SOIL STABILIZATION FOR LOW-VOLUME ROADS

VOL. 4: COST-BENEFIT ANALYSIS

Research, Development, and Technology

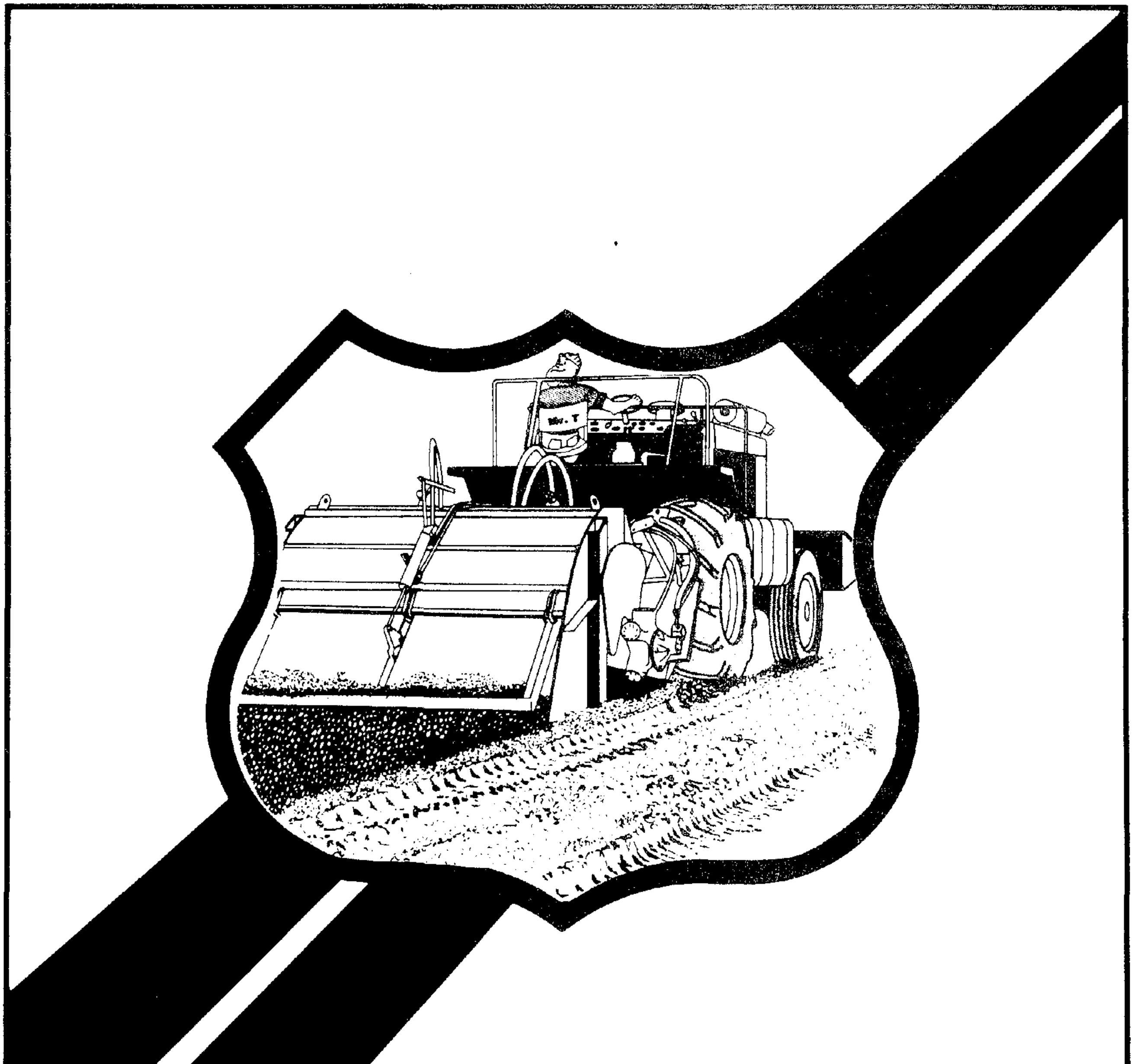
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

U.S. Department of Transportation

Federal Highway Administration

Report No.
FHWA/RD-86/099

Final Report
May 1986



FOREWORD

This report, FHWA/RD-86/099, discusses the results of research conducted by Sheladia Associates, Inc. for the Federal Highway Administration (FHWA), Office of Research, under Contract DTFH61-81-C-00004. The work was part of FCP Project 5M, "Rehabilitation and Maintenance of Low-Volume Roads." Volume 4 -- Cost Benefit Analysis contains information useful in studying the economic evaluations needed to determine if stabilization is a viable option in reducing highway construction costs.

The information in this report discusses the four commonly used methods of soil stabilization in six climatic regions representative of the United States. Cost analyses of stabilization alternatives versus non-stabilization techniques were based on comparison of present worth using assumptions for the interest rate and life cycle time. The alternative having the least present worth was the method generally favored. Some case studies were presented supporting the conclusion that soil stabilization is a preferred design option.

Copies of Volume 1--Executive Summary (FHWA/RD-86/096) and Volume 4 are being given widespread distribution by FHWA to Technology Transfer Centers through the Rural Technical Assistance Program. Additional copies of these reports along with Volume 2--Road Engineer's Guide (FHWA/RD-86/097) and Volume 3--Road Builder's Guide (FHWA/RD-86/098) can be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Richard E. Hay

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-86/099	PB87 134417/AS	

4. Title and Subtitle	5. Report Date
Soil Stabilization for Low-Volume Roads Volume 4 - Cost-Benefit Analysis	May 1986
	6. Performing Organization Code 82-203
7. Author(s) Pritam L. Arora, Lloyd Crowther, Golam Akhter	8. Performing Organization Report No. 203.6
9. Performing Organization Name and Address Sheladia Associates, Inc. 5711 Sarvis Avenue, 4th Floor Riverdale, Maryland 20737	10. Work Unit No. (TRAIS) 34B3-433
	11. Contract or Grant No. DTFH 61-81-C-00004
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Engineering & Hwy. Operations R & D 6300 Georgetown Pike McLean, Virginia 22101	13. Type of Report and Period Covered Phase II - FINAL September 1982-May 1984
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Project Manager - Roger M. Larson (HNR-20)

16. Abstract

Volumes 1, 2, and 3 of this report are guide booklets for administrators, road engineers, and road builders respectively. These guide booklets were developed to provide information on the use of four stabilization treatments, i.e., lime, asphalt, cement, and lime-fly ash in the construction of low-volume roads.

Volume 4, contained herein, documents the use and cost-benefits of the above referenced four soil stabilization treatments used in the construction of low-volume roads. A life cycle costing economic analysis procedure for evaluation of pavement alternatives, i.e.. gravel surfaced road and chip and seal surfaced road with and without the conditions of soil stabilization treatments is illustrated. A data base for 24 case histories with stabilization and equivalent pavement without stabilization is presented and anlyzed to show benefits of stabilization. The study concludes that to realize potential benefits, soil stabilization treatments should be considered as a design alternative in all climatic regions when specification materials are not available in abundance. Additionally, soil stabilization should also be considered: to provide less frost susceptibility; to provide conservation of good quality aggregates; to provide uniform strength for widening an existing roadbed; and to avoid raising the level of an existing roadbed.

17. Key Words	18. Distribution Statement
Cost-Benefit Analysis Low-Volume Roads Soil Stabilization Energy Demand Analysis	No restrictions. This document is available to the public through the National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	63	

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

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

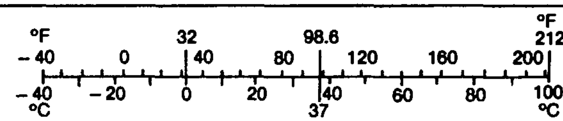
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

CONTENTS

VOLUME 4 - COST-BENEFIT ANALYSIS

LIST OF FIGURES AND TABLES

VOLUME 4 - COST-BENEFIT ANALYSIS

PAGE

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

BACKGROUND

Over 70% of this country's road miles are unpaved. Most of these roads need to be upgraded either to satisfy user's demand or to reduce excessive maintenance costs. American Road Builders Association's Education and Information Guide titled "Materials for Stabilization" (Ref. 1) recommends the consideration of soil stabilization as a tool for economic roadbuilding, conservation of aggregates, investment protection, and roadway upgrading. Inspite of these and other favorable recommendations, the application of soil stabilization treatments has not gained widespread consideration for upgrading of low-volume roads. The definition of low-volume roads adopted for this study is shown in Figure 1.

To promote the consideration of soil stabilization treatments and to realize its benefits a two phase study was initiated. The Phase I study provided for the identification of soil stabilization treatments; development of statistical data from federal low-volume road agencies i.e. US Forest Service, National Park Service, Bureau of Indian Affairs, Bureau of Land Management; development of case situations; and administration of a five member advisory panel to provide input in the development of work plan for Phase II. A two day project review and progress session was held in November 1981. Reference 2 provides a brief report of this two day review session. The Phase I Final Report (Ref. 3) titled "Roadbed Soil Stabilization" was submitted to the Contract Manager in May 1982.

As a result of Phase I progress review session, the Phase II statement of work was finalized in August 1982 and Phase II study was initiated in September 1982. This document titled,

Low-Volume Roads Definition

Low-Volume Roads are Service Roads in a Particular Area

Designed and Constructed with Minimum Serviceability Requirements

As Necessary and Sufficient to Enable All Vehicles Common to the Area

To Travel Unassisted and Safely with Reduced Priority for Speed and Comfort

Figure 1

"Volume 4 - Cost-Benefit Analysis" is one of four documents comprising the project Phase II Report. Volume 1 - Executive Summary, Volume 2 - Road Engineer's Guide, and Volume 3 - Road Builder's Guide are three separate documents representing the Phase II report.

PURPOSE

The cost-benefit analysis of low-volume road pavements with and without the condition of soil stabilization was to document the value received for expenditures made to stabilize roadway soils. The purpose of this analysis was to provide justification for the use (or non-use) of soil stabilization under specific climate and availability of materials.

SCOPE OF WORK

The scope of work for this study required accomplishment of the following tasks:

1. Case study selection and data collection for 24 potential case situations to represent four stabilization treatments (lime, asphalt, cement, and lime-fly ash) in each of six climatic regions and identification of equivalent nonstabilized road sections. The six climatic regions are shown in Figure 2.

2. Conduct cost-benefit analysis of the selected case studies to document the value received for expenditures made to stabilize roadway soils.

3. Summarize cost-benefit analysis to provide justification for the use (or non-use) of soil stablization under specific climate and availability of materials.

FIGURE 2

SIX CLIMATIC REGIONS IN THE UNITED STATES FOR USE IN HIGHWAY TECHNOLOGY

As defined by University of Illinois

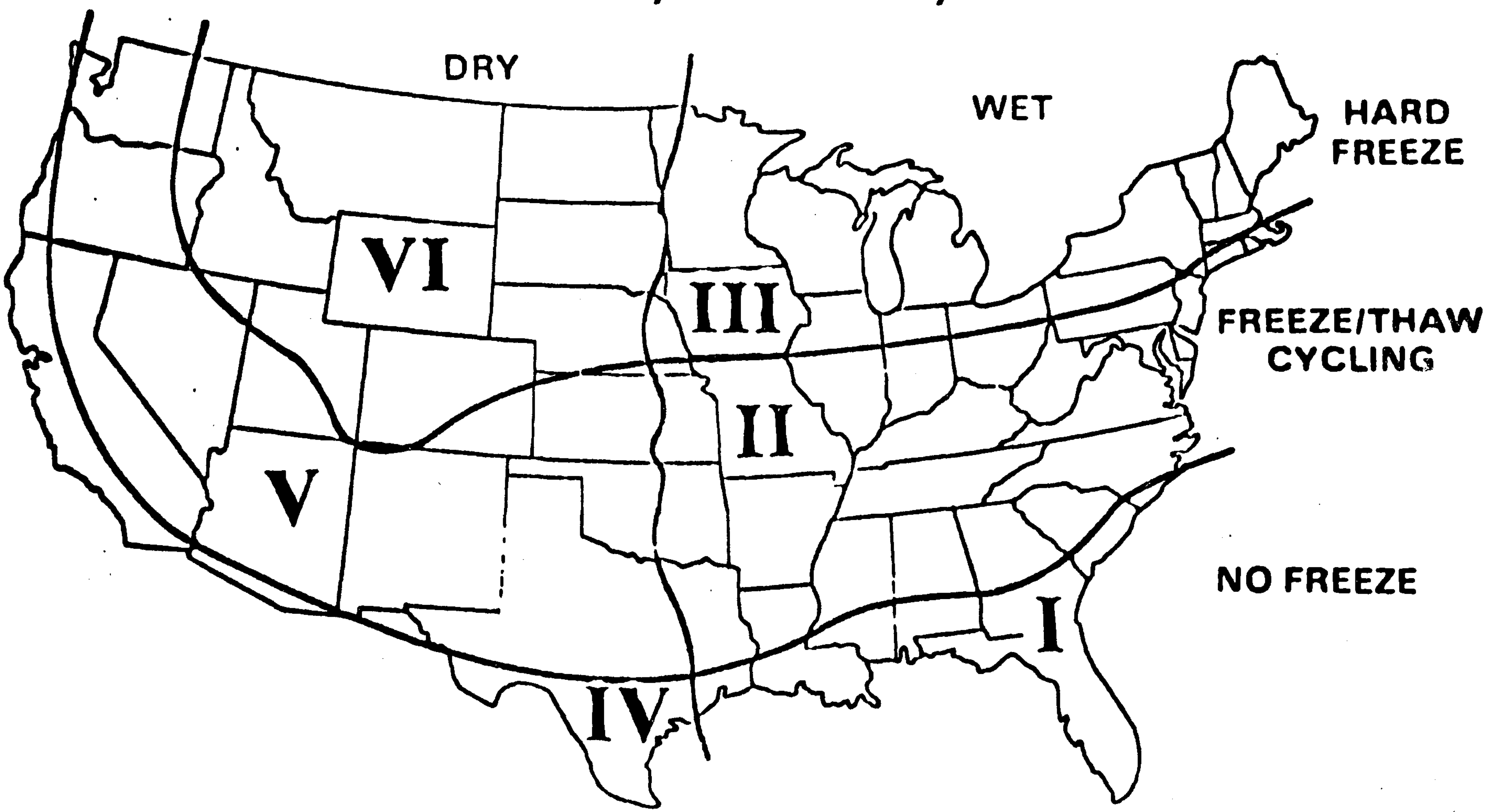


FIGURE 2

SIX CLIMATIC REGIONS IN THE UNITED STATES FOR USE IN HIGHWAY TECHNOLOGY

As defined by University of Illinois

	NO FREEZE	FREEZE/THAW CYCLING	HARD FREEZE
WET	I	II	III
DRY	IV	V	VI

Thornthwaite Index = Zero

Freezing penetrates 5 inches

Freeze Index endures 60 days per year

4. Development of detailed methodology to conduct economic analysis.

5. Development of energy consumption comparison for selected case situations with stabilization and equivalent pavement without stabilization.

METHODOLOGY

The study approach to develop potential case situations included review of available information compiled in Phase I. This review provided a basis to select eight states to represent six climatic regions and to cover four stabilization treatments (lime, asphalt, cement, and lime-fly ash). A listing of the selected states and corresponding climatic region is as follows:

No.	State	Climatic Region
1.	Florida	I
2.	Idaho	VI
3.	Illinois	II & III
4.	Iowa	III
5.	New York	III
6.	Oregon	V
7.	Texas	IV & V
8.	Virginia	II

All county as well state highway departments of the above listed eight states were surveyed for the use and non-use of soil stabilization treatments. This survey identifed almost all the case situations and reasons why soil stabilization was not used. Additional contacts included US Forest Service Region 6, National Lime Association, National Ash Association, Asphalt Institute, Portland Cement Association, Phase I study advisory panel members, and some soil testing laboratories. In addition, several state, county and local highway officials were contacted to provide input with respect to the use of soil stabilization treatments and identification of local design standards for low-volume road pavements.

The project characteristics such as traffic, location, and type of treatment were screened to select localities for site visits. The site visits were coordinated with respective contact officials. The information collected from these site visits and interviews with road officials was catalogued to form the data base.

The current design practices whether rule of thumb designs or formal pavement design procedures utilize equivalency factors for various materials to develop pavement material options. The American Association of State Highway and Transportation Officials (AASHTO) Interim Pavement Design Guide (Ref. 4) lists values of structural layer coefficients for various materials. Reference 5 (Design Guide for Secondary Road Pavements in Virginia) lists equivalent layer thicknesses for pavement materials including aggregates and soil stabilization treatments. Using local equivalency factors, the equivalent pavement design with full depth crushed aggregtes was developed for each of the case situation. The full depth crushed aggregate base course represented the pavement condition without stabilization. Due to generally high cost of full depth bituminous concrete or cement concrete, these pavement options were not considered in the analysis.

The life cycle costing criteria of comparing present worths was selected to document benefits of using soil stabilization treatments. This approach simply means that stabilization should be used when it results in the lowest present worth. The energy analysis was conducted by comparing the energy demand required for pavement with and without stabilization. Reference 6 was used to calculate the energy demand for both conditions with and without stabilization.

Low-volume roads using soil stabilization treatments require some type of seal coat. For the most part one or more coats of chip and seal can provide satisfactory service. For the purposes of this report the equivalent pavement design without stabilization was assumed to be of full depth crushed aggregates or gravel base meeting specifications and having the same seal coat as the pavement with stabilization.

The low-volume unpaved or gravel surfaced roads may also provide satisfactory service for low traffic volumes. However, these gravel surfaced roads require seasonal grading, blading, and application of dust control agents. Regravelling is also required about every 2 to 4 years to replace gravel loss of approximately 1/2" to 1" per year. As traffic volume and intensity increase, the gravel surfaced roads generate more road users complaints such as dusting, flying stones, noise, poor riding quality, increased damage to vehicles and increased travel time. In addition, to provide safe and satisfactory service maintenance costs also increase. The excessive maintenance costs and road users' complaints can be eliminated by upgrading an unpaved road. The upgrading options for unpaved roads should consider the use of both pavement options with and without stabilization. An economic analysis excluding user costs should be conducted to identify the most cost effective approach. The data base does not contain case histories of earth or gravel surfaced roads, however, an economic analysis method is detailed to conduct such an analysis.

COST-BENEFIT ANALYSIS

GENERAL

The main objective of the cost-benefit analysis is to provide information with respect to cost-effectiveness of feasible options. It should be noted that the analysis solution is only a numerical quantity that is used as a tool in reaching the ultimate decision and is not the decision in itself.

For comparing cost-effectiveness of feasible pavement options, Reference 7 (Highway Engineering Economy) recommends four common methods for comparing economic worth of alternative proposals. These methods include:

(1) Comparison of present worth of costs
(2) Comparison of equivalent uniform annual costs
(3) Ratio of annual benefit to annual cost
(4) Rate of return on investment

The use of each method will lead to the selection of the same alternative as being the most advantageous economy-wise. These methods of analysis require the use of standard compound interest formulae to derive a solution. These formulae require the use of i (interest rate/period), n (analysis period), and cash flow disbursements throughout the analysis period.

The technique of comparing present worth of costs is the method selected for the purposes of this report. In this method the alternative having the minimum present worth is selected. The present worth represents the sum which would be required at the present date to finance all future outlays at their appropriate dates. The analysis period must be equal for all alternatives being considered.

ASSUMPTIONS AND DATA REQUIREMENTS

Values are estimated for the values of i, n, and cost components such as administration, construction, maintenance, and user costs. The administration and user costs for pavement options with and without stabilization are generally eliminated; i.e. these costs are assumed to be the same for both options. These costs are generally difficult to define. The interest rate can be estimated based on the probable rate of interest to be paid on long term borrowing by the concerned agency. For this report, an i of 8% per year has beem assumed. The analysis period n is generally taken to be 20 years for paved roads. If present worth cost is to be computed only for gravel surfaced roads, the analyis period of 10 years may be considered more reasonable. The construction costs should be estimated based on prevailing unit prices for various materials, transportation, labor, and equipment costs. The maintenance costs for gravel surfaced roads should include grading, application of dust control, and regravelling to satisfy road serviceability requirements. The maintenance costs for chip and seal surfaced roads with or without soil stabilization should include chip and seal coat. The frequency of maintenance activities and its costs should be based on local experience.

ILLUSTRATIVE PROCEDURE

To illustrate the use of life cycle costing in the decision process, let's assume that three pavement alternatives A, B, and C have been developed for upgrading a one mile section of a gravel surfaced low-volume road. It is assumed that each alternative will provide a satisfactory service level for 20 years; user costs, administrative costs, and residual value are considered same in all alternatives and therefore not analyzed. It is assumed that for each alternative routine inspections, spot patching, grass mowing, shoulder and drainage improvements, if required, will made during the 20-year life, and cost is considered same for all three alternatives. These costs are thus excluded from the analysis.

Alternative A, existing gravel surfaced road without stabilization, provides for no new improvement to the road. Under this alternative it is estimated that the road will require 2 inch compacted gravel to meet minimum serviceability requirements, six gradings per year, six applications of a dust control agent per year, and regravelling (2 inch compacted gravel) every 3 years.

Alternative B, chip and seal surfaced road with stabilization, provides for the upgrading of road by the use of 6 inch soil cement (in place mixing to a strength of 400 psi) and one layer of chip and seal coat. Soil cement is used for illustration only, the appropriate stabilization agent and its rate of application should be determined based on soil inspection and/or analysis. The estimated pavement maintenance includes application of a chip and seal coat every 5 years.

Alternative C, chip and seal surfaced road without stabilization, provides for the upgrading of road by the use of 6 inch depth specifications material of crushed aggregate base and one layer of chip and seal coat. The estimated pavement maintenance includes application of chip and seal coat every 5 years.

Having defined the feasible alternatives including construction and maintenance strategies, the next step is to estimate the appropriate values for i and n. For this illustration, i of 8% per year and n of 20 years have been used.

A summary of estimated costs for each alternative is now developed. The cost estimates, as a rule, should include construction, maintenance and other costs which will be required to provide the desired service over the analysis period. The present worth analysis for alternatives is shown in Table 1A, 1B, and 1C. A summary of present worths for these alternatives is shown in Table 1D.

The equivalent pavement design for conditions with and without stabilization can be computed by using appropriate thickness equivalency values for materials under consideration. A general correlation of thickness equivalency values is shown in Table 2.

COMMENTS

Alternative B, chip and seal surfaced road with stabilization, has the least present worth of $5.92/square yard (sy). During the 20-year analysis period, Alternative B would provide a net saving of $1.75/sy (7.67-5.92) over Alternative A and $1.55/sy (7.47-5.92) over Alternative C. These savings are in constant dollars for year of construction as the base year. For one mile long and 22' wide road section, the total net savings for Alterntive B are estimated to be approximately $22,587.00 (1.75 x 5280 x 22 x 1/9).

Alternative B with stabilization also provides conservation of good quality aggregates. For one mile long and 22' wide section, the net savings in aggreagates are estimated to be approximately 4,000 tons when compared with Alternative C and approximately 10,000 tons when compared with Alternative A.

It should be noted that the present worths are sensitive to the value of i. It is suggested that this value should be carefully selected. It should never be zero. Those who believe that the money used for road improvements is not borrowed and thus i of 0% is justified do not realize the opportunity cost of

TABLE 1A

PRESENT WORTH ANALYSIS OF ALTERNATIVES

ALTERNATIVE A - EXISTING GRAVEL SURFACED ROAD WITHOUT STABILIZATION

COST COMPONENT		COST PER SQUARE YARD	
1. Initial Construction - Referenced time period			
1.1	Gravel (2" compacted) @ source	$ 0.80	
1.2	Haul 25 miles @ $0.10/mile/ton	0.25	
1.3	Manipulation	0.15	
	Total initial construction cost or present worth		1.30
2. Maintenance Activities			
2.1	Grading 6 times per year @2.5¢/Grading	0.15	
2.2	Dust Control (optional) 6 times per year @ 2¢/application	0.12	
2.3	Regravelling (2" compacted) every 3 years	1.20	

Calculations of present worth of maintenance costs

Performed every year: Grading and application of dust control agent activities are performed every year. The yearly cost to perform 2.1 and 2.2 are assumed to be $0.15 and $0.12 per square yard respectively. Hence, the total cost is assumed to be $0.27 per square yard.

The present worth to perform annual application for n years is calculated as follows:

PWM_n = PDC times P/A

where, PWM_n = Present Worth of annual cost to perform annual maintenance for n years (n is 20 years in this illustration)

PDC = Present Day Cost (at time of construction)$0.27 in this illustration.

P/A = Present Worth Factor obtained from appropriate interest rate table in Appendix. Table for i=8% is used in this illustration.

= 9.82 from P/A column for n=20 year

The present worth to perform annual maintenance for 20 years is:

PWM_{20} = 0.27 x 9.82 = 2.65 ———— 2.65

Performed every three years: Regravelling by adding 2 inches of additional gravel is performed every 3 years. For this illustration, the Present Day Cost to perform this maintenance activity is assumed to be $1.20 per square yard.

The present worth to perform regravelling every 3 years for n years is calculated as follows:

PWM_n = PDC times sum of P/F

where, PWM_n = Present worth of all maintenance costs for n years (n is 20 years in this illustration)

PDC = Present Day Cost (at time of construction) of maintenance activity to be performed every 3 years = $1.20 in this illustration

Sum of P/F = Sum of P/F factors obtained from P/F column in Appendix for i=8%. This sum is calculated as follows:

Maintenance Performed in year (n value)	P/F
3	0.79
6	0.63
9	0.50
12	0.40
15	0.32
18	0.25
20*	0.21
Sum of P/F =	3.10

(*) Regravelling is assumed to be performed in the 20th year instead of 21st year.

The present worth to perform maintenance activity 2.3 for 20 years is PWM_{20} = 1.20 x 3.10 = ———— 3.72

Total present worth of construction and maintenance for 20 year period ———— 7.67

TABLE 1B

PRESENT WORTH ANALYSIS OF ALTERNATIVES

(ALTERNATIVE B - CHIP AND SEAL SURFACED ROAD WITH STABILIZATION)

COST COMPONENTS	COST (PER SQUARE YARD)	
1. Initial Construction - Referenced Period		
1.1 Cement delivered to site (30 lbs/per sq. yd)	$ 1.20	
1.2 Manipulation	1.25	
1.3 Chip & seal coat	1.30	
Total initial construction cost or present worth ------------------------------		3.75

2. Maintenance Activity

2.1 Chip & seal coat every 5 years (item 1.3)

Calculation of present worth of maintenance costs

Formula PWM_n = PDC times sum of P/F, where PWM_n, PDC and P/F are defined in Table 1A.

PDC = 1.30 (item 1.3)

Sum of P/F = Sum of P/F factors obtained from P/F column of appropriate interest rate table in Appendix for i=8% as shown below:

Maintenance Performed in year (n value)	P/F
5	0.68
10	0.46
15	0.32
20	0.21
Sum of P/F =	1.67

Present worth to perform maintenace activity 2.1 for 20 years is PWM_{20} = 1.30 x 1.67 = ---------------------- 2.17

Total present worth of construction and maintenance --- 5.92

TABLE 1C

PRESENT WORTH ANALYSIS OF ALTERNATIVES

(ALTERNATIVE C - CHIP AND SEAL SURFACED ROAD WITHOUT STABILIZATION)

COST COMPONENTS		COST (PER SQUARE YARD)
1. Initial Construction - Referenced Time Period		
1.1 Crushed Aggregates to site (6" compacted)	$ 2.75	
1.2 Haul 25 miles @$.10/ton/mile	0.75	
1.3 Manipulation	0.50	
1.4 Chip and Seal Coat	1.30	
Total intial construction cost or present worth		5.30

2. Maintenance Activity

2.1 Chip & seal coat every 5 years (item 1.4)

Calculation of present worth of maintenance costs

Formula PWM_n = PDC times sum of P/F, where PWM_n, PDC, and P/F are defined in Table 1A.

PDC = 1.30 (item 1.4)

Sum of P/F = Sum of P/F factors obtained from P/F columns of appropriate interest rate table in Appendix B, for i=8% as shown below:

Maintenance Performed in year (n value)	P/F
5	0.68
10	0.46
15	0.32
20	0.21
Sum P/F =	1.67

Present worth to perform Maintenance activity 2.1 for 20 years is PWM_{20} = 1.30 x 1.67 = ------------------------------- 2.17

Total present worth of construcation and maintenance ---- 7.47

TABLE 1D

PRESENT WORTH ANALYSIS OF ALTERNATIVES

(SUMMARY)

ALTERNATIVE	PRESENT WORTH FOR i = 8%, n = 20 YEARS
A - Existing Gravel Surfaced Road Without Stabilization	7.67
B - Chip & Seal Surfaced Road with Stabilization	5.92
C - Chip and Seal Surfaced Road without Stabilization	7.47

TABLE 2

THICKNESS EQUIVALENCY VALUES

Based on review of literature and interviews with county and state highway agencies a general correlation for various materials presented in this booklet is as follows:

1)	Crushed Aggregate	1"
2)	Soil-lime, soil-cement, soil-asphalt, or soil-lime-Fly ash	1"
3)	Aggregate-asphalt or Aggregate-cement	1.5"* to 2.0"**
4)	Soil-Aggregate-lime-fly ash, Soil-Aggregate -Cement, or Soil-Aggregate-Asphalt	1.5"* to 2.0"**

* Road Mix
**Plant Mix

NOTE: The thickness equivalency values varies depending upon the design strength of the mix and quality control during construction. The state highway design guides can be used to determine thickness equivalency values for materials used in developing pavement alternatives.

using the money. One of the basic principles of economic analyses is a realization of the time value of money.

The impact of inflation has not been taken into account. The maintenance costs are likely to be higher if inflation is considered. From a comparison point of view, this should not substantially affect the outcome. Therefore, the economic analysis can be made using present day costs.

P/F and P/A values for interest rates 4% to 15% and for n values up to 20 years are included in the Appendix. P/F and P/A values for any particular i and n can also be calculated by the use of the following formulae.

$$\frac{P}{F} = \frac{1}{(1 + i)^n} \quad \text{and} \quad \frac{P}{A} = \frac{(1 + i)^n - 1}{i\,(1 + i)^n}$$

For i = 8% per year and n = 20 years, P/F and P/A are computed as follows:

$$\frac{P}{F} = \frac{1}{(1 + .08)^{20}} = 0.21 \quad \text{and} \quad \frac{P}{A} = \frac{(1 + .08)^{20} - 1}{.08\,(1 + .08)^{20}} = 9.82$$

Using i = 8% table in the Appendix will also give the same values of P/F and P/A. It should be noted that to simplify calculations these values can be rounded off to two decimal places.

CASE HISTORIES

GENERAL DATA

Figure 3 shows the location, climatic region, and the stabilization agent for 24 case histories. These case histories document the nationwide use of four commonly used stabilizers (lime, asphalt, cement, and lime-fly ash) in the construction of low-volume roads. In addition, the use of cement-fly ash is also documented.

Consideration of about 50 possible sites plus information obtained during the site visits was necessary to provide a better understanding and distribution of case histories. Lime-fly ash projects in Texas and Virginia were built for experimental purposes. Due to the limited use of lime-fly ash, these projects have been considered for documentation. Some states in the climatic Region VI indicated no use of soil stabilization treatments. This probably was due to the abundance of aggregates as well as long periods of freezing temperatures. Several jurisdictions have used both calicum chloride and magnesium chloride as stabilization agents. These materials can also be used as dust control agents on earth or gravel surfaced roads.

The general data of case histories is presented in Table 3. This table shows project title, location, designer, builder, climatic region, and type of soil stabilization treatment used for base and/or subbase. In addition, the source of project funding is also indicated. The percentage of aggregates, in the pavement design as-built, was estimated based on discussions with contact officials.

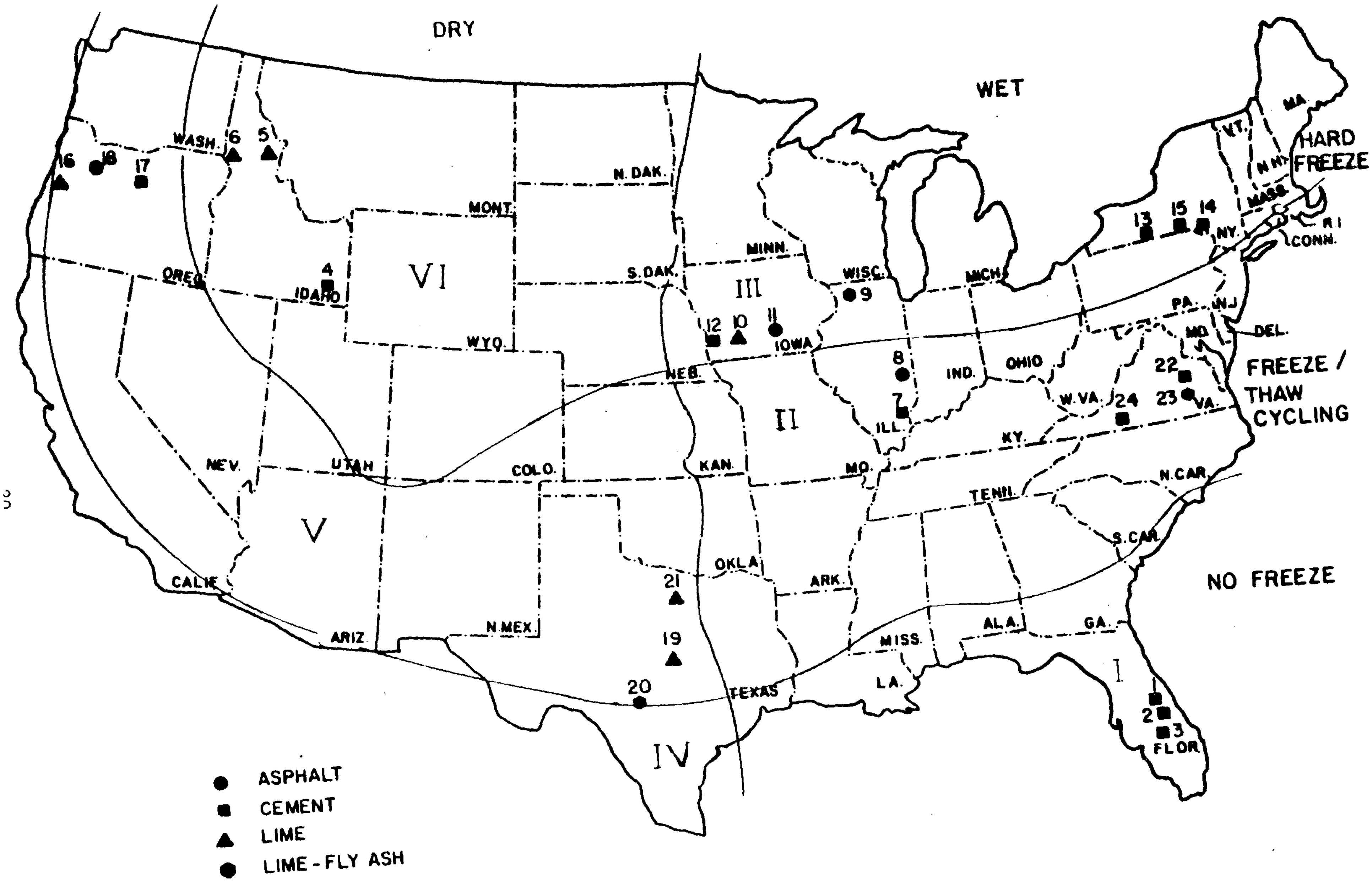


FIGURE 3 LOCATION OF CASE HISTORIES

TABLE 3

GENERAL DATA FOR CASE HISTORIES

CASE HISTORY	TITLE AND LOCATION	DESIGNED BY	BUILT BY	SOURCE OF FUNDING	CLIMATIC REGION	BASE/SUBBASE TREATMENT
1. FL.	Boyce Avenue, Orange County, Floria	Consultant	Contractor	County	Wet-No Freeze (I)	Soil-Cement (5%)
2. FL	Columbia Avenue, Osceola County, Florida	Consultant	County	County	Wet-No Freeze (I)	Soil-Cement (12%)
3. FL	SW 10th Street, Okeechobee, Florida	State	County	County	Wet-No Freeze (I)	Aggregate-Cement (7%)
4. ID	Siphon Road, Bannock County, Idaho	County	County	County	Dry-Hard Freeze (VI)	Soil-Aggregate-Cement (60%, 5%)
5. ID	State Highway No. 8, Clearwater County, Idaho	State	Contractor	Federal(84%) State (16%)	Dry-Hard Freeze (VI)	Soil-Aggregate-Lime (25%, 2%)
6. ID	State Highway No. 7, Nez Perce County, Idaho	State	Contractor	Federal(84%) State (16%)	Dry-Hard Freeze (VI)	Soil-Aggregate-Lime (25%, 4%)
7. IL	County Rt. 29, White County, Illinois	County	County	County	Wet-Freeze Thaw (II)	Soil-Aggregate-Cement (15%, 10%)
8. IL	County Rt. 1, Vermillion County, Illinois	County	Contractor	County	Wet-Freeze Thaw (II)	Aggregate-Asphalt (4%-Recycled)
9. IL	Rose Street, Stephenson County, Illinois	Consultant	County	County	Wet-Hard Freeze (III)	Soil-Aggregate-Lime-Fly Ash (20%, 4%, 12%) (Ref. 8)
10. IA	County Rt. G-61, Adair County, Iowa	State	Contractor	State(80%) County(20%)	Wet-Hard Freeze (III)	Soil-Lime (4%, Subbase)
11. IA	County Rt. F-46, Poweshiek County, Iowa	County	Contractor	State(80%) County(20%)	Wet-Hard Freeze (III)	Aggregate-Asphalt (4% - Recycled)

TABLE 3 (CONTD.)

GENERAL DATA FOR CASE HISTORIES

CASE HISTORY	TITLE AND LOCATION	DESIGNED BY	BUILT BY	SOURCE OF FUNDING	CLIMATIC REGION	BASE/SUBBASE TREATMENT
12. IA	Mud Hollow Road, Pottawattamie County, Iowa	County	County	County	Wet-Hard Freeze (III)	Soil-Aggregate-Cement - Fly Ash
13. NY	County Rt. 42, Steuben County, New York	Consultant	Contractor	County	Wet-Hard Freeze (III)	Soil-Aggregate-Cement (15%, 9%)
14. NY	County Rt. 67, Delaware County, New York	County	County	County	Wet-Hard Freeze (III)	Aggregate-Cement (6%)
15. NY	County Rt. 514, Broome County, New York	County	County	County	Wet-Hard Freeze (III)	Soil-Aggregate-Cement (15%, 6%)
16. OR	Airport Avenue, Benton County, Oregon	County	Contractor	Federal(80%) County (20%)	Dry-No Freeze (V)	Soil-Lime (4%) (Sub-Base)
17. OR	Service Creek--Mitchell Highway (from Richmond Jct. to Girds Creek), Wheeler County, Oregon	State	Contractor	State	Dry-No Freeze (V)	Aggregate-Cement (7%)
18.	Route No. 42, Mt. Hood National Forest, Oregon	U.S. Forest Service	Contractor	U.S. Forest Service	Dry-No Freeze (V)	Aggregate-Asphalt Emulsion (7%) (Two layers (Ref. 9)
19. TX	Rowe Lane, Travis County, Texas	County	County	County	Dry-No Freeze (V)	Soil-Aggregate-Lime (80%, 5%) (Ref. 10)
20. TX	State Rt. FM 1604, Bexar County, Texas	State	Contractor	State	Dry-No Freeze (IV)	Soil-Lime-Fly Ash (3%, 10%)
21. TX	Mercedes St., City of Bennbrook, Texas	Consultant	Contractor	City	Dry-No Freeze (V)	Soil-Lime (5%) (Subbase)

TABLE 3 (CONTD.)

GENERAL DATA FOR CASE HISTORIES

CASE HISTORY	TITLE AND LOCATION	DESIGNED BY	BUILT BY	SOURCE OF FUNDING	CLIMATIC REGION	BASE/SUBBASE TREATMENT
22. VA	State Rt. 721, King & Queen County, Virginia	State	Contractor	State	Wet-Freeze/ Thaw (II)	Soil-Cement (8%) (Subbase)
23. VA	State Rt. 641, Isle of Wight County, Virginia	State	Contractor	State	Wet-Freeze/ Thaw (II)	Soil-Lime-Fly Ash (5%, 10%) (Ref. 11)
24. VA	State Rt. 1821, Roanoke County, Virginia	State	Contractor	State	Wet-Freeze/ Thaw (II)	Aggregate-Cement (5%)

CONSTRUCTION DATA

Table 4 shows the construction data for case histories. This table also shows key project characteristics; i.e., traffic volume, design as-built, and construction cost/square yard. The cost is shown both for the time of construction and at present (1983). The equivalent pavement design without stabilization (Column 10) was computed based on thickness equivalency values for full depth specifications material crushed aggregates. The estimated construction cost of crushed aggregates and equivalent design is also shown both for the time of construction and at present (1983). The amount of money saved by using soil stabilization treatment for the study sections is shown in Column 13 and 14, for the prices for the year of construction and those for 1983 respectively. This saving was computed by comparing the cost of pavement with and without stabilization. The analysis indicate that soil stabilization treatments for the documented case histories (except No. 12, 13, and 18), on the average, saved over $22,000/mile using 1983 prices. For case histories -- No. 12 (in Iowa), No. 13 (in New York), and No. 18 (in Oregon) -- soil stabilization treatments were not found to be cost effective. These three case histories, however, documents the consideration of soil stabilization treatments for the following reasons:

1. To improve frost susceptibility of the base courses;
2. To provide uniform strength to the base course for widening both sides of an existing road;
3. To avoid raising the level of an existing roadbed; and
4. To conserve large quantities of good quality aggregates.

The performance (Column 15) is based on visual observations and interview with contact officials.

TABLE 4

CONSTRUCTION DATA FOR CASE HISTORIES

CASE HISTORY 1	PROJECT TYPE 2	YEAR OF CONST. 3	LENGTH IN MILE 4	WIDTH IN FT. 5	ADT (1982-83) 6	PAVEMENT WITH STABILIZATION: DESIGN (AS-BUILT) 7	COST/SY (YEAR OF CONST.) 8	COST/SY (1983) 9	PAVEMENT WITHOUT STABILIZATION: EQUIVALENT DESIGN 10	COST/SY (YEAR OF CONST.) 11	COST/SY (1983) 12	BENEFITS OF STABILIZATION: WITH YEAR OF CONST. PRICES 13	WITH 1983 PRICES 14	PERFORMANCE 15
1 FL	Rural Residential	1982	0,140	20'	400 (10% Trucks)	1" A.C. 6" Soil-Cement* (5.5%) 300 psi in 7 days	$2,13 2,92	$3,00 4,00	1" A.C. 6" Crushed Aggregate (Haul = 50 miles)	$2,13 5,25	$3,00 6,75	$ 3,827	$ 4,517	Excellent
2 FL	Farm to Market	1983	0,304	20'	750 (7% Trucks)	1" A.C. 6" Soil-Cement* (12%)	1,10 5,20	1,10 5,20	1" A.C. 6" Crushed Aggregate (Haul = 80 miles)	1,10 7,00	1,10 7,00	10,645	10,645	Excellent
3 FL	Urban Residential	1972	0,750	20'	500 (20% Trucks)	1-1/4" A.C. 6-1/2" Aggregate-cement* (7%) (from county shell pit) (400 psi in 7 days)	1,58 1,00	2,36 2,33	1-1/4" 12" Aggregate (Local Shell Pit) (Haul = 2 miles)	1,58 1,10	2,36 2,46	800	1,144	"Fair" Heavy Cracking at Surface, No Base Failure
4 ID	Farm to Market	1978	0,800	24'	400 (20% Trucks)	2" A.C. (Road Mix) 6" Soil-Aggregate-Cement* (60%, 5%)	2,50 1,81	2,80 2,60	2" A.C. (Road Mix) 8" Crushed Aggregate (Haul = 8 miles)	2,50 1,92	2,80 3,00	1,259	2,253	Excellent
5 ID	Commercial	1967	2,500	26'	350 (15% Trucks)	3-1/2" A.C. 6" Crushed Aggregate 12" Soil-Aggregate-Lime* (25%, 2%)	1,00 0,61 0,74	3,94 2,50 3,25	3" A.C. 6" Crushed Aggregate 12" Crushed Aggregate (Haul = 5 miles)	1,00 0,61 1,22	3,94 2,50 5,00	18,303	66,733	Excellent
6 ID	Commercial	1973	4,740	24'	190 (35% Trucks)	2-1/2" A.C. (Road Mix) 6" Crushed Aggregate 8" Soil-Aggregate-Lime*(25%, 4%)	0,87 0,98 1,23	3,28 2,50 3,00	2-1/2" A.C. (Road Mix) 6" Crushed Aggregate 8" Crushed Aggregate (Haul = 5 miles)	0,87 0,98 1,31	3,28 2,50 3,33	5,339	22,034	Excellent

*Road Mix; **Plant Mix

TABLE 4 (CONT'D)

CONSTRUCTION DATA FOR CASE HISTORIES

CASE HISTORY	PROJECT TYPE	YEAR OF CONST.	LENGTH IN MILE	WIDTH IN FT.	ADT (1982-83)	PAVEMENT WITH STABILIZATION			PAVEMENT WITHOUT STABILIZATION			BENEFITS OF STABILIZATION		PERFORMANCE
						DESIGN (AS-BUILT)	COST/SY (YEAR OF CONST.)	COST/SY (1983)	EQUIVALENT DESIGN	COST/SY (YEAR OF CONST.)	COST/SY (1983)	WITH YEAR OF CONST. PRICES	WITH 1983 PRICES	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7 IL	Farm to Market	1961	6.500	20'	300 (10% Trucks)	Double Chip & Seal 7" Soil-Aggregate-Cement*(15%, 10%)	$0.20 0.80	$1.00 2.00	Double Chip & Seal 7" Crushed Aggregate (Haul = 60 miles)	$0.20 1.42	$1.00 4.86	$ 47,285	$218,123	Excellent
8 IL	Farm to Market and Commercial	1982	4.250	20'	325 (15% Trucks)	Chip & Seal 4" Aggregate-Asphalt**(4% - Recycled) 3" Aggregate (In Place)	0.88 3.03	0.88 2.62	Chip & Seal 8" Crushed Aggregate (Haul = 52 miles) 3" Aggregate (In Place)	0.88 3.84	0.83 5.06	40,392	121,675	Excellent
9 IL	Urban Residential	1982	0.336	22'	750 (15% Trucks)	Chip & Seal 6" Soil-Aggregate-Lime-Fly Ash** (20%, 4%, 12%)	0.85 1.93	0.85 1.93	Chip & Seal 12" Crushed Aggregate (Haul = 40 miles)	0.85 2.02	0.85 2.22	390	1,257	Excellent
10 IA	Farm to Market	1963	5.800	22'	500 (15% Trucks)	2" A.C. 6" A.C. 4" Soil-Lime*(4.78%)	0.57 1.54 0.19	3.10 6.90 0.85	2" A.C. 6" A.C. 4" Crushed Aggregate (Haul = 20 miles)	0.57 1.54 0.61	3.10 6.90 1.42	31,441	42,669	Excellent
11 IA	Farm to Market	1977	7.250	24'	350 (5% Trucks)	1" A.C. 4" Aggregate-Asphalt** (4% Recycled)	1.41 2.59	1.84 4.94	1" A.C. 8" Crushed Aggregate (Haul = 14 miles)	1.41 2.49	1.84 3.43	- 16,333 (See Note 1)	- 154,140	Excellent
12 IA	Urban Residential	1979	0.208	24'	545 (9% Trucks)	Double Chip & Seal 6" Soil Aggregate-Cement Fly Ash* (20%, 3%, 13%)	0.57 1.95	0.53 4.10	Double Chip & Seal 9" Crushed Aggregate (Haul = 8 miles)	0.57 2.91	0.53 3.20	2,811	- 2,636	Good

Note 1: Stabilization improved frost susceptibility of the base course

*Road Mix; **Plant Mix

TABLE 4 (CONTD.)

CONSTRUCTION DATA FOR CASE HISTORIES

CASE HISTORY	PROJECT TYPE	YEAR OF CONST.	LENGTH IN MILE	WIDTH IN FT.	ADT (1982-83)	PAVEMENT WITH STABILIZATION: DESIGN (AS-BUILT)	PAVEMENT WITH STABILIZATION: COST/SY (YEAR OF CONST.)	PAVEMENT WITH STABILIZATION: COST/SY (1983)	PAVEMENT WITHOUT STABILIZATION: EQUIVALENT DESIGN	PAVEMENT WITHOUT STABILIZATION: COST/SY (YEAR OF CONST.)	PAVEMENT WITHOUT STABILIZATION: COST/SY (1983)	BENEFITS OF STABILIZATION: WITH YEAR OF CONST. PRICES	BENEFITS OF STABILIZATION: WITH 1983 PRICES	PERFORMANCE
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
13 NY	Farm to Market	1980	1,570	18'	436 (15% Trucks)	Chip & Seal 6" Soil-Aggregate-Cement** (15%, 9%)	$0.57 3.72	$0.80 5.36	Chip & Seal 12" Crushed Aggregate (Haul = 2 miles)	$0.57 2.62	$0.80 3.57	$-18,237 (See Note 2)	$-29,677	Good
14 NY	Farm to Market	1967	2,620	18'	365 (10% Trucks)	Chip & Seal 6" Aggregate-Cement** (6%) 3" Aggregate	0.11 1.26 0.29	0.75 3.78 0.87	Single Chip & Seal 9" Crushed Aggregate 3" Aggregate (Haul = 35 miles)	0.11 1.62 0.29	0.75 2.75 0.87	9,960	-28,497	Good
15 NY	Farm to Market	1981	0.910	20'	500 (5% Trucks)	1-1/2" A.C. (Road Mix) 7" Soil-Aggregate-Cement** (15%, 6.6%)	1.56 6.50	1.56 7.80	1-1/2" A.C. (Road Mix) 14" Crushed Aggregate (Haul = 10 miles)	1.56 7.02	1.56 4.27	5,552	-37,691	Excellent
16 OR	Commercial	1983	1,325	24'	336 (30% Trucks)	4" A.C. 4-1/2" Aggregate 8" Soil-Lime* (4%)	6.00 1.82 2.24	6.00 1.82 2.24	4" A.C. 4-1/2" Crushed Aggr. 8" Crushed Aggregate (Haul = 6 miles)	6.00 1.82 3.24	6.00 1.82 3.24	18,656	18,656	Excellent
17 OR	Farm to Market and Commercial	1977	3,340	28'	100 (35% Trucks)	Chip & Seal (Four Coats) 10" Aggregate-Cement** (7%)	1.20 4.95	1.32 5.24	Chip & Seal (Four Coats) 14" Crushed Aggregate (Haul = 15 miles)	1.20 5.00	1.32 5.31	2,743	3,841	Excellent
18 OR	Forest Service	1970	9.00	24'	250 (20% Trucks)	4" A.C. 3" Aggregate-Asphalt-Emulsion** (7%) 4" Aggregate-Asphalt-Emulsion** (6%)	1.68 1.21 1.61	4.62 1.64 6.65	4" A.C. 14" Crushed Aggregate (Haul = 65 miles)	1.68 2.72	4.62 15.04	-12,672 (See Note 3)	430,848	Excellent

*Road Mix; **Plant Mix

NOTE 2: Stabilization was selected: (1) due to widening of both sides of an existing road to provide uniform strength to base course, and (2) to improve frost susceptibility of existing road base.

NOTE 3: Stabilization was selected to avoid raising the level of existing roadbed and to conserve approximately 45,000 tons of good quality aggregate.

TABLE 4 (CONTD.)

CONSTRUCTION DATA FOR CASE HISTORIES

CASE HISTORY	PROJECT TYPE	YEAR OF CONST.	LENGTH IN MILE	WIDTH IN FT.	ADT (1982-83)	PAVEMENT WITH STABILIZATION			PAVEMENT WITHOUT STABILIZATION			INITIAL COST SAVINGS WITH STABILIZATION		PERFORMANCE
						DESIGN (AS-BUILT)	COST/SY (YEAR OF CONST.)	COST/SY (1983)	EQUIVALENT DESIGN	COST/SY (YEAR OF CONST.)	COST/SY (1983)	WITH YEAR OF CONST. PRICES	WITH 1983 PRICES	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
19 TX	Farm to Market	1983	1.050	24'	210 (10% Trucks)	Double Chip & Seal 4" Crushed Aggregate 6" Soil-Aggr.-Lime* (80%, 5%)	$1.40 1.85 1.65	$1.40 1.85 1.65	Double Chip & Seal 4" Crushed Aggregate 6" Crushed Aggregate (Haul = 20 miles)	$ 1.40 1.85 4.85	$1.40 1.85 4.85	$47,309	$47,309	Excellent
20 TX	Farm to Market	1979	6.570	24'	540 (5% Trucks)	Double Chip & Seal 10" Crushed Aggregate 6" Soil-Lime-Fly Ash* (3%, 10%)	1.00 3.03 1.60	1.10 4.44 2.00	Double Chip & Seal 10" Crushed Aggregate 6" Crushed Aggregate (Haul = 20 miles)	1.00 3.03 1.82	1.10 4.44 2.67	18,501	61,979	Excellent
21 TX	Urban Residential	1982	0.237	44'	1000 (5% Trucks)	2" A.C. 4" A.C. 8" Soil-Lime* (5%)	2.90 5.80 2.11	2.90 5.80 2.11	2" A.C. 4" A.C. 8" Crushed Aggregate (Haul = 50 miles)	2.90 5.80 3.97	2.90 5.80 3.97	11,379	11,379	Excellent
22 VA	Commercial	1982	1.724	22'	821 (25% Trucks)	Double Chip & Seal 4" Aggregate 6" Soil-Cement** (8%)	1.27 1.65 2.13	1.27 1.65 2.13	Double Chip & Seal 4" Aggregate 10" Crushed Aggregate (Haul = 55 miles)	1.27 1.65 4.13	1.27 1.65 4.13	44,502	44,502	Excellent
23 VA	Farm to Market	1958	0.060	22'	650 (5% Trucks)	Double Chip & Seal 6" Soil-Lime-Fly Ash* (5%, 10%)	0.20 1.48	1.38 2.26	Double Chip & Seal 9" Crushed Aggregate (Haul = 150 miles)	0.20 2.07	1.38 3.47	457	2,486	Excellent
24 VA	Urban Residential	1973	0.430	22'	1000 (5% Trucks)	1-1/2" A.C. 6" Aggregate-Cement** (5%)	0.61 1.41	1.17 2.82	1-1/2" A.C. 12" Crushed Aggregate (Haul = 10 miles)	0.61 2.00	1.17 3.43	3,274	3,385	Excellent

*Road Mix; **Plant Mix

MAINTENANCE DATA

The maintenance data of case hisotries is shown in Table 5. The Column 4 of this table presents maintenance criteria for each case history. This maintenance criteria, for the most part, is anticipated maintenance, for the next 20 years (analysis period for present worth analysis). The maintenance cost is shown in Columns 5 and 6 for both the year of construction and for 1983. The present worth for the cost of maintenance for the 20 year analysis period has been computed by using an interest rate of 8% per year. The computed value of present worth of maintenance costs is shown in Column 7. The maintenance critera of the equivalent pavement design with stabilization is assumed to be the same and is not shown in Table 4. At present the maintenance practices do not account for different maintenance criteria for pavement with or without stabilization. This practice coupled with the use of thickness equivalency factors for various materials allows the decision maker to make decision based on the least first cost. However, first cost criteria must not be used when evaluating pavement options which have different maintenance criteria.

TABLE 5

MAINTENANCE DATA FOR CASE HISTORIES

CASE HISTORY 1	YEAR OF CONSTRUCTION 2	PAVEMENT WITH STABILIZATION (AS BUILT) 3	MAINTENANCE CRITERIA 4	MAINTENANCE COST/SY YEAR OF CONSTRUCTION PRICES 5	MAINTENANCE COST/SY 1983 PRICES 6	PRESENT WORTH ('83 BASIS) 7
1 FL	1982	1" A.C. 6" Soil-Cement* (5.5%)	1" A.C. Overlay every 15 years	$ 2.13	$ 3.00	$ 1.15
2 FL	1983	1" A.C. 6" Soil-Cement* (12%)	1" A.C. Overlay every 15 years	1.10	1.10	0.43
3 FL	1972	1-1/4" A.C. 6-1/2" Aggregate-Cement* (7%)	1-1/4" A.C. Overlay every 15 years	1.58	2.36	0.91
4 ID	1978	2" A.C. (Road Mix) 6" Soil-Aggregate-Cement* (60%, 5%)	Chip & Seal every 7 years	0.40	0.50	0.57
5 ID	1967	3-1/2" A.C. 6" Crushed Aggregate 12" Soil-Aggregate-Lime (25%, 4%)	Chip & Seal every 15 years	0.26	0.50	0.19
6 ID	1973	2-1/2" A.C. (Road Mix) 6" Crushed Aggregate 8" Soil-Aggregate-Lime* (25%, 4%)	Chip & Seal every 12 years	0.26	0.50	0.27
7 IL	1961	Double Chip & Seal 7" Soil-Aggregate-Cements* (15%, 10%)	Chip & Seal every 10 years	0.10	0.50	0.34

*Road Mix
**Plant Mix

TABLE 5 (CONTD.)

MAINTENANCE DATA FOR CASE HISTORIES

CASE HISTORY 1	YEAR OF CONSTRUCTION 2	PAVEMENT WITH STABILIZATION (AS BUILT) 3	MAINTENANCE CRITERIA 4	MAINTENANCE COST/SY YEAR OF CONSTRUCTION PRICES 5	MAINTENANCE COST/SY 1983 PRICES 6	PRESENT WORTH ('83 BASIS) 7
8 IL	1982	Chip & Seal 4" Aggregate-Asphalt** (4%-Recycled) 3" Crushed Aggregate	Chip & Seal every 10 years	$ 0.88	$ 0.88	$ 0.60
9 IL	1982	Chip & Seal 6" Soil-Aggregate-Lime-Fly Ash** (20%, 4%, 12%)	Chip & Seal Every 4 years	0.85	0.85	1.85
10 IA	1963	2" A.C. 6" A.C. 4" Soil-Lime* (4.78%)	Chip & Seal every 12 years	0.20	0.93	0.50
11	1977	1" A.C. 4" Aggregate-Asphalt** (4%-Recycled)	1" A.C. overlay every 10 years	1.37	1.79	1.21
12 IA	1979	Double Chip & Seal 6" Soil-Aggregate-Cement-Fly Ash* (20%, 3%, 13%)	Chip & Seal every 10 years	0.57	0.66	0.45
13 NY	1980	Chip & Seal 6" Soil-Aggregate-Cement** (15%, 9%)	Chip & Seal every 5 years	0.57	0.80	1.34
14 NY	1967	Chip & Seal 6" Aggregate-Cement* (6%)	Chip Seal every 4 years	0.11	0.75	1.67

*Road Mix
**Plant Mix

TABLE 5 (CONTD.)

MAINTENANCE DATA FOR CASE HISTORIES

CASE HISTORY 1	YEAR OF CONSTRUCTION 2	PAVEMENT WITH STABILIZATION (AS BUILT) 3	MAINTENANCE CRITERIA 4	MAINTENANCE COST/SY YEAR OF CONSTRUCTION PRICES 5	MAINTENANCE COST/SY 1983 PRICES 6	PRESENT WORTH ('83 BASIS) 7
15 NY	1981	1-1/2" A.C. (Road Mix) 7" Soil-Aggregate-Cement** (15%, 6.6%)	Chip & Seal every 5 years	$ 0.68	$ 0.85	$ 1.42
16 OR	1983	4" A.C. 4-1/2" Aggregate 8" Soil-Lime* (4%)	1-1/2" A.C. Overlay every 15 years	2.25	2.25	0.87
17 OR	1977	Chip & Seal (4 Coats) 10" Aggregate-Cement** (7%)	Double Chip and Seal every 10 years	0.60	0.80	0.54
18 OR	1970	4" A.C. 3" Aggregate-Asphalt (Emulsion)** (7%) 4" Aggregate-Asphalt (Emulsion** (6%)	Chip & Seal every 12 years	0.21	0.42	0.23
19 TX	1983	Double Chip & Seal 4" Crushed Aggregate 6" Soil-Aggregate-Lime* (80%, 5%)	Chip & Seal every 12 years	0.70	0.70	0.38
20 TX	1979	Double Chip & Seal 10" Crushed Aggregate 6" Soil-Lime-Fly Ash* (3%, 10%)	Chip & Seal every 8 years	0.50	0.55	0.52

*Road Mix
**Plant Mix

TABLE 5 (CONTD.)

MAINTENANCE DATA OF CASE HISTORIES

CASE HISTORY 1	YEAR OF CONSTRUCTION 2	PAVEMENT WITH STABILIZATION (AS BUILT) 3	MAINTENANCE CRITERIA 4	MAINTENANCE COST/SY YEAR OF CONSTRUCTION PRICES 5	MAINTENANCE COST/SY 1983 PRICES 6	PRESENT WORTH ('83 BASIS) 7
21 TX	1982	2" A.C. 4" A.C. 8" Soil-Lime* (5%)	Chip & Seal every 6 years	0.77	0.77	1.15
22 VA	1982	Double Chip & Seal 4" Crushed Aggregate 6" Soil-Cement** (8%)	Chip & Seal every 6 years	0.41	0.41	0.89
23 VA	1958	Double Chip & Seal 6" Soil-Lime-Fly Ash* (5%, 10%)	Chip & Seal every 6 years	0.10	0.43	0.89
24 VA	1973	1-1/2" A.C. 6" Aggregate-Cement** (5%)	1-1/2" A.C. Overlay every 12 years	0.61	1.17	0.63

*Road Mix
**Plant Mix

ENERGY DATA

Table 6 shows the energy data for case histories. The energy demand is shown for both pavement designs, with and without stabilization. The energy demand in British Thermal Units (BTU's) was calculated by using Tables 7 thru 10. The energy demand for production, transportation and construction operations has been considered in the energy analysis.

The energy demand for maintenance operations is assumed to be same for both pavement with and without stabilization. It should be noted that if gravel surfaced road is included in these comparisons for alternatives, then the energy demand for maintenance operations should also be analyzed to compare the total energy demand for all alternatives. The purpose of energy demand analysis is to provide the decision maker with a tool for selecting the most beneficial alternative from economic and energy impacts. The energy demand analysis indicate that soil stabilization treatment for the documented case histories (except No. 9, 18 and 23), on the average, consumed additional 63,000 BTU per square yard. For case histories No. 9 (in Illinois), No. 18 (in Oregon), and No. 23 (in Virginia) soil stabilization treatment exhibited energy benefits ranging from 18,000 to 171,476 BTU per square yard.

TABLE 6

ENERGY DATA FOR CASE HISTORIES

CASE HISTORY	PROJECT SIZE (SY)	YEAR OF CONST.	BASE/SUBBASE WITH DESIGN (AS-BUILT)	BASE/SUBBASE WITH BTU'S PER SY	BASE/SUBBASE EQUIVALENT DESIGN	BASE/SUBBASE BTU'S PER SY	BENEFITS OF STABILIZATION (BTU/SY)
1 FL	1,643	1982	6" Soil-Cement*(5.5%)	142,000	6" Crushed Aggr.	69,000	- 73,200
2 FL	5,914	1983	6" Soil-Cement* (12%)	142,000	6" Crushed Aggr.	69,000	- 73,200
3 FL	8,800	1972	6-1/2" Aggregate-Cement* (7%)	198,250	12" Crushed Aggr.	138,000	- 60,250
4 ID	11,264	1978	6" Soil-Aggregate-Cement* (60%, 5%)	183,00	8" Crushed Aggr.	92,000	- 91,300
5 ID	38,134	1967	12" Soil-Aggr.-Lime* (25%, 2%)	284,400	12" Crushed Aggr.	138,000	-146,000
6 ID	66,740	1973	8" Soil-Aggr.-Lime* (25%, 4%)	189,600	8" Crushed Aggr.	92,000	-180,400
7 IL	76,267	1961	7" Soil-Aggr.-Cement* (15%, 10%)	165,900	7" Crushed Aggr.	80,500	- 85,400
8 IL	89,761	1982	4" Aggregate-Asphalt** (4% Recycled)	116,000	8" Crushed Aggr.	92,000	- 24,000
9 IL	4,337	1982	6" Soil-Aggr-Lime-Fly Ash** (4%, 12%)	120,000	12" Crushed Aggr.	138,000	18,000

TABLE 6 (CONTD.)

ENERGY DATA FOR CASE HISTORIES

CASE HISTORY	PROJECT SIZE (SY)	YEAR OF CONST.	BASE/SUBBASE WITH DESIGN (AS-BUILT)	BASE/SUBBASE WITH BTU'S PER SY	BASE/SUBBASE EQUIVALENT DESIGN	BASE/SUBBASE BTU'S PER SY	BENEFITS OF STABILIZATION (BTU/SY)
18 OR	126,721	1970	3" Aggr.-Asphalt-Emulsion** (7%) 4" Aggr.-Asphalt-Emulsion** (6%)	109,200	14" Crushed Aggr.	161,000	51,800
19 TX	14,784	1983	6" Soil-Aggr.-Lime* (80%, 5%)	142,000	6" Crushed Aggr.	69,000	- 73,200
20 TX	92,506	1979	6" Soil-Lime-Fly Ash* (3%, 10%)	120,000	6" Crushed Aggr.	69,000	- 51,000
21 TX	6,118	1982	8" Soil-Lime* (5%)	189,600	8" Crushed Aggr.	92,000	- 97,600
22 VA	22,251	1982	6" Soil-Cement** (8%)	139,878	10" Crushed Aggr.	135,102	- 4,775
23 VA	774	1958	6" Soil-Lime-Fly Ash* (5%, 10%)	91,837	9" Crushed Aggr.	263,313	171,476
24 VA	5,550	1973	6" Aggregte-Cement** (5%)	82,695	12" Crushed Aggr.	72,733	- 9,962

*Road Mix **Plant Mix

TABLE 8

ENERGY ASSOCIATED WITH AGGREGATE PRODUCTION

PRODUCT	OPERATION	ENERGY REQUIREMENT BTU/LB	BTU/TON	BTU/YD^{3*}
	Drilling and shooting	6	12,000	21,000
	Crushing	25.5	51,000	89,500
Crushed Stone	Handling (cranes and and bulldozers)	3.5	7,000	12,000
	Total	35	70,000	123,000
	Total	26	52,000	91,300
	Crushing	17.5	35,000	61,400
Crushed Gravel	Handling (cranes and bulldozers)	2.5	5,000	8,780
	Total	20	40,000	70,000
Natural or Uncrushed Aggregate	Total	7.5	15,000	26,300

*130 lbs/ft^3 assumed unit weight (2100 kg/m^3)

Metric Conversion

1 BTU/lb = 2324 J/kg

1 BTU/ton = 1.164 J/kg

1 BTU/yd^3 = 1381 J/m^3

Source: (6)

TABLE 9

ENERGY REQUIREMENTS FOR AUTOMOBILE AND TRUCK OPERATION

TYPE OF VEHICLE	ENERGY REQUIREMENTS BTU/mi	BTU/hr	BTU/ton mi
Automobile	7,230		
Stationwagon	7,760		
Pickup	11,400		
Maintenance Trucks--Diesel	26,700	97,300	
Maintenance Trucks--Gasoline	26,600	100,000	
Maintenance Trucks--1 ton	15,600		
Maintenance Truck--2 Axle	27,500		
Distributor Truck--Gasoline	31,300		
Truck Tractor--Diesel	30,400		
Truck--2 Axle, 6 Tire, Gasoline			11,000
Truck--3 Axle, Gasoline			4,270
Truck--3 Axle, Diesel			3,800
Truck--3 Axle (combination) Gasoline			7,440
Truck--3 Axle (combination) Diesel			5,840
Truck--4 Axle (combination) Gasoline			5,040
Truck--4 Axle (combination) Diesel			3,270
Truck--5 Axle (combination) Gasoline			2,900
Truck--5 Axle (combination) Diesel			1,960

Metric Conversion:

1 BTU/mi = 656.1 J/km
1 BTU/hr = 1055 J/hr
1 BTU/ton mi = 0.723 J/kg km

Source: (6)

TABLE 10

ENERGY REQUIREMENTS FOR MISCELLANEOUS CONSTRUCTION OPERATIONS

OPERATION*	ENERGY REQUIREMENT				
	BTU/GAL	BTU/TON	BTU/YD^3	EQUIVALENT GALLONS OF DIESEL PER	
				TON	YD^3
Spreading and compacting Granular and Stabilized Base		17,000	30,980	0.122	0.223
Travel Plant Mixing in Windrow		3,000	5,470	0.022	0.039
Blade Mixing		7,820	14,250	0.056	0.103
Central Plant Mixing of Stabilized Base		6,890	12,550	0.050	0.090
Excavation - Earth		39,890	59,100	0.286	
Excavation - Rock		35,500	76,700		
Excavation - Other		39,100	68,700		
Asphalt Distribution, Asphalt Cement	590				
Asphalt Distribution, Cutback Asphalt	445				
Asphalt Distribution	145				
Aggregate Spreading for Seal Coats	9.4**				
Rolling Cold Asphalt Mixes	120***				

*135 lb/ft^3 (2160 kg/m^3) assumed unit weight except for excavation items
**9.4 BTU/yd^2
***120 BTU/yd^2 in.

Metric Conversion: 1 BTU/gal = 278.7 J/1   1 BTU/ton = 1.162 J/kg

1 BTU/yd^3 = 1.381 J/m^3 1 ton = 907 kg

1 yd^3 = 0.764 J m^3 1 in. = 2.54 cm

Source: (6)

CONCLUSIONS

Based on the evaluations of case histories, review of the literature, survey of county engineers for the use and non-use of soil stabilization treatments, interviews with representatives of material industry associations and numerous local and state highway department officials, -- the criteria for consideration of soil stabilization treatments is discussed hereunder.

- Soil stabilization should be considered as a design alternative for upgrading low-volume roads in all climatic regions and when specification materials are not available in abundance. The roadway soils should be inspected and/or analyzed to select the appropriate stabilization agent and its rate of application. Pavement alternatives with and without stabilization should be identified. Once identified, alternatives should be evaluated to develop comparative present worth values using the interest rate applicable for long-term borrowing and the appropriate analysis period (usually 20 years for paved roads). The alternative having the least present worth should be accepted. An illustrative procedure to evaluate alternatives is presented in the section titled Cost-Benefit Analysis.

- Soil stabilization is a preferred design alternative: to provide better frost susceptibility; to provide conservation of good quality aggregates; to provide uniform pavement strength for widening an existing roadbed; and to avoid raising the level of an exiting roadbed.

- Soil stabilization treatment is successful when favorable climatic conditions exist during construction and curing period.

- Frequently the required assistance in planning, mix design, specifications, construction operations, quality control, etc., can be obtained from other experienced local and state highway personnel. The material industry associations can also provide assistance in the application of their products. Additional assistance can also be procured from consulting engineers and soil testing laboratories.

- Soil stabilization treatments can be performed without the use of special mixing machinery or equipment. The farm disc harrows or other similar ploughs can be used successfully to obtain good results for mixing operations.

- The soil inspection and analysis can lead to cost effective solutions. The soil inspection and analysis should be considered as a valuable tool to establish the most cost effective pavement option for upgrading of low-volume roads.

RECOMMENDATIONS

As a result of this study, our recommendations are as follows:

- The soil stabilization treatments should be considered for potential benefits such as reduced cost and improved performance. Some of these cost benefits and better performance results from conservation of good quality aggregates, better frost susceptibility, uniform pavement characteristics for widening, or maintaining the same level of an existing roadbed.

- Good records should be kept to identify comparison in pavement performance and in costs with and without stabilization.

- Other suitable stabilizers should also be considered such as calcium chloride, and magnesium chloride.

- Training seminars should be developed and offered to inform users on the use of soil stabilization treatments in upgrading low-volume roads and on the techniques to conduct cost-benefit and energy demand analysis.

REFERENCES

1. American Road Builders Association, "Education and Information Guide," "Materials for Stabilization", Washington, D.C., September 1976.

2. U. S. Department of Transportation, Federal Highway Administration, "Proceedings of the project-Soil Stabilization Criteria for Low Volume Roads, Progress and Reivew", November 18, 1981.

3. Arora, Pritam L., and Ahmed, T., "Roadbed Soil Stabilization", Phase 1 Report - Soil Stabilization Criteria for Low-Volume Roads, Federal Highway Administration, May 1982.

4. American Associaton of State Highway and Transportation Officals, AASHTO Interim Guide for Design of Pavement Structures", Washington, D.C., 1972.

5. Vaswani, N. K., "Design Guide for Secondary Road Pavements in Virginia", Virginia Highway Research Council, October 1973.

6. U.S. Department of Transportation, Federal Highway Administration, "Soil Stabilization in Pavement Structures: A User's Manual, Volume 1," FHWA-IP-80-2, October 1979.

7. U.S. Department of Transportation, Federal Highway Administration, "Highway Engineering Economy", July 1978.

8. Weber, L., "Lime-Fly Ash Stabilization for Pavement Repair", Public Works, December 1982.

9. U. S. Department of Agriculture, Forest Service Region Six, "Base Stabilization - Paving Skyline Road S-42, Mt. Hood National Forest", February 1971.

10. Ledbetter, W. B., Teague D. J., Long, R. L., and Banister, B. N., "Construction of Fly Ash Test Sites and Guidelines for Construction", Texas Transportation Institute, October 1981.

11. Nichols, F. P. Jr., "Base and Subgrade Stabilization Experiments - Progress Report No. 3", Virgnia Highway Research Council, March 1959.

APPENDIX

COMPOUND INTEREST FACTORS

4% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9615	0.962
2	0.9246	1.886
3	0.8890	2.775
4	0.8548	3.630
5	0.8219	4.452
6	0.7903	5.242
7	0.7599	6.002
8	0.7307	6.733
9	0.7026	7.435
10	0.6756	8.111
11	0.6496	8.760
12	0.6246	9.385
13	0.6006	9.986
14	0.5775	10.563
15	0.5553	11.118
16	0.5339	11.652
17	0.5134	12.166
18	0.4836	12.659
19	0.4936	13.134
20	0.4564	13.590

5% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9524	0.952
2	0.9070	1.859
3	0.8638	2.723
4	0.8227	3.546
5	0.7835	4.329
6	0.7462	5.076
7	0.7107	5.786
8	0.6768	6.463
9	0.6446	7.108
10	0.6139	7.722
11	0.5847	8.306
12	0.5568	8.863
13	0.5303	9.394
14	0.5051	9.899
15	0.4810	10.380
16	0.4581	10.838
17	0.4363	11.274
18	0.4155	11.690
19	0.3957	12.085
20	0.3769	12.462

6% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9434	0.943
2	0.8900	1.833
3	0.8396	2.673
4	0.7921	3.465
5	0.7473	4.212
6	0.7050	4.917
7	0.6651	5.582
8	0.6274	6.210
9	0.5919	6.802
10	0.5584	7.360
11	0.5268	7.887
12	0.4970	8.384
13	0.4688	8.853
14	0.4423	9.295
15	0.4173	9.712
16	0.3936	10.106
17	0.3714	10.477
18	0.3503	10.828
19	0.3305	11.158
20	0.3118	11.470

7% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9346	0.935
2	0.8734	1.808
3	0.8163	2.624
4	0.7629	3.387
5	0.7130	4.100
6	0.6663	4.767
7	0.6227	5.389
8	0.5820	5.971
9	0.5439	6.515
10	0.5083	7.024
11	0.4751	7.499
12	0.4440	7.943
13	0.4150	8.358
14	0.3878	8.745
15	0.3624	9.108
16	0.3387	19.447
17	0.3166	19.763
18	0.2959	10.059
19	0.2765	10.336
20	0.2584	10.594

8% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9259	0.926
2	0.8573	1.783
3	0.7938	2.577
4	0.7350	3.312
5	0.6806	3.993
6	0.6302	4.623
7	0.5835	5.206
8	0.5403	5.747
9	0.5002	6.247
10	0.4632	6.710
11	0.4289	7.139
12	0.3971	7.536
13	0.3677	7.904
14	0.3405	8.244
15	0.3152	8.559
16	0.2919	8.851
17	0.2703	9.122
18	0.2502	9.372
19	0.2317	9.604
20	0.2145	9.818

9% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9174	0.917
2	0.8417	1.759
3	0.7722	2.531
4	0.7084	3.240
5	0.6499	3.890
6	0.5963	4.486
7	0.5470	5.033
8	0.5019	5.535
9	0.4604	5.995
10	0.4224	6.418
11	0.3875	6.805
12	0.3555	7.161
13	0.3262	7.487
14	0.2992	7.786
15	0.2745	8.061
16	0.2519	8.313
17	0.2311	8.544
18	0.2120	8.756
19	0.1945	8.950
20	0.1784	9.129

10% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9091	0.909
2	0.8264	1.736
3	0.7513	2.487
4	0.6830	3.170
5	0.6209	3.791
6	0.5645	4.355
7	0.5132	4.868
8	0.4665	5.335
9	0.4241	5.759
10	0.3855	6.144
11	0.3505	6.495
12	0.3186	6.814
13	0.2897	7.103
14	0.2633	7.367
15	0.2394	7.606
16	0.2176	7.824
17	0.1978	8.022
18	0.1799	8.201
19	0.1635	8.365
20	0.1486	8.514

11% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.9009	0.901
2	0.8116	1.713
3	0.7312	2.444
4	0.6587	3.102
5	0.5935	3.696
6	0.5346	4.231
7	0.4817	4.712
8	0.4339	5.146
9	0.3909	5.537
10	0.3522	5.889
11	0.3173	6.207
12	0.2858	6.492
13	0.2575	6.750
14	0.2320	6.982
15	0.2090	7.191
16	0.1883	7.379
17	0.1696	7.549
18	0.1528	7.702
19	0.1377	7.839
20	0.1240	7.963

12% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.8929	0.893
2	0.7972	1.690
3	0.7118	2.402
4	0.6355	3.037
5	0.5674	3.605
6	0.5066	4.111
7	0.4523	4.564
8	0.4039	4.968
9	0.3606	5.328
10	0.3220	5.650
11	0.2875	5.938
12	0.2567	6.194
13	0.2292	6.424
14	0.2046	6.628
15	0.1827	6.811
16	0.1631	6.974
17	0.1456	7.120
18	0.1300	7.250
19	0.1161	7.366
20	0.1037	7.469

13% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.8850	0.885
2	0.7831	1.668
3	0.6931	2.361
4	0.6133	2.974
5	0.5428	3.517
6	0.4803	3.998
7	0.4251	4.423
8	0.3762	4.799
9	0.3329	5.132
10	0.2946	5.426
11	0.2607	5.687
12	0.2307	5.918
13	0.2042	6.122
14	0.1807	6.302
15	0.1599	6.462
16	0.1415	6.604
17	0.1252	6.729
18	0.1108	6.840
19	0.0981	6.938
20	0.0868	7.025

14% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.8772	0.877
2	0.7695	1.647
3	0.6750	2.322
4	0.5921	2.914
5	0.5194	3.433
6	0.4556	3.889
7	0.3996	4.288
8	0.3506	4.639
9	0.3075	4.946
10	0.2697	5.216
11	0.2366	5.453
12	0.2076	5.660
13	0.1821	5.842
14	0.1597	6.002
15	0.1401	6.142
16	0.1229	6.265
17	0.1078	6.373
18	0.0946	6.467
19	0.0829	6.550
20	0.0728	6.623

15% COMPOUND INTEREST FACTORS

n	P/F	P/A
1	0.8696	0.870
2	0.7561	1.626
3	0.6575	2.283
4	0.5718	2.855
5	0.4972	3.352
6	0.4323	3.784
7	0.3759	4.160
8	0.3269	4.487
9	0.2843	4.772
10	0.2472	5.019
11	0.2149	5.234
12	0.1869	5.421
13	0.1625	5.583
14	0.1413	5.724
15	0.1229	5.847
16	0.1069	5.954
17	0.0929	6.047
18	0.0808	6.128
19	0.0703	6.198
20	0.0611	6.259

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. **Highway Design and Operation for Safety**
Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. **Traffic Control and Management**
Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. **Highway Operations**
This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. **Pavement Design, Construction, and Management**
Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. **Structural Design and Hydraulics**
Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. **RD&T Management and Coordination**
Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.