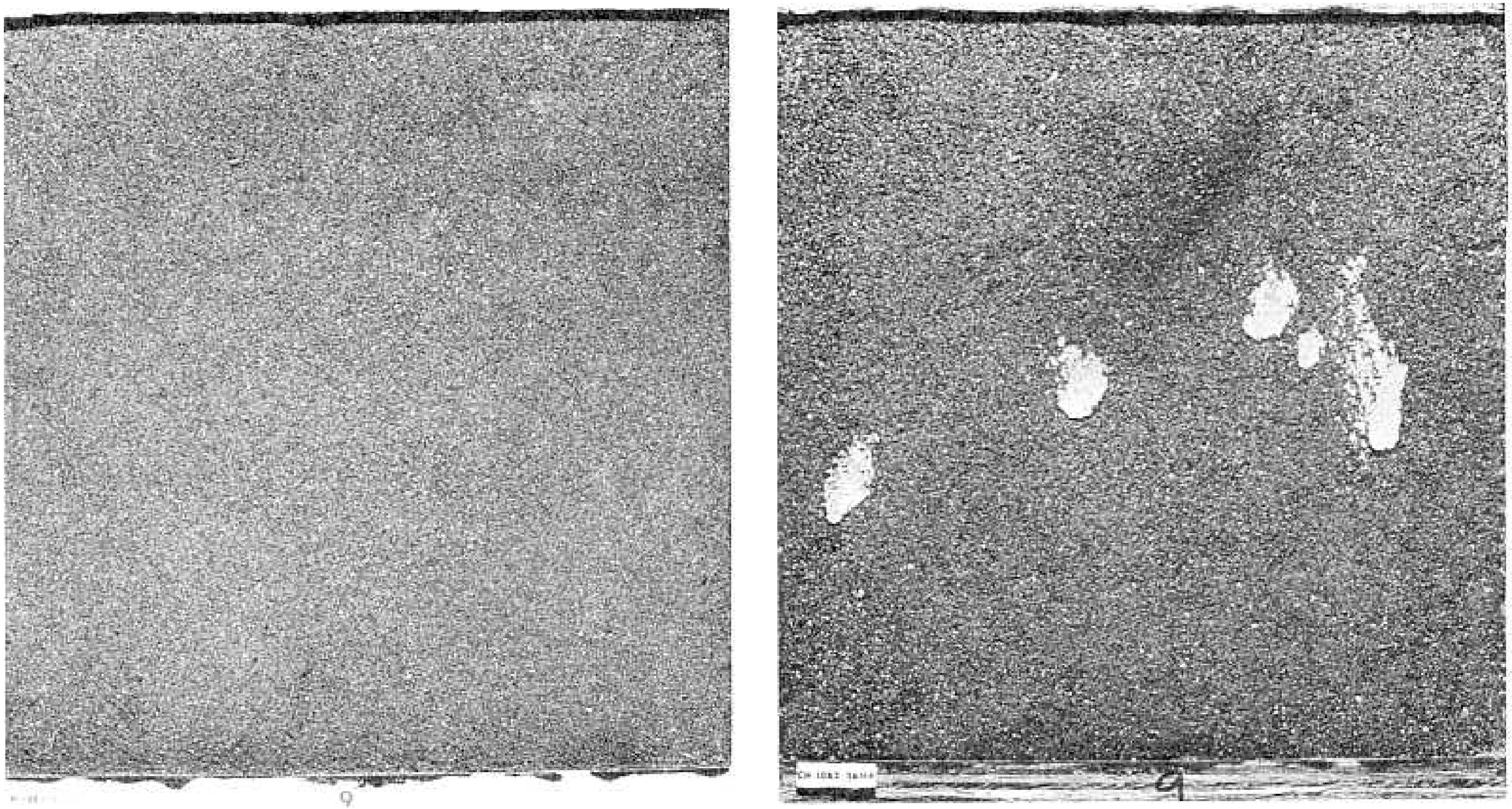
After approimxately 1 year's service all treated areas were examined and found to be in good condition as



a. Date: 2/17/70 (original condition). Photo PX-D-69216

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69217

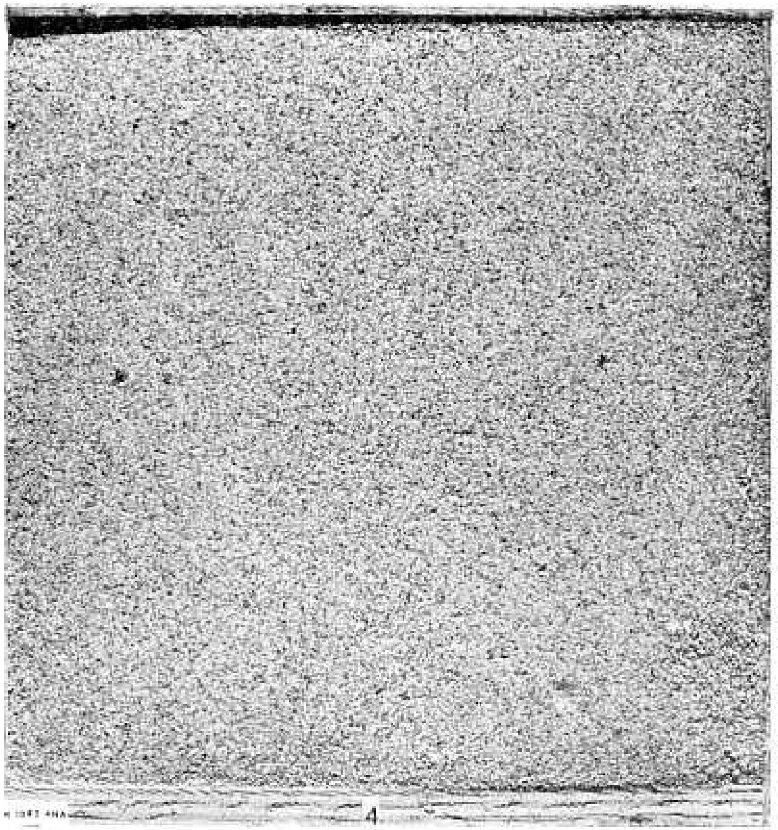
Photograph 6. Outdoor exposure test results for sandy soil treated with liquid asphalt prime material B-5494 at an application rate of 1 gsy (4.6 l/m^2). Sample was in excellent condition after 1 year's weathering.



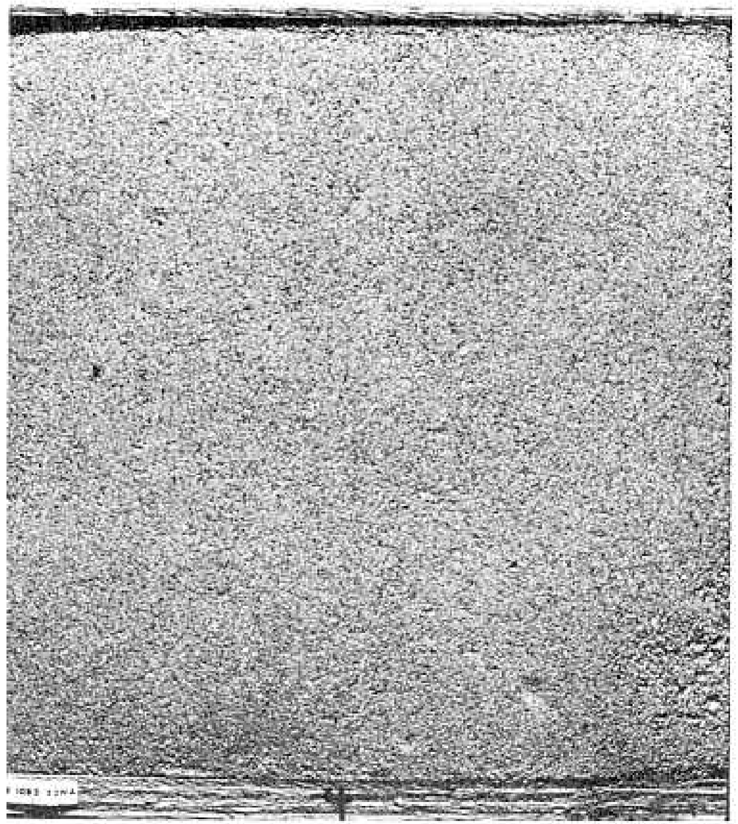
a. Date: 2/17/70 (original condition). Photo PX-D-69218

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69219

Photograph 7. Outdoor exposure test results for sandy soil treated with liquid asphalt prime material B-5494 at an application rate of 0.5 gsy (2.3 l/m^2). Sample was in excellent condition after 1 year's weathering.

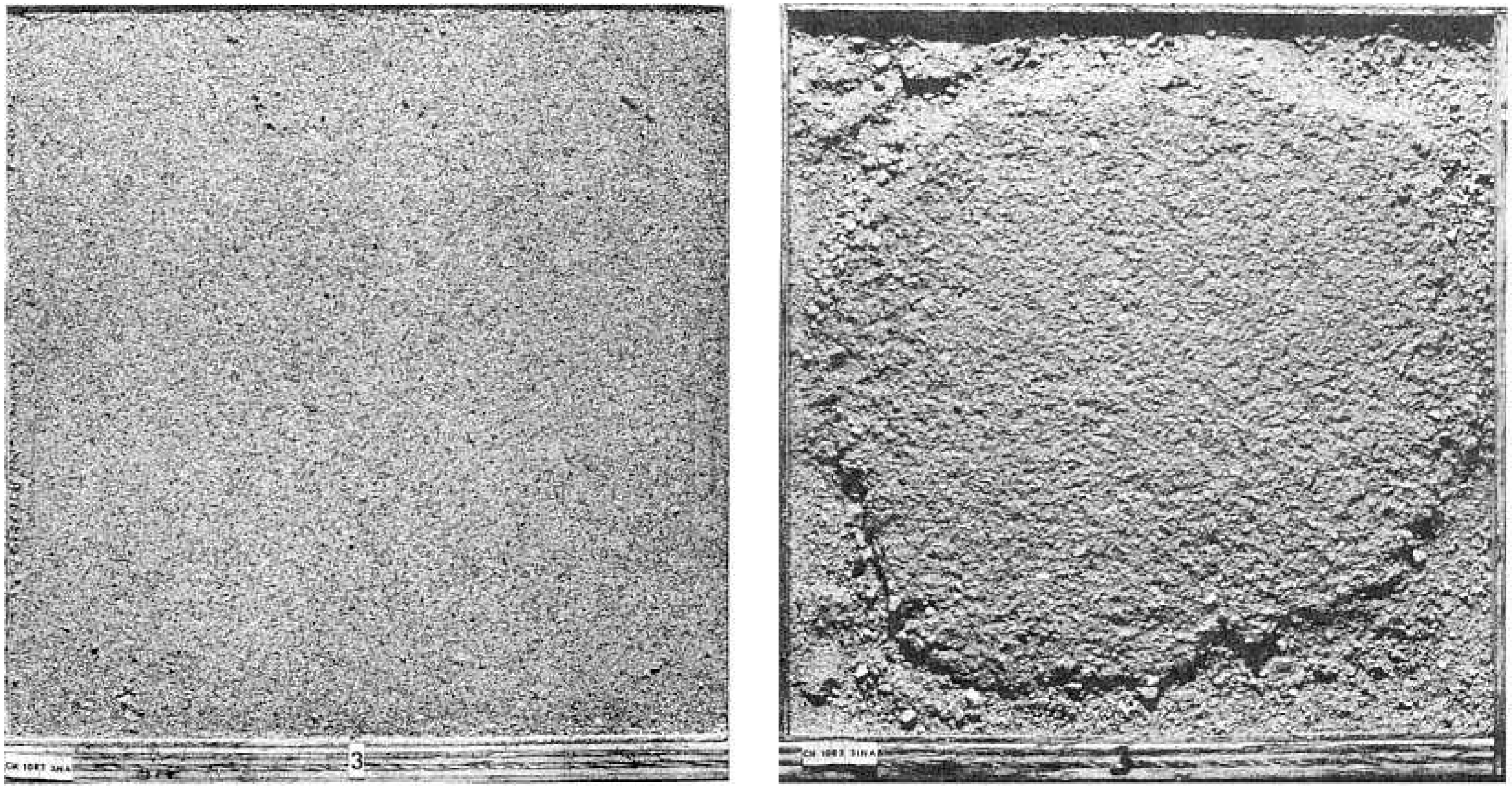


Date: 2/17/70 (original condition). Photo PX-D-69220



b. Date: 2/25/71 (1-year exposure). Photo PX-D-69221

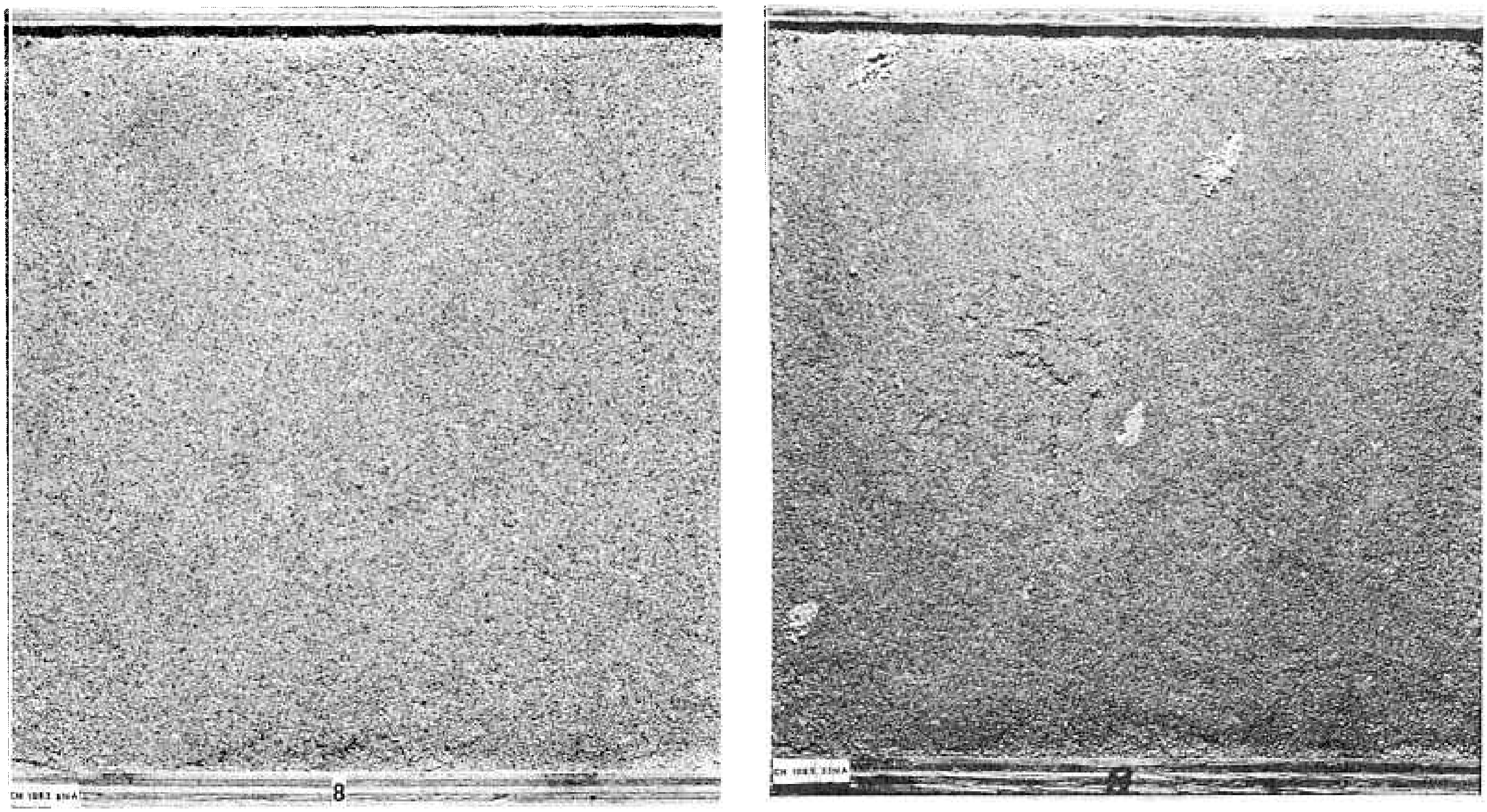
Photograph 8. Outdoor exposure test results for sandy soil treated with a water mixture containing 10 percent vinyl polymer material B-5800. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample was in excellent condition after 1 year's weathering.



a. Date: 2/17/70 (original condition). Photo PX-D-69222

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69223

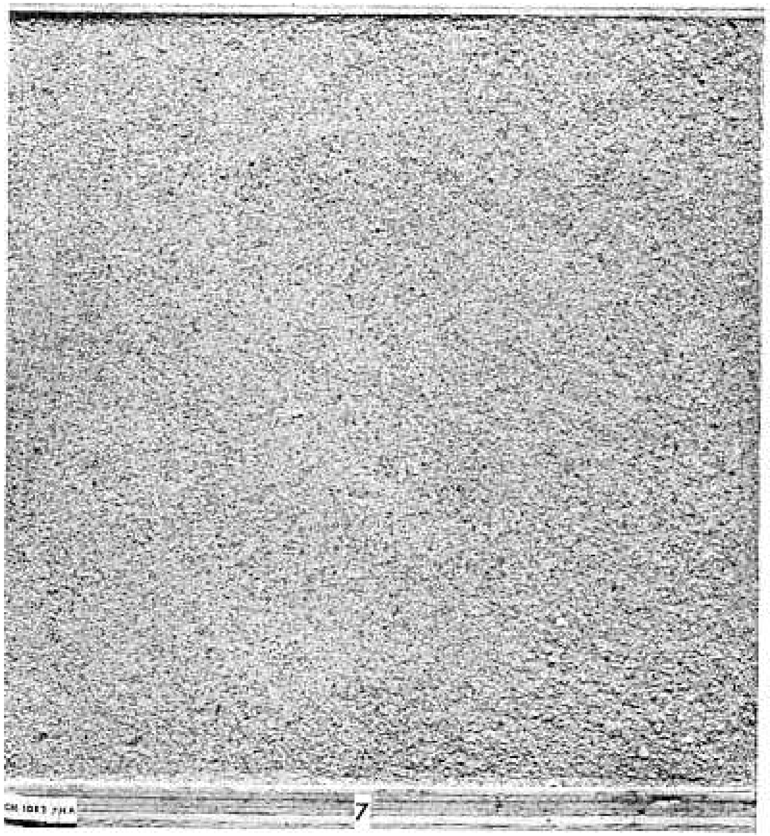
Photograph 9. Outdoor exposure test results for sandy soil treated with a water mixture containing 2.5 percent vinyl polymer material B-5800. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample shows considerable wearing at edges after 1 year's weathering.



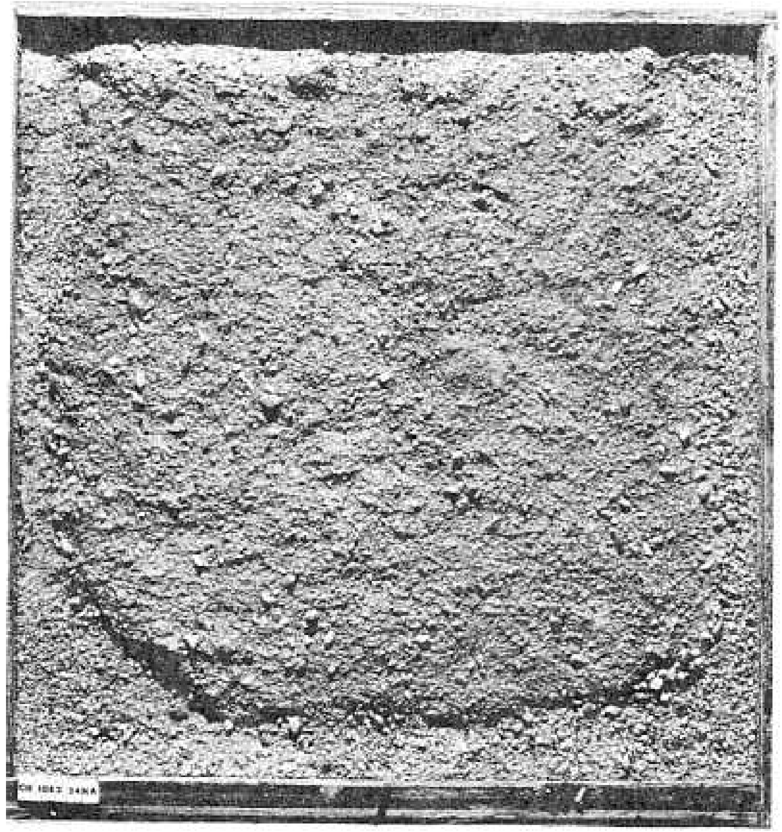
a. Date: 2/17/70 (original condition). Photo PX-D-69224

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69225

Photograph 10. Outdoor exposure test results for sandy soil treated with a water mixture containing 10 percent acrylic copolymer material B-5778. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample was in good condition after 1 year's weathering.

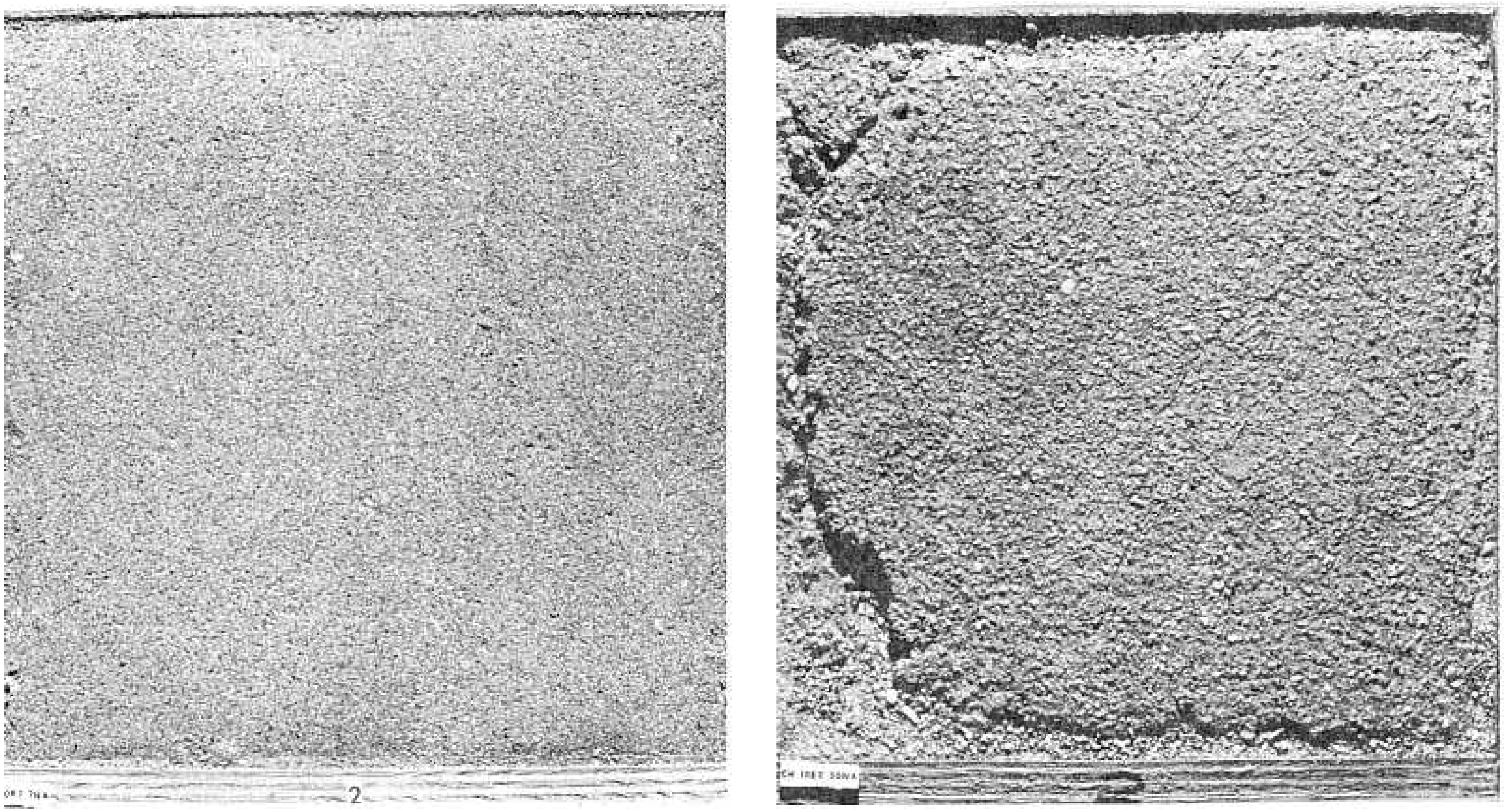


Date: 2/17/70 (original condition). Photo PX-D-69226



b. Date: 2/25/71 (1-year exposure). Photo PX-D-69227

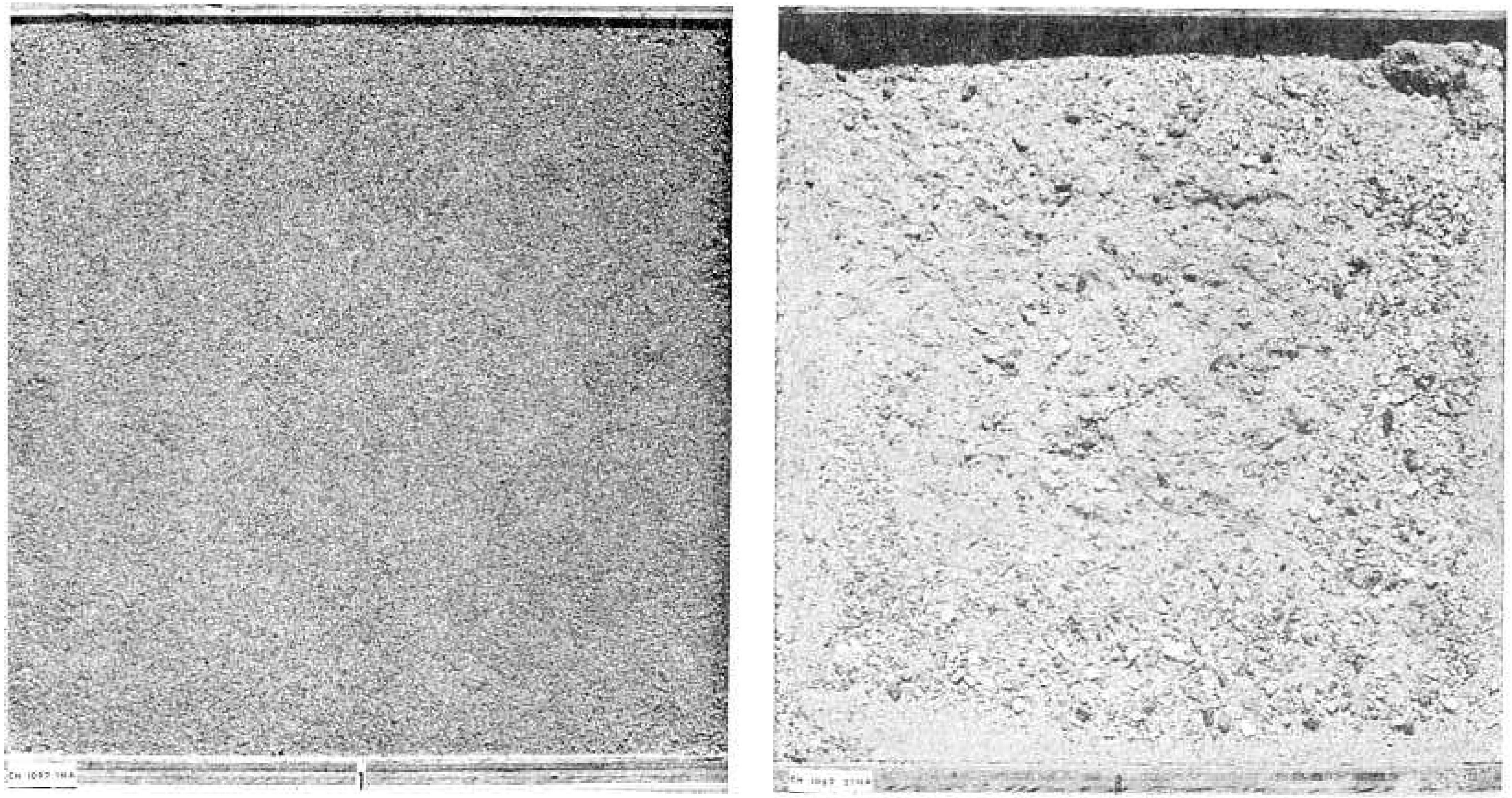
Photograph 11. Outdoor exposure test results for sandy soil treated with a water mixture containing 2.5 percent acrylic copolymer material B-5778. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample showed considerable erosion after 1 year's weathering.



a. Date: 2/17/70 (original condition). Photo PX-D-69228

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69229

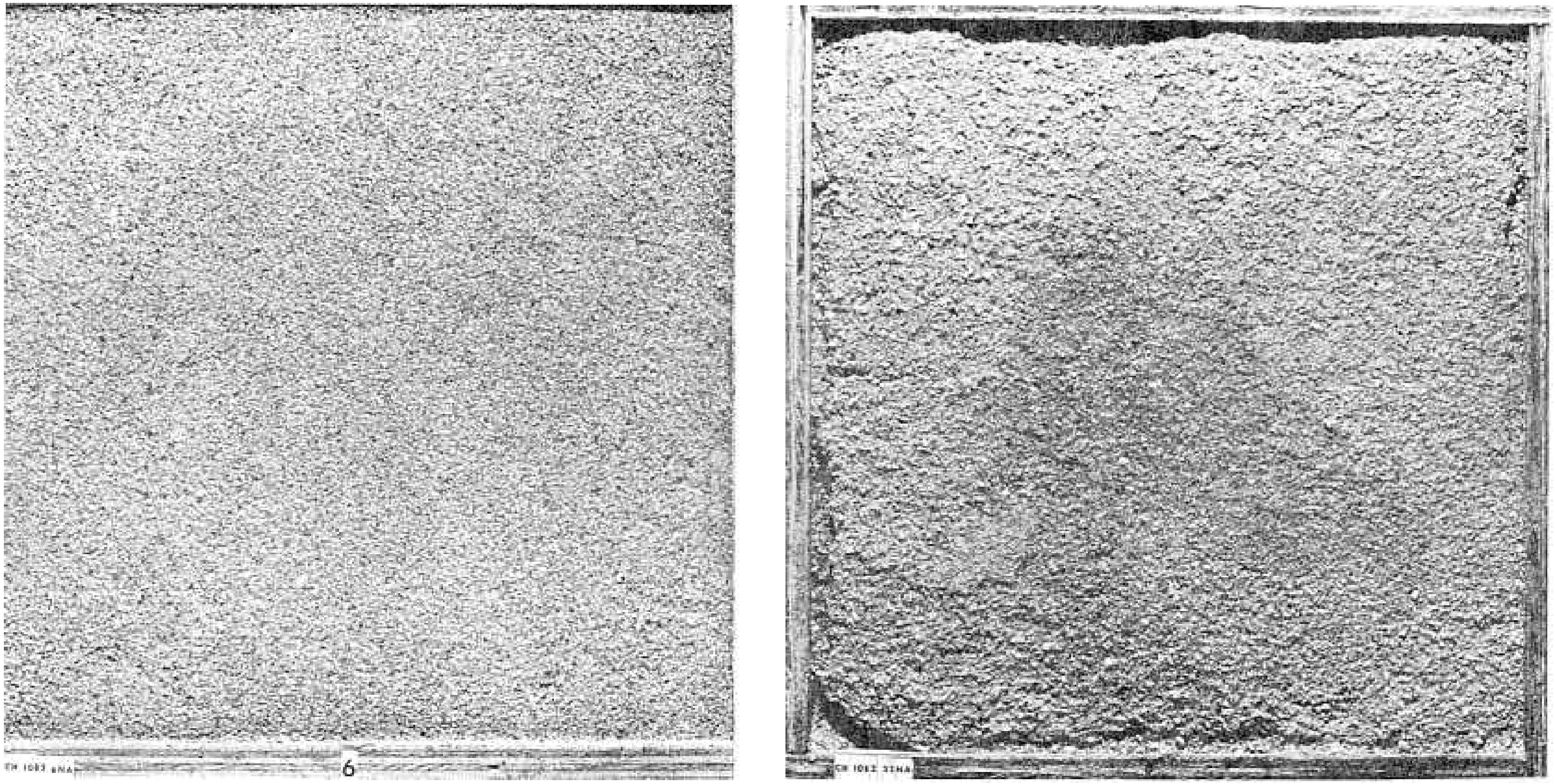
Photograph 12. Outdoor exposure test results for sandy soil treated with a water mixture containing 10 percent elastomeric material B-5856. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample showed some erosion at edges after 1 year's weathering.



a. Date: 2/17/70 (original condition). Photo PX-D-69230

b. Date: 8/20/70 (6-month exposure). Photo PX-D-69231

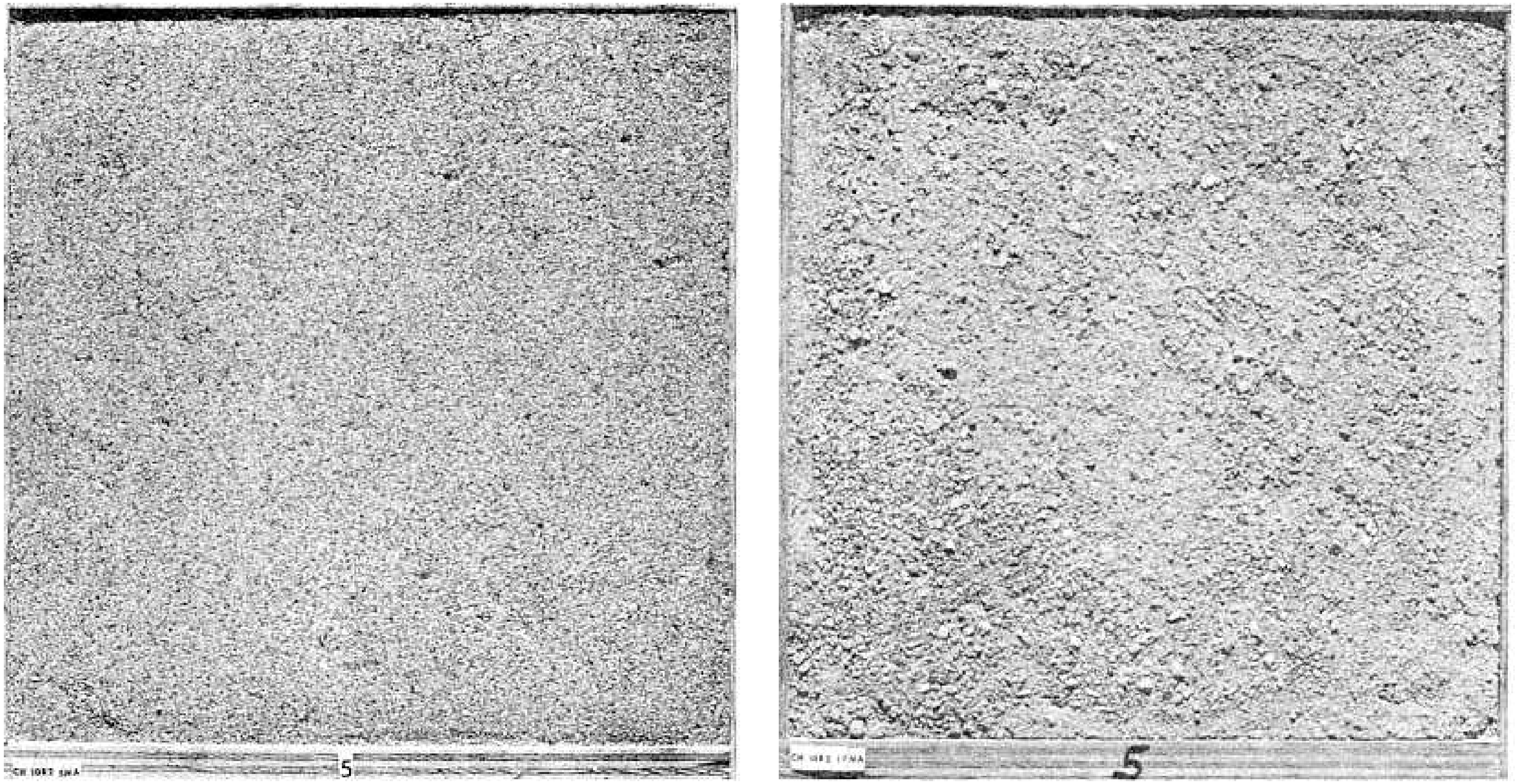
Photograph 13. Outdoor exposure test results for sandy soil treated with a water mixture containing 2.5 percent elastomeric material B-5856. Application rate of mixture was 1 gsy (4.6 l/m^2). Test was discontinued after 6 month's weathering with sample showing extensive erosion.



a. Date: 2/17/70 (original condition). Photo PX-D-69232

b. Date: 2/25/71 (1-year exposure). Photo PX-D-69233

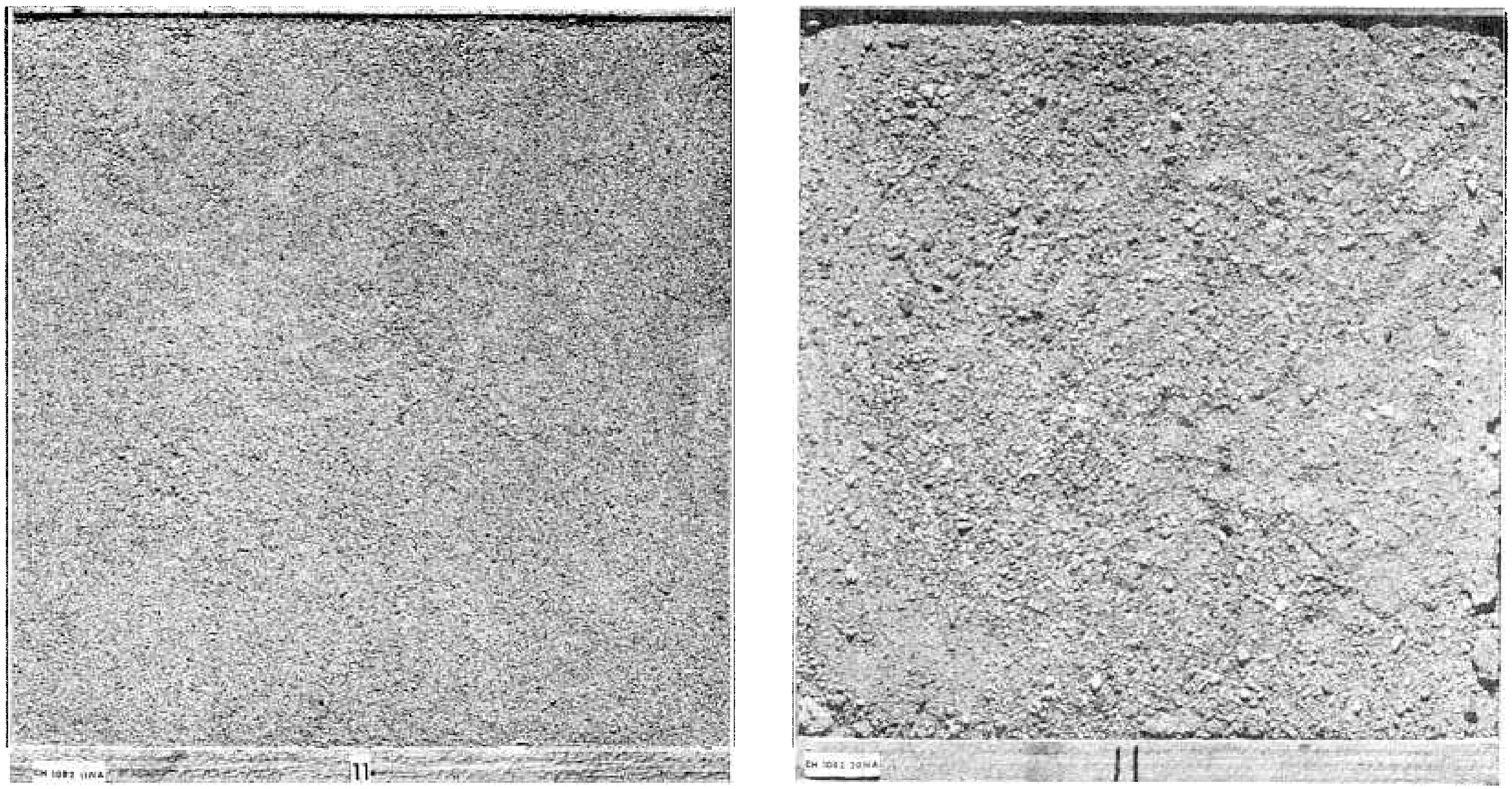
Photograph 14. Outdoor exposure test results for sandy soil treated with a water mixture containing 10 percent epoxized-silicone material B-5551. Application rate of mixture was 1 gsy (4.6 l/m^2). Sample showed some erosion at edges after 1 year's weathering.



a. Date: 2/17/70 (original condition). Photo PX-D-69234

b. Date: 4/27/70 (2-month exposure). Photo PX-D-69235

Photograph 15. Outdoor exposure test results for sandy soil treated with a water mixture containing 2.5 percent epoxized-silicone material B-5551. Application rate of mixture was 1 gsy (4.6 l/m^2). Test was discontinued after 2 month's weathering with sample showing extensive erosion.



a. Date: 2/17/70 (original condition). Photo PX-D-69236

b. Date: 4/27/70 (2-month exposure). Photo PX-D-69237

Photograph 16. Outdoor exposure test results for untreated (control) sandy soil. Test was discontinued after 2 month's weathering with sample showing extensive erosion.

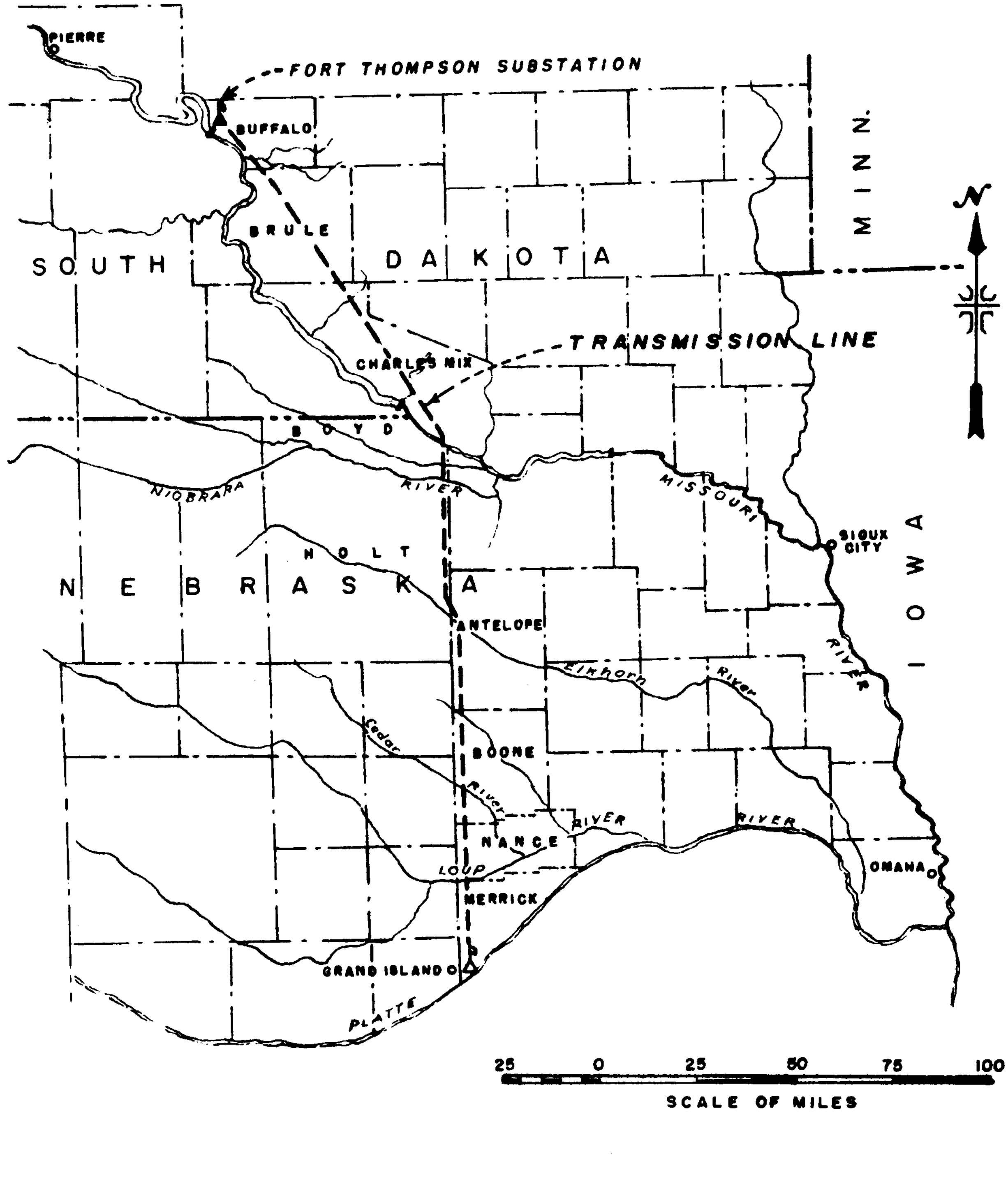


Figure 4. Location map, Fort Thompson-Grand Island 345-kv-Transmission Line.

Table 9

PENETRATION OF ASPHALT PRIME MATERIAL IN DUNE SAND

Density of dune sand			Application rate		Penetration	
lb/ft^3	g/cc	Relative	gsy	l/m^2	in.	cm
91.2	1.46	60	1	4.6	1.3	3.30
			2	9.1	3.0	7.62
			3	13.5	5.3	13.46
99.6	1.59	80	1	4.6	1.2	3.05
			2	9.1	2.8	7.11
			3	13.5	4.2	10.67
105.5	1.69	90	1	4.6	1.2	3.05
			2	9.1	2.8	7.11
			3	13.5	3.9	9.91

shown in Photographs 25 to 27. A well defined crust was noted and the only erosion occurring was in that portion of the Tehama-Colusa Canal opposite Mile 25.0, below the top of the slope that was not treated. The eroded area is shown in Photograph 25, and the results of this test indicate the need for also treating the top of the slope.

The effectiveness of the herbicide was difficult to determine since areas on both sides of the test section on the Tehama-Colusa Canal where it was used, were treated by field personnel afterwards with another herbicide. Also, at the Putah South Canal the treated areas where the herbicide was used were free of vegetation; vegetation was very sparse in the untreated areas. However, field personnel will continue to observe these areas to determine the effectiveness of the herbicide and the performance of the acrylic copolymer for erosion control.

Treatment of Shale Seams to Reduce Air Slaking

The sloughing of rock and material from a road cut on Colorado Highway No. 133 near Paonia Dam created a traffic hazard and maintenance problem. The sloughing of the rock face, shown in Photograph 28, was caused by air-slaking of the shale seams. As the shale weathered and eroded, the sandstone formation above the seams became unstable, resulting in the fallout of large sandstone blocks.

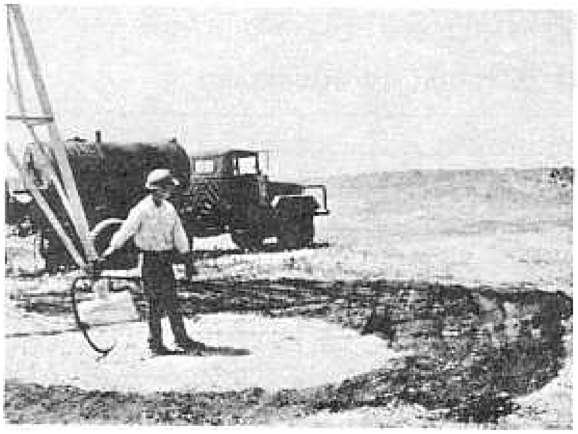
The road cut, located in Reach 1, Figure 5, was rehabilitated under Specifications No. DC-6692. The specifications work consisted of resloping the rock face and providing a wider roadway ditch, Figure 6. A limited amount of funds was provided for experimental treatment of the shale seams. Four coating materials were selected for the experimental treatment. These materials were selected on the basis of earlier laboratory studies, availability, or prior use on similar applications.

The four coating materials included:

1. A liquid cut-back asphalt formulated with a neoprene additive and identified in the report as B-5533. This material, which produces an elastomeric coating, appeared to be one of the more effective in laboratory tests for preventing moisture loss from clay soils. It was hoped that when this material was applied it would penetrate the shale and also bridge the seam and adhere firmly to the sandstone.

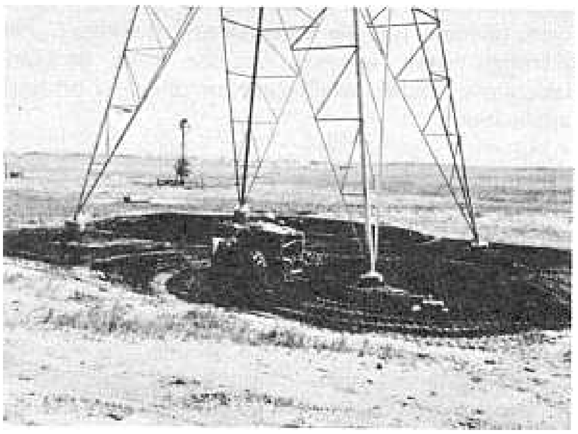
2. The liquid asphalt prime material represented by Sample No. B-5494. This material was selected because of its hard-base residual asphalt, penetrating capabilities, and weatherability. The Wyoming State Highway Department has conducted limited studies with the prime material for stabilizing expansive clay soil.

3. An asphalt emulsion, represented by Sample No. 5144, formulated with mineral fillers and fiber was selected for field evaluation. Laboratory tests indicated this material had excellent weathering characteristics. Also, since this emulsion contains mineral additives, it produces a harder coating than those obtained from standard emulsions. Rapid setting cationic asphalt emulsions (RS-k) have been used by the Bureau in tunnel construction to reduce

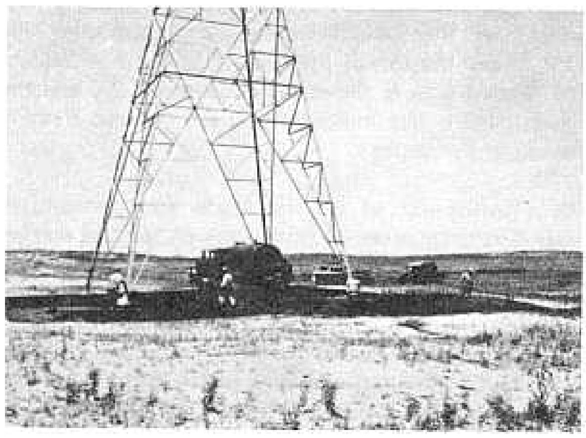


Photograph 17. Fort Thompson-Grand Island 345-kv Transmission Line—The contractor applying the first application of the liquid asphalt prime material at USBR Tower No. 173/5. Photo P-466-602-6638

Photograph 19. Fort Thompson-Grand Island 345-kv Transmission Line—A close-up view showing the condition after the first coat of liquid asphalt had been harrowed at USBR Tower No. 174/2. Photo P-466-602-6627



Photograph 18. Fort Thompson-Grand Island 345-kv Transmission Line—Contractor's harrowing operation used between coats of penetrating asphalt application at USBR Tower No. 174/2. Photo P-466-602-6625.



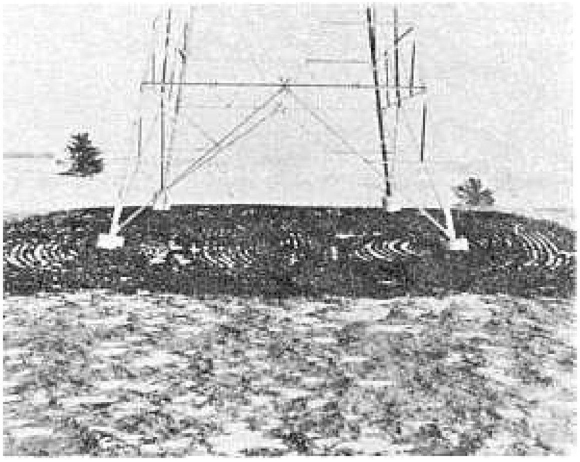
Photograph 20. Fort Thompson-Grand Island 345-kv Transmission Line—The contractor applying the second coat of liquid asphalt at USBR Tower No. 174/2. Photo P-466-602-6632

air slaking of shales. However, their use has not been too successful since the residual coatings were soft and susceptible to physical damage by workmen and equipment. In addition, workers complained that the presence of soft coatings created unfavorable working conditions; the asphalt rubbed off on their clothes when they accidently brushed against the coated surfaces.

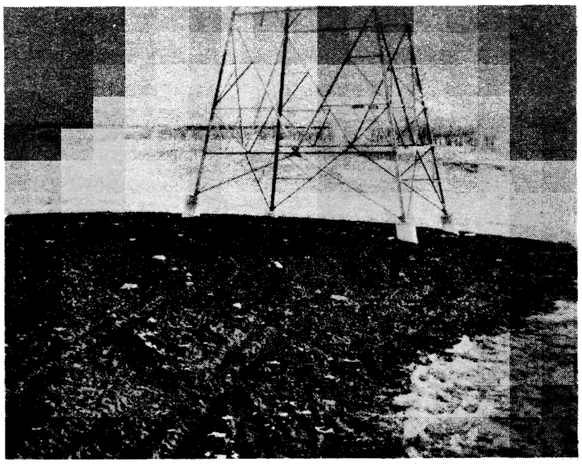
4. A synthetic resin emulsion, represented by Sample No. B-3750, which has been used with some success in the Blanco Tunnel near Pagosa Springs, Colorado, for sealing shales. The Corps of Engineers also have used this material on several jobs to prevent air slaking of shales.

In addition to these four materials, an exterior acrylic water-base paint was also included in the field evaluation.

During the spring of 1969, the five protective coatings were applied to the shale seams. The quantity of materials used and the areas treated in Reach No. 1 are summarized in Table 10. The contractor used a Grayco



Photograph 21. Fort Thompson-Grand Island 345-kv Transmission Line—View looking east at USBR Tower No. 162/2 showing the excellent condition of the asphalt treated soil after 6 months' service. Photo P-466-602-6817



Photograph 22. Fort Thompson-Grand Island 345-kv Transmission Line—View looking southeast at USBR Tower No. 163/4 showing the excellent condition of the asphalt treated soil after 6 months' service. Photo P-46-602-6819

Powerflo pressure pump in conjunction with an Ingersoll-Rand (I.R.) 600 air compressor to spray-apply the protective coatings. Before application, an air pipe was used to clean the shale surfaces.

In April 1970, after approximately 1 year's service, an on-site inspection was made by the Project Construction Engineer, Montrose, Colorado, to determine the performance of the protective coatings. At that time there was no indication of any of the coatings adhering to the shale seams previously treated. The liquid asphalt B-5494, latex paint, and the asphalt emulsion B-5144 were in evidence on the rock surfaces adjoining the shale seams. The condition of the seams at the time of inspection is shown in Photographs 29 and 30.

The inspection showed that for protective coatings to be effective on the shale seams as encountered at Paonia, a substantial increase in the amount of material applied would be required. Also, the materials should be applied as quickly as possible to the newly excavated surfaces; otherwise effective adhesion of the coatings is not attained.

RECOMMENDATIONS

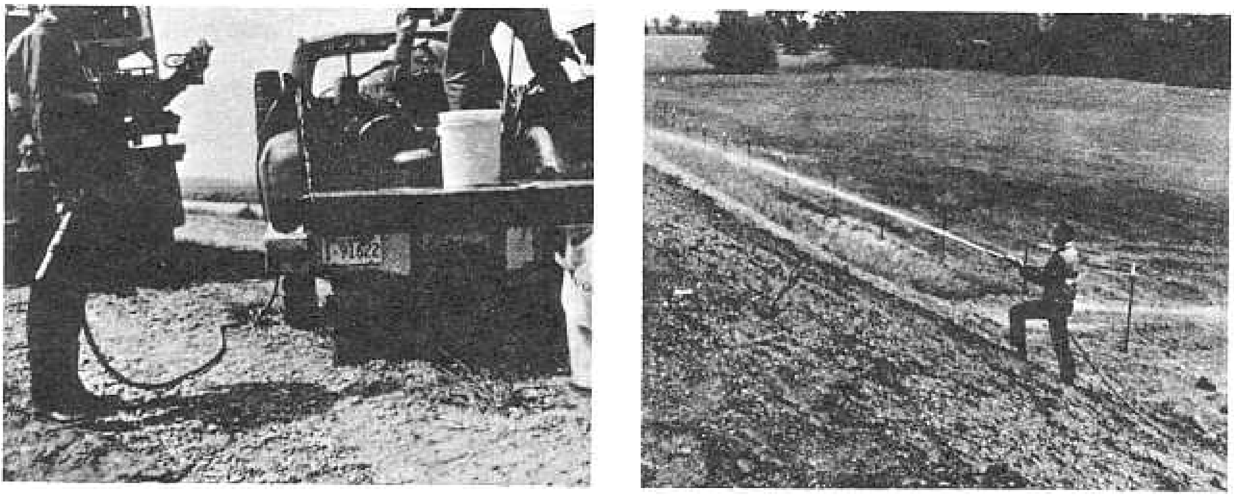
1. Conduct laboratory tests under WRER Research Program No. DR-302* to evaluate the vinyl polymer material B-5800 for sealing shales and clays to reduce air slaking.

2. Conduct laboratory tests under WRER Research Program No. DR-302 to evaluate various petrochemicals for stabilizing stockpiled earth materials to prevent environmental pollution.

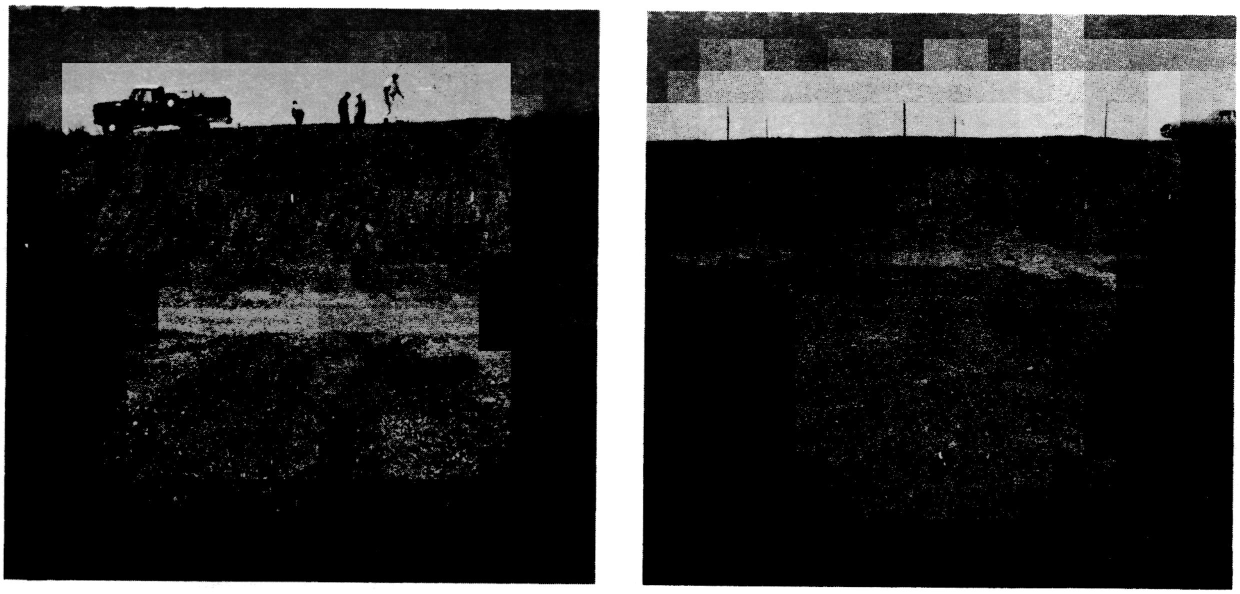
3. Conduct a survey of the various Bureau of Reclamation Regional and Field Offices to determine typical stabilization problems and methods of control. Based on this survey, a research program could be

Photograph 23. View of spoil bank opposite Mile 25.0 on the Tehama-Colusa Canal, Central Valley Project, California. This area has a history of sloughing which required rebuilding the fence, shown in Photograph 24, numerous times. Photo P602-D-69238

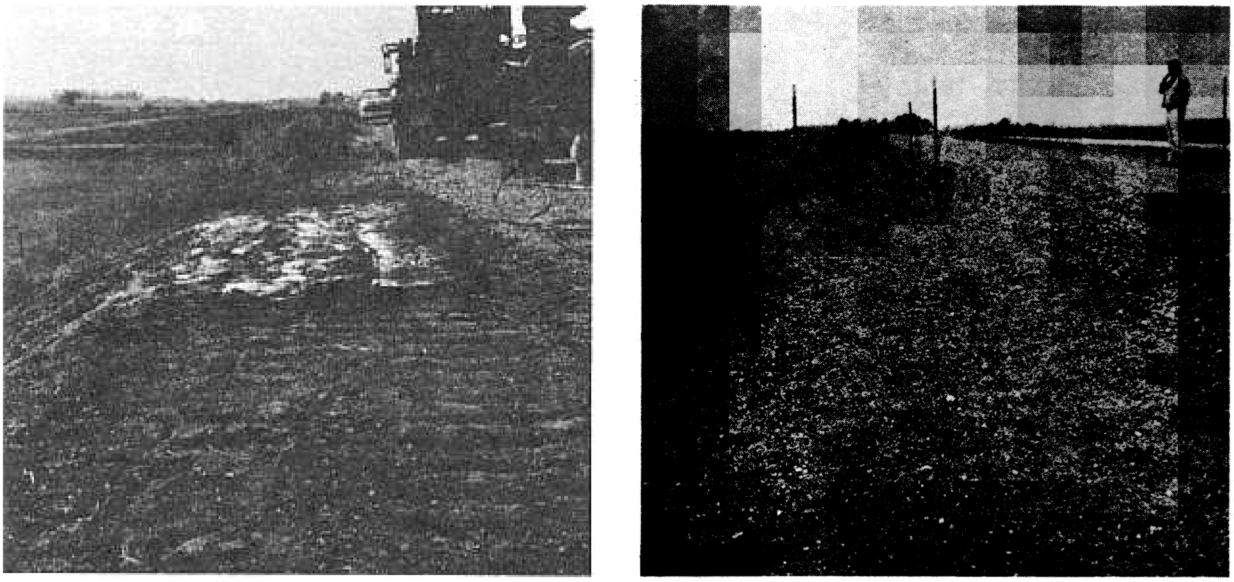
*"Petrochemicals for Erosion Control, Stabilization, Grouting, and Linings."



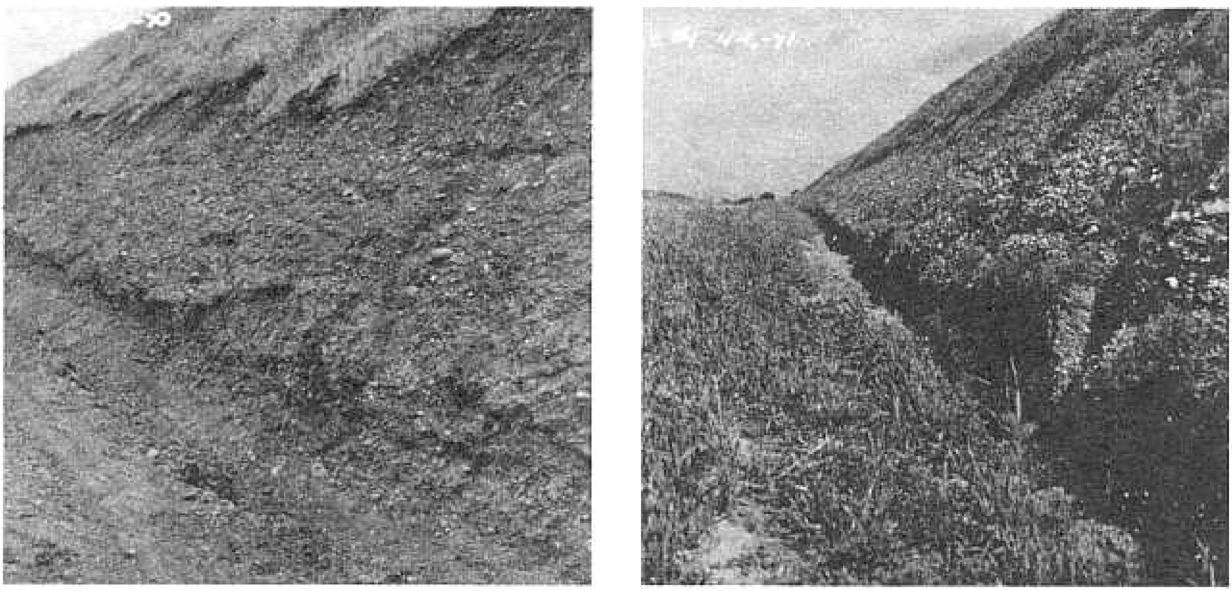
Photograph 24. Treatment of spoil bank for erosion control. A water-base acrylic copolymer was used for the stabilization application. View at left shows spray rig used in application. Left Photo P602-D-69239, right Photo P602-D-69240



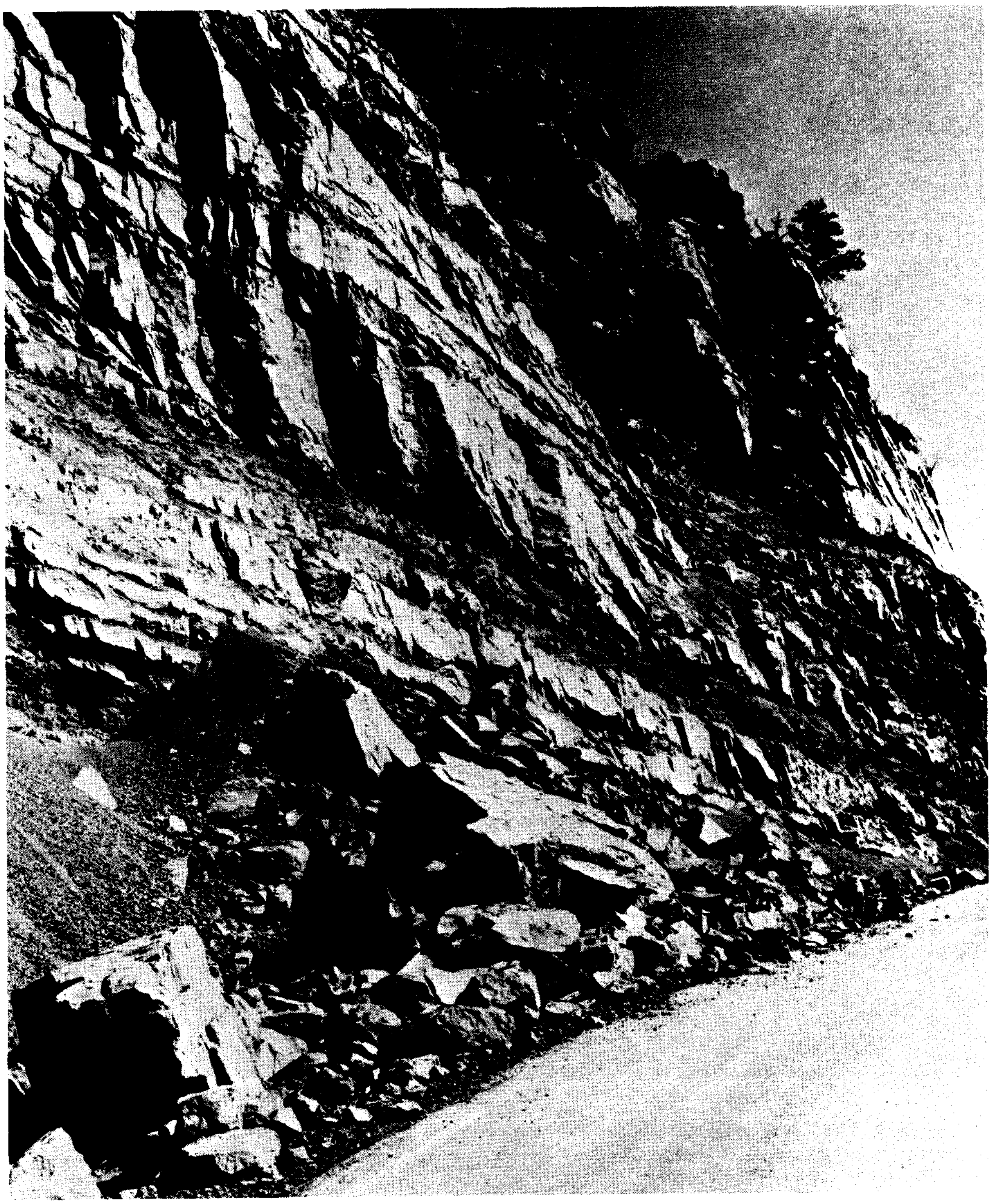
Photograph 25. View at left is of left slope opposite Mile 25.0 prior to treatment. View at right shows condition approximately 1 year later. Eroded area on the right is below the top of the bank that was not treated (see Photograph 26). Left Photo P602-D-69241, right Photo P602-D-69242



Photograph 26. View at left shows top of left slope immediately after treatment. Condition after 1 year is shown at right. Only a portion of the top slope was treated which resulted in the erosion shown in Photograph 25. This would indicate the need for treating the top of the slope. Left Photo P602-D-69243, right Photo P602-D-69244



Photograph 27. View at left looking downstream at area to be treated on right bank of the O&M road opposite Mile 0.09, Putah South Canal. Condition after 1 year is shown at right. Slope was stable with a well-defined crust, and the material appeared to penetrate very well in the sandy-gravel deposit. Left Photo P413-D-69245, right Photo P413-D-69246



Photograph 28. Rehabilitation of Colorado Highway No. 133—View looking along the road showing rock and material sloughed off the cut. Photo P-551-427-141 NA

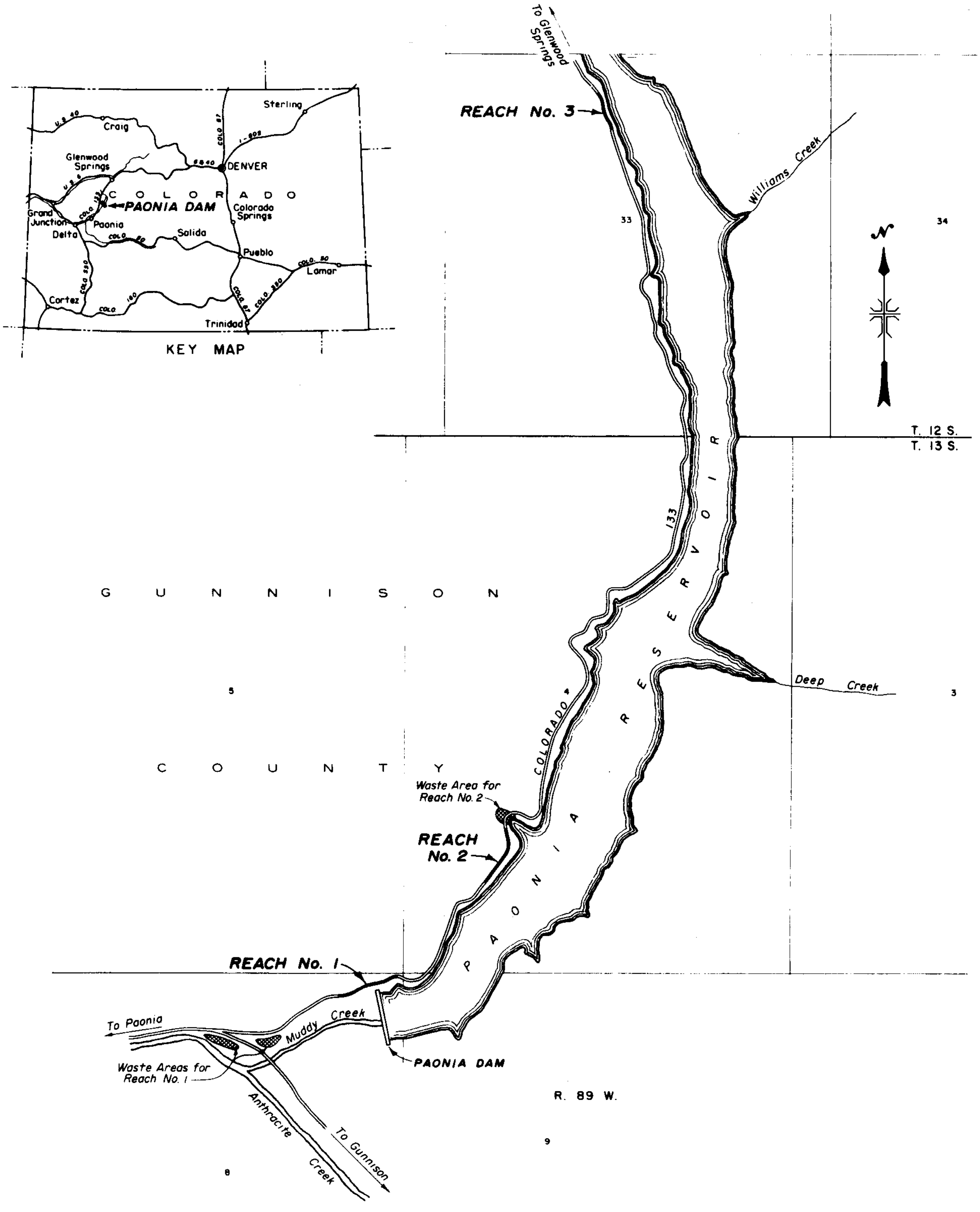


Figure 5. Location map, rehabilitation of Colorado Highway No. 133.

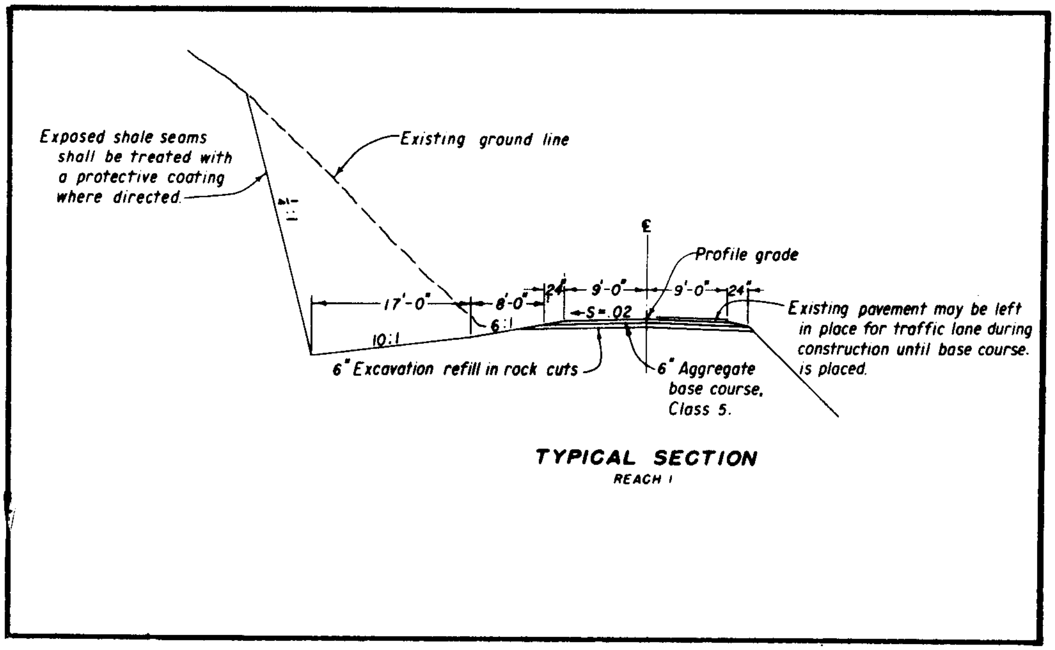


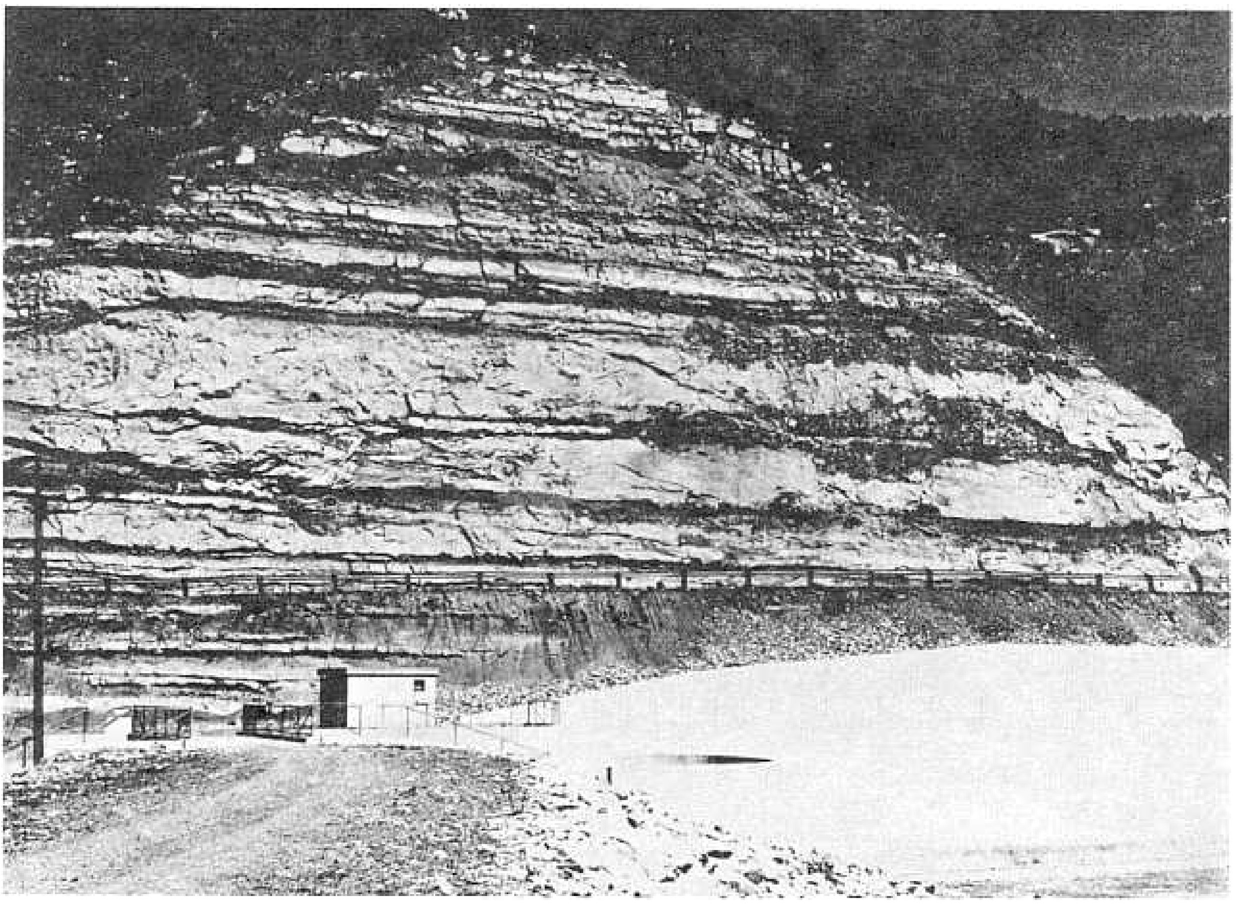
Figure 6. Typical section in Reach 1—Rehabilitation of Colorado Highway No. 133.

Table 10

APPLICATION OF PROTECTION COATINGS ON SHALE SEAMS IN TEST AREA REACH NO. 1—SPECIFICATIONS NO. DC-6692 REHABILITATION COLORADO HIGHWAY NO. 133—PAONIA DAM

Station	Material applied	Quantity used		Approximate area of coverage		Application rate*	
		gallons	liters	yd^2	m^2	gsy	l/m^2
10+75 to 12+50	B-5533	[1] 105	397	260	217	0.40	1.80
12+50 to 14+25	B-5494	100	378	400	334	0.25	1.10
14+25 to 16+00	B-3750	[2] 15	57	565	472	0.03	0.14
17+75 to 19+50	B-5144	[3] 247	935	500	418	0.50	2.3
16+00 to 17+75	Latex paint	[4] 20	76	642	537	0.03	0.14

*Based on stabilizer material quantity.
[1] Diluted with 15 gallons of thinner.
[2] Diluted with 133.5 gallons of water.
[3] Diluted with 98 gallons of water.
[4] Diluted with 3 gallons of water.



Photograph 29. Rehabilitation of Colorado Highway No. 133—View from crest of dam showing road cut from Station 16+50 to Station 19+50. Photo P-551-427-142 NA

performed to develop new techniques and materials for effective, low-cost soil stabilization.

REFERENCES

1. Morrison, W. R., Dodge, R. A., and Merriman, J., "Pond Linings for Desalting Plant Effluents, (Final Report)." Bureau of Reclamation Laboratory Report REC-ERC-71-25

2. Havens, R. and Dean, K. C., "Chemical Stabilization of the Uranium Tailings at Tuba City, Arizona." Bureau of Mines Report of Investigations 7288, August 1969

3. Hickey, M. E., "Evaluation of Special Liquid Asphalts for Stabilization of Sandy Soil," Bureau of Reclamation Laboratory Report No. CHE-22, June 1964

Photograph 30. Rehabilitation of Colorado Highway No. 133—View of area at Station 19+50 to Station 17+75 where coating B-5144 was applied. Evidence of coating can be seen on the sandstone formation. Photo P-551-427-136 NA

Table 11

MATERIALS LISTING

Laboratory Sample No.	Material
B-5800	Water-base vinyl polymer formulation
B-5778	Water-base acrylic copolymer formulation
B-5856	Elastomeric emulsion
B-5551	Water-base epoxized-silicone formulation
B-5494	Liquid cutback asphalt
B-4645	Liquid cutback asphalt
B-4646	Liquid cutback asphalt
B-4647	Liquid cutback asphalt
B-5040	MC-70 liquid cutback asphalt
B-5089	Petroleum-base resin
B-5090	Petroleum-base resin
B-5533	Neoprene-asphalt coating
B-5144	Asphalt emulsion with mineral fillers and fiber
B-3750	Synthetic resin emulsion

7-1750 (3-71)
Bureau of Reclamation

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, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in 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.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*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
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*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
Short tons (2,000 lb)	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
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	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
Pounds per cubic foot	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
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	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
Feet 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
Miles 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
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	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 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*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)	*0.092903	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

Laboratory and field evaluations of several petrochemical, liquid soil stabilizers were conducted. Laboratory tests indicated that a sprayable liquid vinyl polymer has excellent properties for stabilizing sandy soil. Initial observations showed that a deep penetrating liquid cutback asphalt was performing satisfactorily in stabilizing dune sand around transmission tower sites along the Fort Thompson-Grand Island 345-kv Transmission Line. A water-base acrylic copolymer is providing satisfactory erosion control on test sections of spoil banks at the Tehama-Colusa and Putah South Canals in California. However, the high cost would limit the use of the material to minimum wind and water erosion control. None of 5 protective coatings applied to shale seams at Paonia Dam, Colorado, were effective in reducing air-slaking.

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