GUIDELINES FOR CHEMICALLY STABILIZING PROBLEMATIC SOILS

FHWA/MT-20-002/9389-522/PMR

Performance Measures Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

April 2020

prepared by
Bhaskar Chittoori, Ph.D., P.E. | Boise State University |
Boise, ID

RESEARCH PROGRAMS

MDT

Guidelines for Chemically Stabilizing Problematic Soils

Performance Measures Report

Prepared by:

Bhaskar Chittoori, Ph.D., P.E.,

Associate Professor

Civil Engineering Department

Boise State University

1910 University Dr.

Boise ID 8372

Prepared for the

MONTANA DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

April 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/MT-20-002/9389-522		

4. Title and Subtitle Guidelines for Chemically Stabilizing Problematic Soils: Performance Measures Report	**5. Report Date** April 2020 **6. Performing Organization Code**
7. Author(s) Bhaskar C. S. Chittoori, Ph.D., P.E.	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Civil Engineering Department Boise State University 1910 University Dr. Boise ID 8372	**10. Work Unit No.** **11. Contract or Grant No.** Contract # 9389-522
12. Sponsoring Agency Name and Address Research Programs Montana Department of Transportation (SPR) 2701 Prospect Avenue PO Box 201001	**13. Type of Report and Period Covered** Final Report (April, 2017-April, 2020) **14. Sponsoring Agency Code** 5401

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. This report can be found at.(https://www.mdt.mt.gov/research/projects/geotech/chemical_stablize.shtml).

DOI: https://doi.org/10.21949/1518309

Preferred Citation:
Bhaskar C. S. Chittoori, 000-0001-8583-1003. 2020. Guidelines for chemically stabilizing problematic soils. https://doi.org/10.21949/1518309. United States. Montana Department of Transportation. http://dx.doi.org/10.13039/100009209

16. Abstract

The main goal of this project was to establish protocols for conducting efficient chemical stabilization design for problematic soils with and without soluble sulfates within the state of Montana. A major portion of chemical stabilization protocols involves the selection of type and amount of the additives. The proper selection of type and concentration of additive for a given soil should consider, the complex interactions between the mineralogy of the materials and additives, the presence or absence of moisture, and the method of construction and curing. Keeping this in mind several tasks were undertaken to meet the project goal. The study focused on lime and cement as additives and six different soils with varying geology were selected from different parts of Montana. This report contains a summary of the life cycle costs analysis performed as a performance measure for the different alternatives at MDT's disposal to tackle problematic soils.

17. Key Words	18. Distribution Statement
Problematic soils, soil stabilization, soil tests, sandy soils, clay soils, soil types, limestone soils, soil remediation, additives, calcium oxide, fly ash, soil samplers, mix design, cement, accelerating agent, curing and setting agents, freeze thaw durability, durability tests, wetting and drying tests, life cycle analysis	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	12	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER STATEMENT

This document is disseminated under the sponsorship of the Montana Department of Transportation (MDT) and the United States Department of Transportation (USDOT) in the interest of information exchange. The State of Montana and the United States assume no liability for the use or misuse of its contents.

The contents of this document reflect the views of the authors, who are solely responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or official policies of MDT or the USDOT.

The State of Montana and the United States do not endorse products of manufacturers.

This document does not constitute a standard, specification, policy or regulation.

ALTERNATIVE FORMAT STATEMENT

MDT attempts to provide accommodations for any known disability that may interfere with a person participating in any service, program, or activity of the Department. Alternative accessible formats of this information will be provided upon request. For further information, call 406/444.7693, TTY 800/335.7592, or Montana Relay at 711.

ACKNOWLEDGEMENTS

The author acknowledges the financial support of the Montana Department of Transportation, the technical oversight of the MDT technical panel formed for this project and the project manager.

TABLE OF CONTENTS

TABLE OF TABLES

INTRODUCTION

The Montana Department of Transportation (MDT) initiated this project, in 2017, to research and develop guidelines for chemical stabilization of problematic subgrade soils in the state of Montana. The research was conducted through the Sustainable and Resilient Geotechnical Engineering (SuRGE) lab at Boise State University (BSU) in coordination with technical panel from MDT. The goal of this project was to develop a comprehensive guideline to effectively and in an accelerated manner evaluate the suitability and concentration of chemical additives. A survey of stabilization practices of Department of Transportation (DOTs) neighboring the State of Montana indicated that many states surrounding Montana doesn't have much experience with chemical stabilization of subgrade soils. Thus, the stabilization guideline developed through this study will not only help MDT but provide a reference to the nearby states as well.

To develop a chemical stabilization guideline for tackling problematic soils, the research team studied the effects of lime and cement treatments on soils from six different locations in Montana. The six soils were named after their location of origin or plasticity characteristics: Great Falls (GF), Dry Creek (DC), Bad Route (BR), Chinook (CNK), North Three Fork-High Plastic (NTF_HP) and North Three Fork-Low Plastic (NTF_LP). The selected soils were stabilized referring to various existing guidelines on cement and lime treatment, and changes in physical, chemical and mineralogical properties were studied. The response of the soils to different additive types and contents were initially tested by targeting an unconfined compressive strength of chemically treated soils to a value of 50 psi. The treated samples were cured using various protocols and a new curing protocol was developed that reduced the standard curing time from 7 days to 1 day. The treated soil samples that passed the strength requirements were then tested for durability against freezing/thawing and wetting/drying cycles.

In an effort to understand the performance of stabilized soils in comparison to special borrow material (current MDT alternative when problematic soils are encountered) Life-Cycle Cost Analysis (LCCA) was conducted with a goal to help engineering managers make informed decisions on adopting appropriate methods to counter problematic soils. As a part of this task, several life-cycle cost analyses were performed on pavements designed for six subgrade types studied in this research. Pavement sections were designed for untreated subgrade, chemically treated subgrade, and special borrow replaced subgrade. This performance measures report summarizes these findings. More information on LCCA and methods can be found in Chapter 7 of the final report (https://www.mdt.mt.gov/research/projects/geotech/chemical_stablize.shtml).

Calculations

The life cycle cost comparisons were made based on typical flexible pavement sections designed using the 1993 AASHTO Guide and pavement design guidelines published by the MDT. The pavement sections were designed as a two-layer structure consisting of an asphalt layer surface and crushed aggregate base course (CAC). To incorporate the chemically stabilized subgrade, a 12-inch-thick stabilized soil subbase was assumed to be a part of the pavement structure.

Similarly, for the method of replacement with special borrow, which is currently preferred by MDT, a 12-inch-thick replaced subbase layer was assumed and the remaining pavement layer thicknesses were calculated.

80 kN (18,000 lb.) daily equivalent single axle loads (ESAL) of 200 and a design life of 20 years was assumed for the design of pavement alternatives. Initially, the thickness of the asphalt layer was chosen based on the daily ESAL, as recommended by the MDT guidelines for flexible pavement design. The thicknesses of the remaining layers were then chosen to satisfy the required design ESAL. Table 1 presents the different layer thicknesses for the untreated, chemically treated, and special borrow (replaced) alternatives calculated for the NTF_LP soil.

A 12 ft wide and 1-mile long pavement section was considered for calculating quantities of items involved in construction as well as repair and maintenance. The unit costs of items for construction and maintenance activities are the general cost averages used by the MDT.

Table 2 shows the construction costs calculated for the pavement alternatives in NTF_LP soil.

Table 1 Layer thickness for different pavement alternatives (NTF_LP)

Alternative	**Asphalt layer thickness (in)**	**CAC Layer thickness (in)**	**Subbase [Chemically treated/Special Borrow] (in)**
Untreated	4	14	N/A
Cement Treated	4	11	12
Special Borrow	4	8	12

Table 2 Construction costs for alternative pavement sections (NTF_LP)

Item Description	Quantity	Unit	Unit Cost	Cost
		Untreated Subgrade		
Asphalt	1531	ton	100	$ 153,105.91
Base	2738	cyd	28	$ 76,650.73
			Total	**$ 229,756.64**
		Cement Treated Subgrade		
Asphalt	1531	ton	100	$ 153,105.91
Base	2151	cyd	28	$ 60,225.57
Subbase	2346	cyd	15	$ 35,196.76
Cement	2.54	ton	165	$ 419.01
			Total	**$ 248,947.25**
		Special Borrow		
Asphalt	1531	ton	100	$ 153,105.91
Base	1564	cyd	28	$ 43,800.41
Special Borrow	2346	cyd	19	$ 44,582.56
Excavation and Haul	2346	cyd	10	$ 23,464.51
			Total	**$ 264,953.40**

The life cycle costs of the alternatives were compared based on changes in the long-term treatment and repair activities on the pavements over an analysis period of 40 years. The procedures suggested in the Interim Technical Bulletin published by FHWA (1998) titled "Life-Cycle Cost Analysis in Pavement Design" was followed for the analysis. The costs related to future activities in a project are accounted for by using the time value of money. A discount rate is used to convert the cost of future maintenance activities a pavement option into present value. The basic Net Present Value (NPV) formula for discounting discrete future amounts at various points in time back to a select base year is:

$$NPV = Initial\ Cost + \ Rehab\ Cost_k \times \frac{1}{(1+i)^{n_k}}$$

Where i = discount rate and n = year of expenditure

Table 3, Table 4 and Table 5 show the life cycle activities assumed for the alternative pavement sections on the NTF_LP soil and their corresponding NPVs.

Table 3 Life cycle cost of pavement on untreated subgrade (NTF_LP)

Age	**Activity**	**Quantity**	**Unit**	**Unit Cost**	**Cost**	**Discounted Cost @ 4%**
0	Construction				$ 229,756.64	**$ 229,756.64**
6	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 6,230.85**
9	Thin Overlay	*7039*	*syd*	*$ 2.24*	$ 87,498.45	**$ 61,475.25**
14	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 4,552.82**
18	Minor Rehab	*7039*	*syd*	*$ 14.95*	$ 105,237.48	**$ 51,948.18**
23	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 3,198.75**
30	Thin Overlay	*7039*	*syd*	*$ 2.24*	$ 87,498.45	**$ 26,977.41**
35	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 1,997.93**
40	End of Analysis (no residual value)				$ -	**$ -**
					NPV	**$ 386,137.82**

Table 4 Life cycle cost of pavement on cement treated subgrade (NTF_LP)

Age	Activity	Quantity	Unit	Unit Cost	Cost	Discounted Cost @ 4%
0	Construction				$ 248,947.25	**$ 248,947.25**
6	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 6,230.85**
9	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 5,539.20**
14	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 4,552.82**
18	Minor Rehab	7039	syd	*$ 14.95*	$ 105,237.48	**$ 51,948.18**
23	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 3,198.75**
30	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 2,430.79**
35	Crack Seal and Cover on 50% area	3520	syd	*$ 2.24*	$ 7,884.01	**$ 1,997.93**
40	End of Analysis (no residual value)				$ -	**$ -**
					NPV	**$ 324,845.77**

Table 5 Life cycle cost of pavement on special borrow (NTF_LP)

Age	Activity	Quantity	Unit	Unit Cost	Cost	Discounted Cost @ 4%
0	Construction				$ 264,953.40	**$ 264,953.40**
6	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 6,230.85**
9	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 5,539.20**
14	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 4,552.82**
18	Minor Rehab	*7039*	*syd*	*$ 14.95*	$ 105,237.48	**$ 51,948.18**
23	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 3,198.75**
30	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 2,430.79**
35	Crack Seal and Cover on 50% area	*3520*	*syd*	*$ 2.24*	$ 7,884.01	**$ 1,997.93**
40	End of Analysis (no residual value)				$ -	**$ -**
					NPV	**$ 340,851.92**

The above-mentioned procedures were followed to obtain NPVs for all alternatives on each of the six soils studied in the research. Table 6 shows the summary of life cycle costs calculated for pavement alternatives on all soil types. The highlighted cells represent the lowest cost alternative for each soil type. Chemically treated alternatives are the least cost alternatives on soils that passed the durability tests (CNK, DC, NTF_LP). Special borrow is the better cost alternative when the durability of chemical treatment is low (BR, GF and NTF_HP). The cost analyses in this study are based on assumptions about the long-term pavement activities that can depend on a large number of environmental factors and soil conditions. These alternatives should be validated with data collection from real world applications. Since the best cost alternative can change based on various factors including soil type, location and environmental conditions, LCCA must be conducted each time, before selecting the best method to deal with problematic soils.

CONCLUSIONS

Based on the results of LCCA, it can be concluded that using chemical stabilization on problematic soils is more advantageous than special borrow, if the durability of the treatment is high. When durability results are poor for chemical treatments, special borrow is more cost advantageous in the long term.

Table 6 Summary of Life Cycle Costs

Soil	Alternative	NPV at Discount Rate 4%
Great Falls (GF)	Untreated	$ 402,562.98
	Cement Treated	$ 366,485.31
	Special Borrow	$ 357,277.07
Dry Creek (DC)	Untreated	$ 402,562.98
	Cement Treated	$ 341,276.64
	Special Borrow	$ 357,277.07
Bad Route (BR)	Untreated	$ 386,137.82
	Cement Treated	$ 349,580.55
	Special Borrow	$ 340,851.92
North Three Forks – Low Plastic (NTF_LP)	Untreated	$ 386,137.82
	Cement Treated	$ 324,845.77
	Special Borrow	$ 340,851.92
North Three Forks – High Plastic (NTF_HP)	Untreated	$ 391,612.87
	Cement Treated	$ 354,987.65
	Special Borrow	$ 346,326.97
Chinook (CNK)	Untreated	$ 435,413.29
	Cement Treated	$ 374,061.71
	Special Borrow	$ 390,127.38

REFERENCES

FHWA. (1998). *Life-Cycle Cost Analysis in Pavement Design - Interim Technical Bulletin.* Washington DC: Federal Highway Administration.