Environmental Consideration for Shotcrete

by Richard A. Kaden

This article presents a procedure for up-dating your environmental knowledge and keen awareness for a deeper appreciation of our surroundings. It discusses the new regulations for implementing the procedural provisions of the National Environmental Policy Act. The design engineer or manager in charge of a major development should be aware of the project's impact on the environment. The article discusses the planning of architecturally colored shotcrete for an acceptable procedure to enhance the environment around the immediate project that required slope stabilization. The laboratory design study matched color samples from the natural rock slope so that the resulting product blends with the landscape. Colored shotcrete has caused construction costs to increase, but it may be worth the added expense if the project can be saved from an environmental controversy. Identified are two field locations where colored shotcrete was used. A visit to inspect a field application may be needed to sell the concept of colored shotcrete.

Keywords: colors (materials); **environments;** laboratories; **shotcrete; slope protection;** soil erosion; soil stabilization.

WHAT IS SHOTCRETE TO YOU?

Its meaning differs dependent on your perspective. If you are a design engineer or manager, you have come to rely on shotcrete as a versatile construction material. If you are involved with equipment design or sales, you may be continuously trying to improve your product. As technology changes, the private enterprise system creates the competitive atmosphere for providing machines that will be in demand by the construction industry. If you are a contractor that works in this specialized field, you may know shotcrete to be your complete livelihood and your process of application is of most importance to your business. You are constantly striving to find acceptable ways to increase production, reduce operating costs, and maintain a comfortable profit margin. Now on the other hand, suppose you have no interest in any of the above items, and conservation of our Nation's environment is one of your highest priorities in life. Your opinion of shotcrete, no doubt would be somewhat different. Let us assume that shotcrete had been used for stabilization on a dark unstable rock mass of natural material. The untrained eye may perceive the off-white colored shotcrete to be an ugly, glaring, scare that reflects the bright sunlight on a beautiful clear day. This use of shotcrete then becomes an objectionable impact to the environment and could terminate the

Conventional shotcrete placed over a dark basalt rock formation. Texture variation provides some shading

Conventional shotcrete placed adjacent to a major highway. The environmental consideration may be questioned

development of the proposed project. So as a brief summary, the term shotcrete has different meanings for different folks. The remainder of this article is to provide some guidance to the designers, owners, contractors, and others of the importance in planning shotcrete projects.

ENVIRONMENTAL CONSIDERATIONS

ARE THERE DISADVANTAGES WITH SHOTCRETE?

The method in which raw materials, aggregate, and cement are handled may be ojectionable to the environmentalist. Dust from either the fine aggregate and/or cement can settle to the ground around the application area. This potential problem must be considered when designing or applying a shotcrete coating. It is also necessary to identify the prevailing winds and velocities in order to predict the total effect. Some special type of enclosure may be necessary to confine the area designated for batching, mixing, or charging the gun. The potential risk should be anticipated while preparing the bid documents so there is a meeting of the minds between owner and contractor. In addition to the potential dusting problem, rebound is an item that has to be cleaned up and hauled to an approved waste area. The amount of rebound is usually a function of the type of shotcrete, aggregate size used, the density of the material which is being covered, and the workmanship of the nozzleman.

WHAT DOES NEPA MEAN TO YOU?

First of all, let's review the conservationist's perspective for all environmental matters. The list and short description shown below is provided to make you aware of the legislation and regulation that governs the environmental process:

1. *The National Environmental Policy Act of 1969, as Amended.* The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate danger to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council of Environmental Quality.

2. *The Environmental Quality Improvement Act of 1970 and Title II — Environmental Quality (of the Water Quality Improvement Act of 1974).* The purposes of this title are: (1) To assure that each Federal department and agency conducting or supporting public works activities which affect the environment shall implement the policies established under existing law; and (2) to authorize an Office of Environmental Quality, which notwithstanding any other provision of law, shall provide the professional and administrative staff for the Council on Environmental Quality established by Public Law 91-190.

Conventional shotcrete placed adjacent to a major railroad. Aesthetics may have been improved if colored shotcrete would have been used

Conventional shotcrete placed below a major highway but adjacent to a major waterway

Colored shotcrete adjacent to a roadway at Lower Granite Lock and Dam, Snake River, Washington. Shotcrete placed as rock slope stabilization

Colored shotcrete with rock fragments of natural material

Colored shotcrete transition with natural rock slope

Colored shotcrete adjacent to a project access road, Lower Granite Lock and Dam

3. *Executive Order 11514, March 5, 1970: Protection and Enhancement of Environmental Quality as amended by Executive Order 11991, May 24, 1977.*

4. *Regulations for Implementing the Procedural Provisions of the "National Environmental Policy Act, NEPA."* This is the basic national charter for protection of the environment and is under the responsibility of the Council on Environmental Quality, Executive Office of the President. The NEPA regulation establishes policy, sets goals, and provides means for carrying out the policy.

The designer must keep in mind that environmental values will be given equal consideration with economic, social, and technical factors to insure decisions in the public interest. Although not specifically related to shotcreting, the decision-makers should be knowledgeable of the environmental process. There are other items of legislation to be aware of from the initiation of project planning through design, construction, operation, and maintenance. The environmental analysis must consider the impact to the following categories:

1. *Clean Water Act of 1977, formerly known as the Federal Water Pollution Control Act Amendment of 1972.* This primarily deals with the effects of the discharge of dredged or fill material into waters of the United States, including consideration of the Section 404.

2. *Coastal Zone Management Act of 1972, as Amended.* Proposed projects and activities significantly affecting land or water used in the Coastal Zone of the State or Territory must be coordinated with the appropriate State agency responsible for administrating the State's approved Coastal Management Program.

3. *Endangered Species Act of 1973, as Amended.* The owner shall initiate early coordination with the appropriate Regional Director of the Fish and Wildlife Service (FWS) or National Marine Fisheries Service (NMFS) to determine if any listed endangered or threatened species or species proposed for listing or these critical habitat may be present in this area of the proposed project.

4. *Fish and Wildlife Coordination Act.* The owner will initiate early coordination with the appropriate Regional Director of the FWS, the appropriate NMFS, and the head of the agency representative for fish and wildlife for the state.

5. *Marine Protection, Research and Sanctuaries Act of 1972, as Amended.* The owner will be responsible for compliance with Section 102, Guidelines of the Act involving the transportation of dredged material by vessel for the purpose of dumping it in the ocean waters pursuant to Section 103 or the Act.

6. *National Historic Preservation Act of 1966, as Amended; also Referred to as the "Reservoir Salvage Act"; Executive Order 11593, Protection and Enhancement of the Cultural Environment, 13 May 1971.* The owner will coordinate with the appropriate state historic preservation offices, the Historic Conservation and Recreation Service, the Advisory Council on Historic Preservation, and other groups with cultural resources expertise to identify and determine potential effects of the proposed project on significant cultural resources.

7. *Executive Order 11988. Flood plain Management, 24 May 1977.* The owner will be responsible for compliance with the applicable provisions of the Executive Order. Inclusion of the analysis and findings in the EIS Documents for studies and projects will be circulated for public review and comment will satisfy the opportunity for early public review requirements.

8. *Analysis of Impacts on Prime and Unique Farmlands in EIS, CEQ Memorandum, 30 August 1976.* The owner will be responsible for including an analysis of the effects on proposed projects on prime and unique farmlands in the course of preparing environmental documents.

WHERE SHOULD SHOTCRETE BE USED AND DOES IT AFFECT THE ENVIRONMENT?

With all fairness to the "Political System," the above laws and regulations have been established to provide the necessary protection to the environment. Keeping this in mind, all designers and managers who contemplate the use of shotcrete should

ask themselves some basic questions as to where can it be used successfully. Shotcrete has been used to correct and stabilize many types of geological hazards or abnormalities, where it is used as a coating. If additional methods of stabilization are needed such as rock bolting, earth anchors, prestress assemblies, and/or drilled drain holes are employed; then specific detail should be given to the connection between the coating and anchorage. The actual cause for correction may have been the result of floods, earthquakes, landslides, coastal erosion, expansive soils, subsidence, creep, fault displacement, liquefaction of sand and clay, wind erosion, and others. It is quite evident how the above hazards directly effect the planning, design and construction of highways, transportation systems, pipelines, powerlines, water control structures, drainage facilities, and housing locations and density. Another more limited use of shotcrete may be in the construction of aesthetically pleasing structures for zoological gardens, amusement parks, and entertainment centers.

In studying solutions to the potential problems mentioned above, one should make use of the earth science information available. In addition, probably the most important question to be asked by the designer would be "Is the Shotcrete Application in Public View?" If the location is in a remote area, then the environmental impact may be considered less dramatic than in populated areas. In either case, the impact may be reduced by establishing some natural looking obstacles and color shades that blend to the surroundings. The basic criteria for the designers to remember is "Will the finished product complement the Environment?" If coloring of the coating is necessary, then it would be added as an architectural coating of approximately 19 mm (¾ in.) depth ± 8.5 mm (⅓ in.). The following paragraphs will outline some laboratory investigations that were conducted in order to provide shades of color for shotcrete. The structural application for shotcrete was placed in accordance with standard procedures. Fig. 1 shows a color coat over a fibrous shotcrete structural section at Ririe Dam.

HOW SHOULD SHOTCRETE BE COLORED?

The most acceptable procedure that was found, required the selection of field specimens of the various rock types and colors that were representative of the local projects environment. The leading suppliers of color admixture for concrete products provide sample kits or color charts for various, so called, earth tones. These were quite helpful when selecting the type of cement and proportions of color pigment, fine aggregate, and water content. The color study should define several cement types and preferably from a variety of manufacturers that supply the geographical area. It has been found that premium architectural cements such as white, warmtone, buff, or other light colored products when combined with color pigment provide superior earth tones. Thus less color admixture is used as compared with the

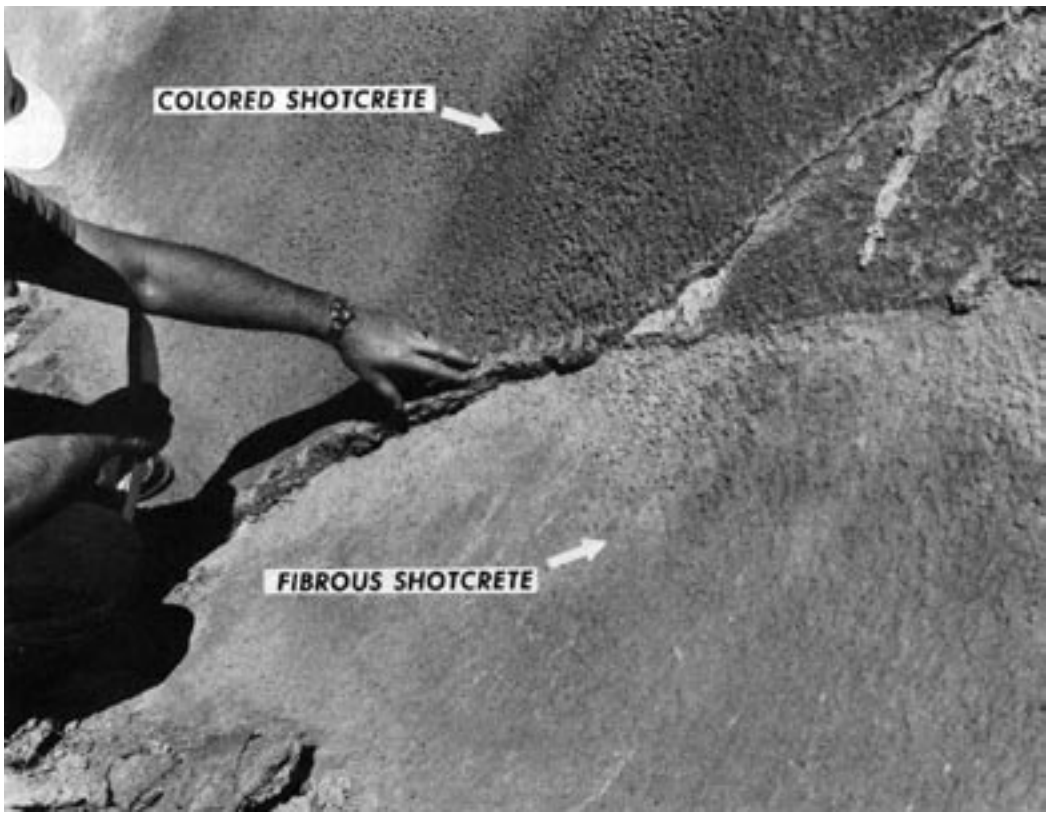

Fig. 1: Colored coat over fibrous shotcrete

Fig. 2: Ririe Dam Spillway channel

Fig. 3: Ririe Dam right abutment stabilization

standard cement types. One other item that could effect the shotcrete color is the fine aggregate. In general, the lighter color of the sand, the better for obtaining the earth tones. If dark colors of brown and black are desired, then darker sands should be evaluated. The other variable that may effect the final color of shotcrete is the cement selected. Since cement is the highest unit/volume cost material, it could be advantageous to use a pozzolan replacement for as much as 30 percent by volume. There are certain natural pozzolans which are produced commercially that may provide the desired color when used as a portion of the total cementitious material. These colors are normally associated with the light tan colors. When color pigment is added to the mixture, a reduction in strength can occur.

WHAT TEST RESULTS WERE OBTAINED?

The testing for three laboratory studies is consolidated in Tables 1-4. A summary of chart mortar mix properties for a sampling of the mixtures that used natural pozzolans for coloring are shown in Table 1. The colored pozzolan only tinted the final product and did not alter the appearance significantly. Each mix variation containing pozzolan was compared to a control run absent of pozzolans. The investigation used two different types of natural pozzolans supplied by Airox and Basalt Corporations and two suppliers of portland cement. It should be noted that Mix No. 1-6 used Lehigh, Type II and Mix No. 1A-6A used Sunlight, Type II. Corresponding compressive strengths of cube specimens at ages 7, 28 and 90 days are shown in Table 2. The compressive strengths indicate somewhat of a reduction for early ages of mixtures batched with Sunlight, Type II cement and this trend was typical through the 90-day breaks. The reverse was true for the Lehigh, Type II cement. The next colored shotcrete study discussed used Mix No. 7 with 13 batch variations of colored admixtures. The pigment colors were Iron

TABLE 1 — Summary of cast mortar mix properties

Lewiston Levees Project

	Cement		Pozzolan			Water			Admixture	
	CWT/yd	(k/m³)	%	lb/cu yd	(kg/m³)	W/C	lb/cu yd	(kg/m³)	Gal/cu yd	(kg/m³)
Mix 1	6.61	(392)	0	0	0	0.49	321.0	(190)	0	0
Mix 2	4.63	(275)	30	198	(117)	0.49	321.0	(190)	0	0
Mix 3	4.63	(275)	30	198	(117)	0.49	321.0	(190)	0	0
Mix 4	6.57	(390)	0	0	0	0.50	328.5	(195)	5.25	(43.73)
Mix 5	4.60	(273)	30	197	(117)	0.50	328.5	(195)	5.25	(43.73)
Mix 6	4.60	(273)	30	197	(117)	0.50	328.5	(195)	5.25	(43.73)
Mix 1A	6.61	(392)	0	0	0	0.49	321.0	(190)	0	0
Mix 2A	4.63	(275)	30	198	(117)	0.49	321.0	(190)	0	0
Mix 3A	4.63	(275)	30	198	(117)	0.49	321.0	(190)	0	0
Mix 4A	6.57	(390)	0	0	0	0.50	328.5	(195)	5.25	(43.73)
Mix 5A	4.60	(273)	30	197	(117)	0.50	328.5	(195)	5.25	(43.73)
Mix 6A	4.60	(273)	30	197	(117)	0.50	328.5	(195)	5.25	(43.73)

NOTES: (1) Cement — Mix 1-6, Lehigh II; Mix 1A-6A, Sunlight II.
(2) Pozzolan — Mix 2, 5, 2A, and 5A used Airox; Mix 3, 6, 3A and 6, 3A and 6A used Basalt.
(3) Aggregate — Ririe Sand, Southeastern Idaho, Cement/Aggregate Ratio 1:4.5 (by loose volume).
(4) Admixture — Liquid Sigunit, Sika Chemical Corporation.

TABLE 2 — Compressive strength

Lewiston Levees Project
Cubes 2 x 2 x 2 in. (51 x 51 x 51 mm)
Cement/Aggregate Ratio 1:4.5

	7-day		28-day		90-day	
	psi	(MPa)	psi	(MPa)	psi	(MPa)
Mix 1	2815	(19)	4625	(32)	5625	(39)
Mix 2	2925	(20)	4590	(32)	4990	(34)
Mix 3	2425	(17)	4535	(31)	5775	(40)
Mix 4	2275	(16)	3160	(22)	4225	(29)
Mix 5	2360	(16)	4210	(29)	5135	(35)
Mix 6	2350	(16)	4025	(28)	5210	(36)
Mix 1A	3575	(25)	3960	(27)	7835	(54)
Mix 2A	2750	(19)	4635	(32)	5565	(38)
Mix 3A	2650	(18)	4425	(31)	5625	(39)
Mix 4A	2875	(20)	4260	(29)	5750	(40)
Mix 5A	2530	(17)	4425	(31)	5550	(38)
Mix 6A	2585	(18)	4640	(32)	4665	(32)

TABLE 3 — Mix design studies for colored shotcrete

Lost Creek Project

		Color Admixture lb/cu yd (kg/m³)			
Mix No.	Batch No.	Iron Black Oxide	Red Oxide	Chocolate Brown	Alaskan Brown
7	1	2.0 (1.2)	1.0 (0.6)		
7	2				4.0 (2.4)
7	3			4.0 (2.4)	
7	4	2.0 (1.2)			
7	5	4.0 (2.4)	1.0 (0.6)		
7	6			8.0 (4.8)	
7	7	6.0 (3.6)			
7	8	22.5 (13.4)			
7	9	30.0 (17.8)			
7	10	37.5 (22.3)			
7	11	33.75 (20.0)			
7	12				45.0 (26.7)
7	13	30.0 (17.8)			45.0 (26.7)

NOTES: (1) Cement — 750 lb/cu yd (445 kg/m³) laboratory blend of Lehigh, Idaho, and Oregon type I and II Cement; water/cement ratio approximately 0.70 by weight.
(2) Aggregate — Blend of natural and crushed sand from Rogue River Basin. Cement/aggregate ratio 1:4 by weight.
(3) Admixture — Iron black and red oxide supplied by Frank D. Davis Co. and Grace Construction Materials Company supplied Chocolate and Alaskan Brown color pigment.

TABLE 4 — Summary of colored mortar mix properties

Lost Creek Project

			Colored Admixture g/Batch Run				
Mix No.	Run No.	Cement	Air Mortar wt. 16	Intense Brown	Chocolate Brown	Alaskan Brown	Linoleum Brown
8	20	(A)	768	1.25			
8	21	(A)	769	3.75			
8	35	(B)	769		1.25		
8	37	(B)	758		3.75		
8	50	(C)	755			1.25	
8	51	(C)	760			3.75	
8	53	(C)	764				1.25
8	54	(C)	761				3.75
8	87	(D)	779	1.25			
8	91	(E)	771	1.25			
8	92	(F)	759	1.25			
8	98	(G)	780	1.25			
8	99	(G)	781	3.75			

NOTES: (1) Cement legend — (A) Oregon II; (B) Trinity Warmtone; (C) Riverside White; (D) Columbia Buff; (E) Oregon Limelite; (F) Shasta Golden; and (G) Lone Star Buff.
(2) Mix design for colored mortar = 250 g cement; 687.5 g sand; 114-117 g water and 1.4-2.0 g AEA.
(3) Aggregate — Lost Creek manufactured sand.
(4) Admixture — all colored pigment supplied by Grace Construction Materials Company.

Black Oxide, Red Oxide, Chocolate Brown, and Alaskan Brown. The batch proportions are summarized in Table 3. The cement used was a laboratory blend of typical cements within the Pacific Northwest and color admixtures came from Frank D. Davis and Grace Construction Materials Companies as noted. A portion of an earlier study is shown in Table 4, Summary of Colored Mortar Mix Properties. The Mix No. 8 was held basically constant, except for variations in cement suppliers; and types and proportions of colored admixtures. There were seven different cement suppliers and four shades of brown coloring. Since there were two basic proportions 1.25 and 3.75 g, a comparison could be made for the various cement types. The mix variation with the lesser amount of colored pigment produced tints, and deeper tones were achieved when more pigment was used. The color tones were much richer when white or near white colored cements were used. Thus any premium for cement would have to be compared to added proportions of pigment color to see which alternate would be cost effective. It can be readily seen that any laboratory costs would offset an environmental impact. All color studies were performed by the North Pacific Division, U.S. Army Corps of Engineers, Materials Testing Laboratory.

WHAT CONCLUSIONS CAN BE DRAWN?

1. SHOTCRETE conveys a different meaning for different people.
2. SHOTCRETE may affect the Environmental Quality and should be evaluated early in planning a project.
3. SHOTCRETE has been used to correct many types of geological hazards or abnormalities.
4. SHOTCRETE coloring can be identified by laboratory study.
5. SHOTCRETE can be colored to provide an aesthetically pleasing structure or project.
6. SHOTCRETE laboratory study is a very small investment as compared to an adverse environmental impact.

WHERE CAN COLORED SHOTCRETE BE INSPECTED?

For the benefit of the doubting Thomases, successful colored shotcrete has been placed at the Ririe Dam in Southeastern Idaho and the Lower Granite Lock and Dam in Southeastern Washington. These applications were examples of rock slope stabilization and proved to be very effective in reducing the environmental impact. Typical samples of colored shotcrete over stabilization rock zones adjacent to the spillway channel and right abutment at Ririe Dam are shown in Fig. 2 and 3.

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