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Investigation of Natural Cementation to Mitigate Corrosion-Promoting Characteristics of Unsurfaced Roadways

Final Report on Project F10-AR06

David M. Bailey and Sean W. Morefield

July 2018

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Investigation of Natural Cementation to Mitigate Corrosion-Promoting Characteristics of Unsurfaced Roadways

Final Report on Project F10-AR06

David M. Bailey and Sean W. Morefield

*Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 6822*

Final report

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Under Project F10-AR06, "Accelerating Natural Cementation for Road Stabilization"

Abstract

Military ground vehicles operate in a variety of harsh terrains that subject their undercarriages and coatings to serious corrosion risk from abrasion by dust and impacts by gravel and rocks. This type of damage occurs on U.S. military service roads on training lands and in overseas areas of operation. Current expedient construction methods for such roads can be improved to reduce vehicle corrosion hazards by developing naturally cementitious material blends that effectively stabilize native soils. This report describes field and laboratory tests of an alkali-activated natural cement blend containing no Portland cement, which is costly to procure and transport to the remote locations where expedient roads are mission-required. The material, described as a roller-compacted chemically bound soil (RCCBS) technology, consists of local basalt aggregate from the demonstration site plus fly ash, imported lime, slag, and soda ash.

This material was used to construct two small test slabs at a Hawaii Army installation using different paving equipment. Also, a quarter-mile road bed was prepared for a production-scale batch, but the demonstration could not be completed because the RCCBS flash-set in the batch mixer and was unusable. The project return on investment was zero, and RCCBS cannot be recommended for use.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control (CPC) Project F10-AR06, “Accelerating Natural Cementation for Road Stabilization.” The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD (AT&L) Corrosion), Ismael Melendez (IMPW-E), and Valerie D. Hines (DAIM-ODF).

The project was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research Center, Construction Engineering Research Laboratory (ERDC-CERL). A portion of the work was performed by Mandaree Enterprise Corporation, Warner Robins, GA. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Michael K. McInerney, CEERD-CFM, was the ERDC CPC Program Coordinator. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

Christopher M. Moore, Stacy S. Holton, Dr. Charles A. Weiss, Jr., Samuel L. Craig, Dr. Robert D. Moser, and Dr. Philip G. Malone, ERDC Geospatial and Structures Laboratory (Vicksburg, MS), are acknowledged for their contributions to this project.

COL Bryan S. Green was the Commander of ERDC and David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms

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1 Introduction

1.1 Problem statement

Department of Defense (DoD) installations and ranges include a large inventory of unpaved roads. Heavy usage of these unsurfaced roads may result in dust particles that create wear on the vehicles that use them. For the military, the release of dust from unpaved roads can also pose a serious safety issue due to the reduction of visibility during movements convoys. The current practice on many military training lands is to suppress dust using dust-control products, many of which are produced with magnesium and calcium chloride salts. Such products, which are hygroscopic, keep the surface of the road moist (Rushing et al. 2006) by adding materials that agglomerate soil fines. A considerable problem with such currently available materials is that many are highly corrosive to exposed metals on vehicle undercarriages.

Depending on the location and purpose of utilitarian military service roads, acceptable functionality requires more than dust suppression. Soil stabilization, using binders that produce more durable surfaces, is needed to support heavy traffic loads while resisting fragmentation that can launch gravel, rocks, and other debris at moving vehicles. Such debris can create danger for vehicle passengers when it impacts windows, and also can inflict excessive wear on undercarriage mechanical systems and anti-corrosive paint systems. Paving with Portland cement concrete is the conventional solution in civil engineering applications, but for Army training service roads or expedient vehicle trails in an area of operation, Portland cement is generally too expensive and time-consuming to use expediently. Other market-available solutions aren't purpose-designed for military vehicle load requirements, and many do nothing to mitigate vehicle damage of the type described above. Also, like Portland cement, market-available soil stabilizers must be hauled to remote locations at a significant logistical cost. Some of these products also contain environmentally hazardous materials.

To address the Army's need for affordable and effective soil-stabilization technologies that maximize the opportunity for using indigenous soils instead of manufactured additives, the DoD Corrosion Prevention and Control Program (CPC) funded a field investigation to determine the

performance and cost of a “natural cement” formula that might structurally stabilize the surface of unpaved service roads. This natural cement uses alkali-activated glassy silicates and silicate-rich industrial byproducts, such as granulated blast-furnace slag and fly ash, that react with sodium carbonates, silicates, and lime to produce a hard, dust-free road surface.

1.2 Objective

The objective of this work was to demonstrate and validate the batching, mixing, and placement of this alkali-activated “natural cement,” described above, for effective stabilization of austere, semi-permanent military service roads in remote locations. A key aspect of the project was to scale up a laboratory-scale production protocol to support an acceptable real-world level of batching, mixing, and placement productivity and effectiveness.

1.3 Approach

The objective of the demonstration was to stabilize a 24 ft wide, half-mile length of the unpaved access roadway linking Bradshaw Army Air Field (AAF) to the Pohakuloa Training Area (PTA), HI. The field work was performed in two phases and supported by laboratory material strength testing.

The first phase of field work consisted of preparing two small test sections of unpaved road bed, then batching, mixing, and placing the demonstrated natural cement using two different techniques in order to determine the best methodology. The second phase of field work was executed under contract by a construction company, with the task being to prepare a road bed and stabilize a portion of the natural surface, as described above, to demonstrate and validate the efficacy of the natural cementation blend.

A laboratory testing program, performed independently under contract by the University of Hawai‘i at Manoa (Ooi and Coskey 2018), was executed using an alkali-activated natural-cementation formulation similar to the one used in the demonstration. The purposes of the testing were to characterize the individual components and as-blended mixture, and to perform standard compression and flexural testing on cured test specimens.

1.4 Metrics

The additives selected to stabilize the road were determined on the basis of soil-stabilization test protocols published in Unified Facilities Criteria 3-250-11; TM 5-822-14/AFJMAN 32/1019.

Criteria for success included confirmation of the mechanical strength of the field material by compression testing of sample cores. In order for the materials in this project to be used in expedient military road construction, as defined in FM 5-410 (Military Soils Engineering), they had to meet one of two minimum strength criteria. For successful use as a sub-base course, the material had to meet a minimum unconfined compressive strength of 200 psi (1.38 MPa). For use as a base course, the material had to meet a minimum unconfined compressive strength of 500 psi (3.45 MPa). For reference, concrete mixes for moderate-traffic roads in the United States are designed to meet a minimum 28-day unconfined compressive strength of 4,061 psi, or 28 MPa (AASHTO M 203).

1.5 Scope of execution

For reasons explained in the main body of the report (sections 2.3.3.2 and 3.1), this project produced only two small test slabs of roadway using the demonstrated natural cementation formulation. During execution of the scaled-up production of the formulation, critical difficulties occurred as the materials were being wet-mixed in the onsite batching plant. The exothermic heat of mixing was much greater it had been during mixing of the smaller batches for the test slabs. The resulting evolution of heat accelerated curing of the materials to such an extent that they flash set inside the mixer, destroying it. Consequently, the production-scale portion of the demonstration could not be completed.

2 Technical Investigation

2.1 Technology overview

The demonstrated material is a fine-grained, high-calcium glass sand combined with alkali additives such as fly ash, slag, lime, and soda ash to produce a cementing reaction that uses no Portland cement. Functionally, the material tested was somewhere between a dust palliative and a surface wearing course of Portland cement. FM 5-410, Military Soils Engineering, describes minimum road-performance requirements for varying military maneuvers. It includes specifications for dust palliatives, minimum pavement base and sub-base mechanical strengths, and surfaced pavement strengths.

Alkali-activation technology such as the material specified for this project has potential to serve as a sustainable, economical method for using reactive soils and waste glassy materials (e.g., slag or fly ash) to replace soil-stabilization methods using Portland cement. The demonstrated technology uses soils and industrial materials commonly found in theaters of operation around the world. It also has the advantage of potentially mitigating various causes of corrosion that degrade vehicles using military service roads. Properly specified blends can reduce chemical corrosivity potential of the bound soil and suppress paint-damaging impacts to vehicle surfaces by dislodged gravel or pavement fragments.

2.2 Chemical composition and proportions

The demonstrated material (i.e., alkali-activated cementation system) is referred to roller-compacted chemically bound soil (RCCBS). It is composed of native volcanic soil, ground granulated blast furnace slag (GGBFS), fly ash (FA), sodium carbonate (i.e., industrial chemical soda ash), and lime. Diversified Minerals, Inc., supplied the GGBFS (slag grade 120), that conformed to specification requirements in ASTM C 989 (2010). The chemical composition of the slag is provided in Table 1.

Table 1. GGBFS chemical composition.

Constituent	Mass (%)
Amorphous silica, hydrated	30–45
Calcium compounds	30–45
Magnesium compounds	8–15
Aluminum compounds	5–15
Sulfur	0–4
Iron compounds	0–1
Titanium compounds	0–1
Manganese compounds	0–1
Potassium compounds	0–1
Crystalline silica	0–0.2

The AES Hawaii coal power plant in Oahu, HI, donated the FA. Table 2 summarizes its chemical composition. The FA provided did not meet the requirements of ASTM C 618 (2010) Class F or C for use in Portland cement concrete.

Table 2. Fly ash (FA) chemical composition.

Constituent	Mass (%)
Alumina (Al_2O_3)	11–15
Calcium oxide (CaO)	5–22
Iron oxide (Fe_2O_3)	2–5
Silica (SiO_2)	59–63
Magnesium oxide (MgO)	Trace
Potassium oxide (K_2O)	Trace
Calcium sulfate (CaSO_4)	Trace

The sodium carbonate and hydrated lime needed for the RCCBS blend were laboratory-grade products sourced from commercial suppliers.

Quarrying, crushing, and grading of the native volcanic soil used in the mixtures was done at PTA. The gradation of the crushed native volcanic soil is shown in Table 3.

Table 3. Grain size distribution of native material.

Sieve Size		Percent Passing Limits	
Opening (in.)	Mesh No.	Lower	Upper
1.500	—	100	100
0.750	—	70	100
0.375	—	50	80
0.187	4	35	70
0.094	8	25	55
0.047	16	10	45
0.003	200	0	15

A summary of the mixture proportions for the RCCBS is shown in Table 4. Dry mixing of the individual constituents consisted of combining the volcanic soil, slag, FA, and lime together in a volumetric mixer. The sodium carbonate was premixed with water that was then added to the dry mix.

Table 4. Mixture proportions for RCCBS.

Material	Percentage of total dry weight
Volcanic Soil Material	77+2
Slag	9.2+2
Fly ash	4.6+2
Lime	4.6+2
Sodium carbonate	4.6+2

A water/material (w/m) ratio was used for the RCCBS mixture proportion instead of the standard water/cement (w/c) ratio used for Portland cement. This approach was taken because during mixing, the basalt aggregate breaks down and becomes a binder. Generally, a w/m ratio of 0.18 to 1 by weight of dry constituents is used for RCCBS mixtures. The activator used in the RCCBS mixture is a solution prepared by dissolving calcium hydroxide ($\text{Ca}(\text{OH})_2$) and sodium carbonate (Na_2CO_3) in the mix water, which generates a sodium hydroxide and calcium carbonate (CaCO_3) solution.

2.3 Construction procedure

This section describes the road-construction procedure as applied to two small-scale test patches

2.3.1 Batching and mixing process

The basalt aggregate was stored at the worksite in free-draining stockpiles for at least 24 hours immediately before use to facilitate continuous, uninterrupted operation of the mixing plant when the RCCBS was being placed

An onsite portable batching system was used to mix the constituents. It consisted of two material hoppers, a conveyor system, and a revolving-drum mixer. Once complete mixing was achieved, the material was placed within about 15 minutes, followed immediately by compaction.

2.3.2 Small-scale test slabs

2.3.2.1 *Mixing and placing*

The materials were dry-blended in the batch mixer and then placed dry on top of the prepared test slab base layer. The mixed RCCBS was placed and spread on each test slab using two different methods.

The first placement method used an asphalt paver (Figure 1) to deposit the material to a thickness of 9 inches (± 1 in.). The RCCBS was dumped from the mixer into the front-end loader, transported, and placed into the paver's hopper. Then the RCCBS was distributed evenly with two augers and leveled by the leveling bar as it was deposited.

Figure 1. Trial placement with asphalt spreader.

The asphalt spreader proved unsuitable for placing the RCCBS. The consistency of the material was more fluid and tackier than typical asphaltic material or roller-compacted concrete, so placement was somewhat uneven. Also, the asphalt spreader could not consistently place the material at the required thickness. The use of a conventional slip-form concrete paver might be more effective, but this was outside the project scope.

A road grader was used to achieve the desired thickness and crown. Subsequently, the teeth on the bucket of a front-end loader were used to put grooves (approximately 3–4 in. deep) into the dry material to promote thorough penetration and proper hydration of the dry-blended materials. The material was allowed to harden for approximately 8–10 minutes, after which water was applied to promote the cementation reaction, and the RCCBS was compacted to its required thickness and density.

2.3.2.2 Compaction, finishing, and curing

A self-propelled vibratory roller (Figure 2) was used to compact the RCCBS material to its required final thickness and density.

Figure 2. Self-propelled vibratory roller.

Compaction began within 10 minutes of spreading and was completed within 45 minutes of the time mixing had begun.

Applying more water to the surface test-slab 2 after final compaction prevented premature dehydration, and that appeared to improve curing strength and finish. (No additional water was added to test slab 1 after compaction.) Evidence of the continued reaction in the second slab was observed as mottled blue-green areas on the surface of the RCCBS in the days following placement. This coloration, which is not evident as such in Figure 3, indicates a continued reaction of the slag with other compounds.

The strength gain in slab 2 was confirmed, but not measured, in comparative trafficking after both slabs had fully cured. When a loaded water truck drove over the first test slab, braking action resulted in spalling and formation of several potholes in the first section. These types of surface distress are responsible for both dust formation and launching fragments of fractured pavement that can damage vehicle undercarriages and protective coatings. By contrast, braking action in trafficking trials over the second test slab produced no spalling or potholes.

Figure 3. Compacted RCCBS after curing.

2.3.3 Production-scale demonstration

2.3.3.1 Road bed preparation

The full-scale phase of the demonstration involved an attempt to apply RCCBS to a two-lane, quarter-mile section of a military access road linking Bradshaw Army Air Field with PTA. This phase of the work is described in the Appendix.

2.3.3.2 Batching and mixing difficulties

The intended workflow began with a wet mix in the onsite batching plant, followed by placement using the road grader and roller compaction. Based on the results for test slab 2, the plan included application of more water after compaction to promote curing.

Critical difficulties were encountered as the materials were being wet-mixed in the batching plant. The exothermic heat of mixing was substantially greater than what had occurred during mixing of the smaller batches for the test slabs. The resulting evolution of heat accelerated the curing of the materials to such an extent that they flash set inside the mixer, destroying it. Consequently, RCCBS was not applied to any part of the quarter-mile road bed and the field work came to an end.

2.4 Laboratory material testing program

The University of Hawai'i was contracted to perform laboratory testing and evaluation of an alkali-activated natural cementation material similar, but not identical, to RCCBS. (In practice, the composition of this type of a material would vary somewhat depending on the characteristics of indigenous materials available at a given worksite.) The laboratory testing included characterization of the constituent materials as well as unconfined compressive strength testing and flexural testing of the cured material. The results of the unconfined compressive strength of the cured material are included in section 3.2. A complete account of this testing program and its results is published separately as ERDC/CERL CR-18-1 (Ooi and Coskey 2018).

2.4.1 Compression test procedure

Mechanical tests were performed on cores from cured specimens of a laboratory mix very similar to the RCCBS field mix to determine unconfined

compressive strength. Three 76 mm diameter by 152 mm long cores were tested at two curing times (7 day and 28 days) to determine the compressive strength. The compressive strength tests were performed in accordance with ASTM C 39 (2010). The cylinders were sulfur-capped, and the caps were allowed to cool for 2 hours before testing (Ooi and Coskey 2018).

2.4.2 Flexural test procedure

The flexural tests were conducted using 152 mm by 152 mm by 533 mm saw-cut beams that were cured for 28 days. Testing was conducted in accordance with ASTM C 78 (Ooi and Coskey 2018).

3 Results and Discussion

3.1 Field investigation results

Based on trials in the field, it was determined that adding the water to the dry materials (basalt aggregate, slag, fly ash, lime and soda ash) during mixing of a production-scale batch resulted in flash setting and hardening in the drum mixer. The hardened RCCBS could not be completely removed from the mixer using electric concrete chipping hammers. The flash setting was caused by the scale of the exothermic reaction of the soda ash when mixed with water.

In order to identify and mitigate the cause of the excessive heat reaction, the soda ash was pre-dissolved in the mixing water in order to attempt dissipation of the heat generated from the exothermic reaction before adding it to the batch mixer. This procedure did reduce the amount of flash setting, but the flash setting that occurred during the first mixing attempt had already destroyed the onsite batch plant. The prime contractor halted the execution of the contract at that point and deemed the project “unconstructible,” thereby prematurely terminating the full scale field demonstration.

3.2 Laboratory test results

3.2.1 Compression test results

Once the cast cylinders were cured, density tests were run. Results were between 132–136 lb/cu ft with an average compressive strength of 12.1 MPa. Cylinders of lower density had compressive strengths of 7.9 and 11.3 MPa (Ooi and Coskey 2018).

The compression test results are presented in Table 5 (7-day cure) and Table 6 (28-day cure). Core samples taken from a test slab at the University of Hawai'i had an average 7-day strength of 4.20 MPa, and 28-day compressive strength of 7.46 MPa (Ooi and Coskey 2018).

Table 5. Specimen dimensions and 7-day unconfined compressive strength test results.

Sample ID	Avg. Diameter mm (in.)	Avg. Length mm (in.)	Compressive Strength MPa (psi)
A1	70.9 (2.79)	172.2 (5.6)	3.65 (530)
A2	70.9 (2.79)	172.2 (5.6)	4.69 (680)
A3	70.9 (2.79)	172.2 (5.6)	4.27 (620)
Average strength = 4.20 MPa (610 psi)			
Std. Dev = 0.52. (75.5)			

Table 6. Specimen dimensions and 28-day unconfined compressive strength test results.

Sample ID	Diameter mm (in.)	Length mm (in.)	Compressive Strength MPa (psi)
A4	70.9 (2.79)	142.2(5.6)	7.00 (1030)
A5	70.9 (2.79)	142.2(5.6)	7.75 (1140)
A6	70.9 (2.79)	142.2(5.6)	7.62 (1120)
Average strength = 7.46 MPa (1096.6 psi)			
Std. Dev = 0.40 (58.6)			

The unconfined yield strength in compression for the cores as tested by the University of Hawaii was 4.20 MPa for a 7-day cure with an average of 7.46 MPa for a 28-day cure. Therefore, the RCCBS material displays a structural strength similar to a low-strength concrete. For comparison, concrete mixes for moderate traffic roads in the U.S. are designed to meet a minimum 28-day compressive strength of 28 MPa. For soil stabilization of a road base course the minimum strength is 3.45 MPa, and 1.38 MPa for a sub-base course (FM 5-410, Table 9-4). The test results from the cores show adequate strength gain for both of these applications.

The data indicate that the compressive strengths are within the range previously observed for the RCCBS treatment of Hawaiian basalt soils (Muhunthan and Sariosseiri 2008; Allison et al. 2011; Hart et al. 2010). The values are twice the minimum unconfined compressive strength specified for a stabilized pavement base material (the required minimum for a Portland-cement soil cementation system) that used a 10% cement addition.

3.2.2 Flexural test results

The flexural test results are presented in Table 7 (28-day cure).

Table 7. Sample dimensions and 28-day flexural strength test results.

Sample ID	Width mm (in.)	Depth mm (in.)	Flexural Strength MPa (psi)
B1	155.2 (6.11)	154.1 (6.07)	3.07 (445)
B2	154.5 (6.08)	153.7(6.05)	2.21 (320)
B3	153.2 (6.03)	153.4 (6.04)	2.24 (325)
Average strength = 2.50 MPa (363.3 psi)			
Std. Dev = 0.49 (70.77)			
Support Span = 457.2 mm (18 in.) Nose Span = 76.2 mm (3 in.)			

The 28-day flexural strengths were approximately 34% of the 28-day compressive strengths. The data for compressive strengths of laboratory cored samples and the modulus of rupture obtained by Hart et al. (2010) showed a modulus of rupture that was 25% of the compressive strength.

3.3 Lessons learned

During placement of the small test slabs, the use of a conventional asphalt spreader proved to be unsuitable for the purpose. The consistency of the RCCBS material was more fluid and tacky than typical asphaltic material, so placement was somewhat uneven. In particular, the asphalt spreader could not consistently place the material at the required thickness.

During the scaled-up field test, the mixing of water with all the dry materials at once resulted in an unexpectedly high exothermic reaction that caused flash setting and hardening of the RCCBS, destroying the onsite drum mixer. Following this incident, the field team tried pre-dissolving the soda ash in the mixing water first, and this helped to dissipate the excessive heat before adding the solution to the rest of the materials. This approach reduced the amount of flash setting, and the result may serve as a point of departure for further investigation of scaling up to production levels.

4 Economic Summary

4.1 Costs and assumptions

Total actual costs for the execution of this demonstration project are shown in Table 8, as provided by the prime contractor, Mandaree Enterprise Corporation (Warner Robins, GA).

Table 8. Summary of actual costs for Project F10-AR06.

Category	Cost
Labor for project management and execution	\$152,433
Travel for project management, installation work, and monitoring	\$84,259
Batch Plant and equipment	\$92,034
Engineering and Environmental	\$80,829
Paving contractor, labor, equipment and materials	\$802,373
Total	\$1,211,928

In Chapter 3, section 3.1, it was explained why the technology could not be demonstrated as planned at the work location. Consequently, no economic benefit data were obtained from the project and no return on investment (ROI) could be calculated.

The two scenarios that follow, projecting the economic benefit the demonstrated technology versus current practice, are summarized from the original project management plan. The description of Scenario 2 does not represent an actual economic return on the PTA demonstration, but is offered to explain the potential return on a successfully implemented system at the time the project proposal was accepted.

Scenario 1 (Current Technology). DoD properties include 49,000,000 sq yd of unsurfaced roadways, which is the equivalent to 5,220 miles of road measuring 16 ft wide. The 2004 construction cost for conventional lime/cement stabilization of unpaved roads is \$6,500/mile (for two eight-foot-wide lanes). The 2004 six-month maintenance costs for conventional lime/cement stabilization of unpaved roads, which comprised blading and recompaction, included the following cost items per mile: \$2500 for labor, equipment, and stone; \$940 for a conventional stabilization product; and \$400 for traffic control. The activities yield a total of \$3,840/mile.

Natural stabilization can be applied to one fourth of the DoD unpaved road surfaces, which amounts to 1,305 miles of 16 ft roadway. The 2010 construction costs for natural cementation stabilization were estimated to be 75% of 2010 construction costs for conventional stabilization.

The maintenance interval for natural stabilization was assumed to be once every 9 months, as compared to once every 6 months for conventional stabilization. Costs for maintenance events for natural stabilization will be same as for conventional stabilization. An inflation rate of 3% was used to determine 2010 costs from 2004 costs. Resulting 2010 costs for conventional stabilization were estimated as follows: the construction cost is \$7,761 per mile, and the maintenance cost is \$4,585/mile.

Scenario 2 (Demonstrated Stabilization Technology). When this demonstration was proposed, prospective benefits of the new system were determined by using twice the \$4,585 annual maintenance costs for conventional methods versus 1.33 times \$4,585 annual maintenance costs of the demonstrated technology (9 month intervals). Those costs were extrapolated for a quantity of 1,305 miles to determine the dollar amounts in column E of Table 9 (next page). The expected service life for each stabilization method was assumed to be 6 years. After that period of time, complete restabilization would have to be performed.

4.2 Projected return on investment (ROI)

Because the technology could not be implemented and validated as planned, the actual ROI for this demonstration project is zero.

When this project was proposed in 2009, a favorable projected ROI of 48.58 was calculated based on the assumptions presented above and the guidelines prescribed by OMB Circular A-94 (OMB 1992). Table 9 reproduces the original calculations to illustrate the project team's conception of how costs and benefits would accrue over the 30-year analysis period. This figure is included to illustrate the potential size of ROI for technologies that could be scaled up to meet these Army demands in a cost effective way.

Table 9. Reproduction of original ROI calculation from F10-AR06 project management plan (September 2009).

Return on Investment Calculation

Investment Required			950,000
Return on Investment Ratio	48.58	Percent	4858%
Net Present Value of Costs and Benefits/Savings	18,481,068	64,634,005	46,152,937

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	10,128,000		7,596,000		7,099,222	9,465,629	2,366,407
2				4,009,000		3,501,461	3,501,461
3				4,009,000		3,272,547	3,272,547
4				4,009,000		3,058,466	3,058,466
5				4,009,000		2,858,417	2,858,417
6				4,009,000		2,671,197	2,671,197
7	10,128,000		7,596,000		4,730,029	6,306,706	1,576,676
8				4,009,000		2,333,238	2,333,238
9				4,009,000		2,180,495	2,180,495
10				4,009,000		2,037,775	2,037,775
11				4,009,000		1,904,676	1,904,676
12				4,009,000		1,779,996	1,779,996
13	10,128,000		7,596,000		3,152,340	4,203,120	1,050,780
14				4,009,000		1,554,690	1,554,690
15				4,009,000		1,452,862	1,452,862
16				4,009,000		1,357,848	1,357,848
17				4,009,000		1,269,249	1,269,249
18				4,009,000		1,186,263	1,186,263
19	10,128,000		7,596,000		2,100,294	2,800,392	700,098
20				4,009,000		1,035,926	1,035,926
21				4,009,000		968,174	968,174
22				4,009,000		904,831	904,831
23				4,009,000		845,498	845,498
24				4,009,000		790,174	790,174
25	10,128,000		7,596,000		1,399,183	1,865,578	466,394
26				4,009,000		690,350	690,350
27				4,009,000		645,048	645,048
28				4,009,000		602,954	602,954
29				4,009,000		563,665	563,665
30				4,009,000		526,783	526,783

5 Conclusions and Recommendations

5.1 Conclusions

Based on the results of the demonstrated roller-compacted chemically bound soil (RCCBS) cementation technology, the following conclusions are offered:

- a. The RCCBS technology as demonstrated created two small demonstration test patches that met the minimum strength requirements for expedient construction. Based on limited trafficking over test patch 2, the cured RCCBS appeared to inhibit dust formation and fractures that would present corrosion hazards to vehicles.
- b. The attempt to scale the technology up was unsuccessful because excessive heat produced during the larger-scale batching process caused flash-setting of the material, destroying the mixing equipment.
- c. The field test team found that it is possible to reduce the probability of flash setting of the RCCBS by mixing the water and alkali salts first, separate from the other reagents, and allowing the solution to cool off.
- d. The return on investment for this technology demonstration was zero.

5.2 Recommendations

5.2.1 Applicability

The demonstrated RCCBS technology is still at an experimental level of development and has no practical applicability.

5.2.2 Implementation

Because the demonstrated material formulation and application procedure have no practical use for stabilizing unsurfaced military service roadways, the technology cannot be recommended for implementation.

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Appendix: Supplementary Field Test Details

A.1 Preparation

The roadway surface was cleared and grubbed using a bulldozer. The roadway base was then brought to grade while simultaneously creating side-walls to confine the RCCBS later during placement. A 2 in. thick compacted base course was then placed on the roadbed. Prior to placing the RCCBS, the road base was lightly moistened using a large water truck. The preparation work is shown in Figures A1–A4.

Figure A1. Road condition prior to start of work.

Figure A2. Base layer placement at 2 in. thickness.

Figure A3. Prepared road base layer after rolling, showing 6 in. sidewalls for RCCBS edge restraint.

Figure A4. Mixing and material staging and storage area.

A.2 Material handling

A front-end loader was used to remove the basalt aggregate from the upper two-thirds of the stockpiles to minimize the inclusion of foreign debris in the mix. A front-end loader mixed the basalt aggregates in the stockpiles to blend materials prior to loading them into the bins of the batch plant.

All of the cementitious materials were transported from the suppliers in weather-tight super sacks and were placed individually on separate wood pallets. A tarp was also placed over the materials when in storage to protect them from the elements.

An onsite portable batching system was used to mix the constituents. The central batching unit was composed of two material hoppers and a revolving-drum mixer as shown in Figure A5. This batch plant allowed the production of a uniform and homogeneous mixture. The plant was located alongside the demonstration road bed to minimize time elapsing between mixing and placement. Once complete mixing was achieved, the material was placed with about 15 minutes, followed immediately by compaction.

To expedite batching operations, a material-dispensing rack was constructed (Figure A6). The rack provided a method to weigh the dry binder

materials prior to adding them to the mixer. The rack was designed to dispense the materials into a dump skiff that was placed on a pallet scale. The pallet scale was track-mounted to slide between two sacks, as shown in Figures A7 and A8.

To insure proper reaction of the RCCBS, mixing water meeting the requirements of COE CRD-C 400 (1963) was used. This is the same requirement used in standard concrete construction.

Figure A5. Onsite batching plant, consisting of portable mixer and two hoppers.

Figure A6. Preliminary testing of rack dispensing system design with weight scales.

Figure A7. Preparing rack dispensing system at the site.

Figure A8. Rack dispensing system in operation with scales.

The four pre-weighed binder materials were transferred from two dump skiffs into one of the two-batch plant hoppers, and the basalt aggregate was loaded in the other. The plant then proportionally transferred all of the materials into the mixer while adding the proper quantity of water. The plant was designed to dispense water into the mixer from only the “charging” end of the mixer, which initially caused a problem of poor wetting and subsequent mixing. To resolve this problem, the water-dispensing system was modified to spray water into the mixer at two locations. The addition of the second water nozzle decreased the water flow rate into the mixer and required adjustments of the hydraulic diverter valves to increase the flow rate being dispensed. After this modification, the plant was able to prepare the RCCBS mix as specified.

The mobile concrete batch plant dispensed the materials from the hoppers via a belt into a towable concrete mixer (as shown in Figure A5). A 3 cu yd mixer was used for mixing the material. The mixer had mechanically controlled dumping; hydraulic controls, rotatable barrel, and dump dispensing capability. The total amount of material batched per mixer was limited to 63% of the mixer’s capacity (for drum style mixers) to minimize wear on the mixer and optimize mixing action.

The hoppers of the batch plant’s main unit were loaded with the prepared basalt aggregate using a track-mounted end loader. The batch plant computer had built-in load cells to measure the specific mass of basalt aggregate material. Supplemental cementitious materials were pre-weighed into multiple sets of super sacks for efficient batching. These were measured at a separate auxiliary loading site with computerized digital scales and hoppers, and then were poured into the batch plant’s larger hopper above the conveyor belt.

Material batching quantities were weighed to the mixture proportions and tolerances listed in Table 4 (main body of report). The crushed basalt aggregates, cementitious materials, and water were conveyed to the mixer in proportions as required. The crushed aggregates and binder materials were charged into the mixer and dry-mixed for at least 15 seconds, as defined by the interval of time between the opening of the weigh hopper and the application of water. The water was added over a period of 10 minutes, and mixing continued for an additional 3 minutes. The drum speed of the mixer was maintained at the manufacturer’s recommended speed with the engine set at 2500 revolutions per minute. Mixer and mixer blade surfaces

were kept free of hardened RCCBS and other contamination by washing after each load and scraping the mixing blades, etc.

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14. ABSTRACT Military ground vehicles operate in a variety of harsh terrains that subject their undercarriages and coatings to serious corrosion risk from abrasion by dust and impacts by gravel and rocks. This type of damage occurs on U.S. military service roads on training lands and in overseas areas of operation. Current expedient construction methods for such roads can be improved to reduce vehicle corrosion hazards by developing naturally cementitious material blends that effectively stabilize native soils. This report describes field and laboratory tests of an alkali-activated natural cement blend containing no Portland cement, which is costly to procure and transport to the remote locations where expedient roads are mission-required. The material, described as a roller-compacted chemically bound soil (RCCBS) technology, consists of local basalt aggregate from the demonstration site plus fly ash, imported lime, slag, and soda ash. This material was used to construct two small test slabs at a Hawaii Army installation using different paving equipment. Also, a quarter-mile road bed was prepared for a production-scale batch, but the demonstration could not be completed because the RCCBS flash-set in the batch mixer and was unusable. The project return on investment was zero, and RCCBS cannot be recommended for use.					
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