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MATERIALS EVALUATED AS POTENTIAL SOIL STABILIZERS

by

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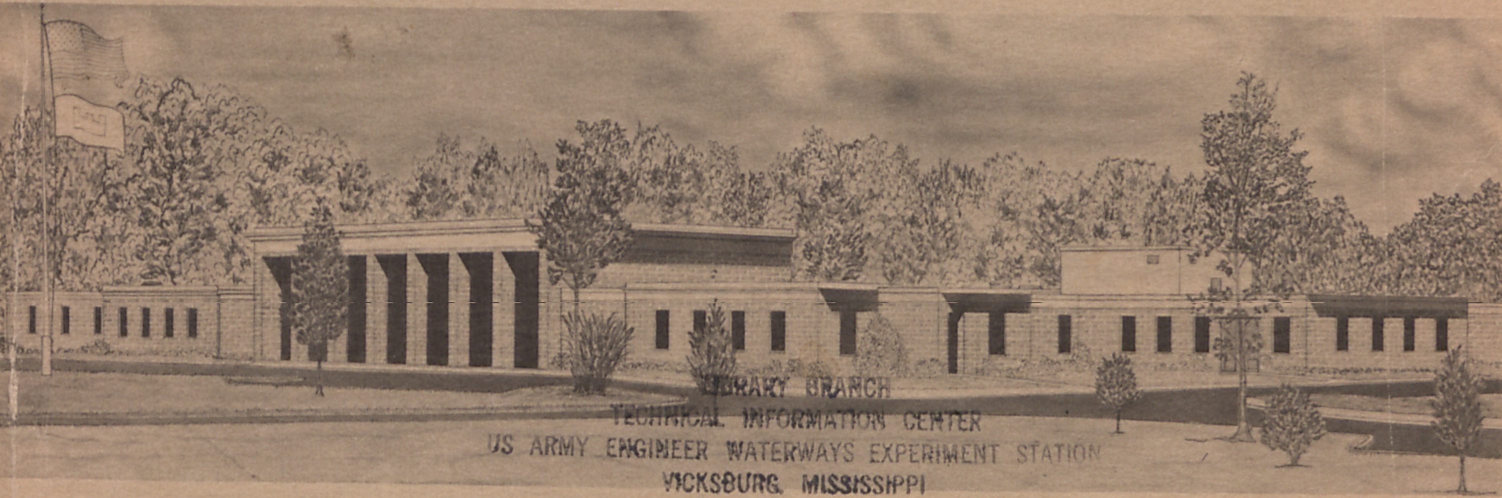

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This report documents the history of a program initiated in 1946 to evaluate materials for use as chemical soil stabilizers by the military. A number of Government agencies, universities, and private firms were involved in the program. In addition, many other companies submitted candidate materials for evaluation. Appendix A presents documentation of all materials evaluated including category, components, cost, applicability with regard to soil type, mixing capability, and related effectiveness. Also given are (Continued)

20. ABSTRACT (Continued)

the agencies which conducted the evaluation and appropriate references in which more detailed information of the materials can be found.

The most effective soil stabilizers and the compressive strengths produced by them in four general types of soils are summarized as follows:

	Unconfined Compressive Strengths, psi				
Soil Type	Untreated	Cement	Lime	Asphalt	Other Best Material
Silt	20	80-280	230-860	225	Sodium silicate - 650
Loess	20	100	160-970	--	Powders A and B - 385
Clay	20	76-300	100-340	104-289	Calcium oxide - 315
Sand	20	150-425	--	--	Aropol 7110 - 1170-1890

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PREFACE

Efforts to find a method of solidifying or stabilizing soils for military operations were initiated in May 1946 by the U. S. Army Corps of Engineers. From its beginning in 1946 to 1975, this program of tests to evaluate potential stabilization materials was conducted under the sponsorship of the Office, Chief of Engineers, U. S. Army, and the U. S. Army Materiel Development and Readiness Command. Various private firms also were involved with the tests as well as the U. S. Army Engineer Research and Development Laboratories (now the U. S. Army Mobility Equipment Research and Development Command) and the U. S. Army Engineer Waterways Experiment Station (WES).

This report was prepared at WES by Messrs. Jessie C. Oldham, Royce C. Eaves, and Dewey W. White, Jr., of the Materiel Development Division (MDD), Soils and Pavements Laboratory (S&PL), under the direct supervision of Messrs. William L. McInnis, Chief, MDD, and James P. Sale, Chief, S&PL.

Directors of WES during preparation of this report were COL G. H. Hilt, CE and COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
cubic feet	0.02831685	cubic metres
square yards	0.8361274	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C - (5/9) (F-32). To obtain Kelvin (K) readings, use: K = (5/9) (F-32) + 273.15.

MATERIALS EVALUATED AS POTENTIAL SOIL STABILIZERS

Background

1. In 1946, the U. S. Army Corps of Engineers (CE) initiated a research and development program having the objective of developing improved materials and methods to expeditiously solidify or stabilize soils for use in construction of roads and airfields and in support of military operations over soft ground. During the period 1946-1954, the U. S. Army Engineer Research and Development Laboratories (now the U. S. Army Mobility Equipment Research and Development Command (MERADCOM)) was responsible for the stabilization program. In 1954, the program was assigned to the U. S. Army Engineer Waterways Experiment Station (WES), where research has continued to the present time.

Purpose

2. This report is being published to document this study of chemical soil stabilization. Through both in-house research and contracted efforts, a wide range of materials was tested and this document serves to record all materials evaluated. This report is not intended to provide guidance in selection of materials or in construction methods. Additional information on each material is provided in the listed reference. Guidance in material selection and construction methods is provided in WES Miscellaneous Paper S-74-23, "Soil Stabilization for Roads and Airfields in the Theater of Operations," by W. N. Brabston and G. M. Hammitt, II, September 1974.

Review of Research

3. From 1946-1955, extensive literature reviews and limited laboratory studies were performed, initially under contract with the Massachusetts Institute of Technology (MIT), the University of California at Los Angeles, and Cornell University. Extensive contract work was

performed by MIT on stabilizer material development with emphasis on resin systems including melamines, furfurals, formaldehydes, ureas, silicates, acrylamides, vinyls, styrenes, epoxies, and acrylates. Special attention was given to calcium acrylate, which had been found unique in developing high strength in very wet soils. This polymer resin was studied extensively by MERADCOM both in the laboratory and in the field. Although unique in its mechanism, calcium acrylate had the disadvantages of high cost; the need for large quantities for effective use; heavy dependency on soil type, catalyst, and degree of mixing; and water sensitivity. Much work was devoted to studies of mixing and to development of a field mixing unit to apply calcium acrylate and of various additives to aid incorporation.

4. Simultaneously, Cornell University undertook a contract study of the fundamental properties of clay-water systems and their relation to engineering behavior of soils. Additional work by Cornell was devoted to lignin and chrome-lignin systems for stabilization. The concept of using chrome-lignin to prepare small pillow-shaped briquets of stabilized soil that could be used as artificial aggregate or fill material to bridge weak areas was explored. This technique was tested in the field but was determined to be impractical due to large-scale production requirements and mixing problems in plant production.

5. During this same period, several miscellaneous studies were performed including soil compaction by vibration (California Institute of Technology), low-angle X-ray scattering in soils (Armour Research Foundation), stabilizing soils by freezing (U. S. Bureau of Mines), and theoretical analysis of thin flexible surfaces under load over flexible subgrades (MIT).

6. Following the transfer of responsibility to WES in 1954, a series of state-of-the-art summary reviews of various soil stabilizing methods and materials was prepared including lignins (1955), calcium acrylate (1956), soil-cement (1956), bituminous materials (1956), lime (1957), mixing principles and equipment (1961), and electrical stabilization (1961). The stabilization problem was defined objectively in terms of specific military road and airfield operational needs, and realistic

requirements and criteria for various stabilization situations or categories were established to afford direction to the research program. These requirements have been revised periodically to conform to changing military operational concepts and needs.

7. Continued research by MIT from 1955-1961 was directed toward improving the capabilities of conventional stabilizers (asphalts, cement, and lime) and developing new stabilizing systems. This research led to the concept of stabilization with chemicals that attack and react with certain constituents of soil, forming cementitious products in situ. This approach resulted in extensive studies of acid and acid-forming systems, notably the phosphoric acid compounds, and led to improved chemically modified asphalt, cement, and lime systems. Additionally, research by MIT included new resin systems, soil-modifier systems, special asphalt emulsions, and sodium silicate formulations. From 1962-1972, MIT research was directed toward the development of a more fundamental understanding of the structural behavior of stabilized soil and the elucidation of the basic strength-producing mechanisms, both chemical and physical, of soil-additive systems. One phase of research completed by MIT was concerned with the chemical stabilization of selected tropical soils. The results confirmed the utility of cement and lime for improving a spectrum of initially weak soils of tropical origin for military mobility purposes.

8. A contract research effort was conducted by Cornell during 1964-1968 to establish the feasibility of electrokinetic processes for stabilization of soils for military mobility purposes. The study included uses of theoretical concepts of electrokinetics, laboratory investigations, and a field test program which involved the unique use of metal mat as one of the electrodes and embedded metal rods as the other electrode. The use of electrical energy to increase soil strength both by dewatering and by electrochemical injection was determined to be feasible, but the benefits achieved were highly dependent upon soil type and conditions, and considerable time was required to achieve significant increases.

9. Contract work was conducted during 1965-1974 by the University of California at Berkeley to investigate the influence of repetitive

loading on stabilized soil behavior. The results of this work have assisted in establishing appropriate design criteria for stabilized soil layers and procedures for the most efficient use of stabilizing materials.

10. During the time that this project has been assigned to WES, the soil stabilization research and development effort has consisted of two phases, contract research and in-house research. These two phases are closely linked. Contract research has been monitored closely, and materials showing potential have been examined in the in-house research program. In-house efforts have consisted of monitoring technical publications for potential materials or methods and testing and evaluation of materials submitted from industry or discovered in the literature. Positive results obtained from contract research have been explored further in laboratory and field testing. Contract reports documenting these results have been published, and in-house research of significance has been reported and made available to other Government agencies and other interested parties.

11. Materials showing significant potential have been fully evaluated in the laboratory, and field test sections have been constructed at WES and trafficked. Significant and major investigations are listed in the following paragraphs.

- a. Calcium acrylate was investigated by MIT and a test lane was constructed at MERADCOM prior to the soil stabilization program being moved to WES. Test lanes were constructed, tested, and evaluated at WES in 1955. Performance of this material was extremely good, but calcium acrylate was later dropped from consideration since it could not withstand rainfall and was too costly.
- b. Quicklime was evaluated as a soil stabilizer in laboratory and field tests during 1956-1957. Field tests indicated this material could stabilize weak, wet soils very rapidly; however, nonuniform strength resulted because proper mixing was very difficult to obtain.
- c. Major research was conducted in 1958 on the use of chemically modified cement in soil stabilization. Laboratory investigations were conducted to determine how various chemicals in combination with portland cement would perform as soil stabilizers. A number of materials were investigated in the laboratory, and results indicated sodium sulfate with cement alone.

d. Another major research project was conducted in 1958 consisting of laboratory and field investigations of phosphorus pentoxide as a soil stabilization chemical. Results indicated that phosphorus pentoxide had excellent potential for stabilizing some soils; however, traces of calcium carbonate in some soils partially neutralized the effects, and the rapid reaction of this material in wet soils left insufficient time for adequate mixing and compaction.

e. Major research in 1959 was directed toward developing additional information on the use of quicklime as a stabilizer of wet, weak soils for use by the military. Laboratory and field tests indicated the need for additional research to improve quicklime stabilization by chemical modification with supplementary secondary additives to overcome certain limitations.

f. Additional research was conducted in 1960-1961 on the use of supplementary chemicals to enhance the stabilization benefits of quicklime. Laboratory and field tests proved that a number of chemicals were beneficial in lime stabilization; however, the best of these was magnesium sulfate. Laboratory and field tests proved that use of magnesium sulfate in combination with the quicklime resulted in an agent that was much more effective than quicklime alone.

g. During 1955-1961, seven summary reviews were made and the results published concerning soil stabilization processes. These reviews covered work at WES and MERADCOM and literature surveys of work by others. The purposes of these reviews were to outline work by the military and others and to document advantages and disadvantages of various stabilizers.

h. Laboratory and field studies were conducted during 1961-1962 on stabilization of soils using portland cement with sodium hydroxide. These investigations indicated that appreciable benefits could be achieved in some soils using sodium hydroxide as a modifier. Excellent tolerance to wetting was achieved using these materials as stabilizing agents.

i. A program was conducted during 1963-1964 to develop design data on cement-stabilized soils. Variables included different strength subgrades, different thicknesses of stabilized layers, varied rates of cement treatment, and four different wheel loadings. A great amount of data was developed and used to verify or generate design criteria for stabilized layers.

j. From 1966-1972, research and development for dust control was conducted. The concept used was to develop a surface stabilizer, a spray-on system versus admix-type stabilization, to achieve strengths.

Summary

12. The number of materials and secondary additives tested in this program were many. The materials have been divided into two groups--effective and noneffective. Table 1 contains the materials that had some degree of effectiveness. Table 1 lists the basic materials, secondary materials or additives, soil type, and the number of the page in Appendix A of this report on which detailed information is presented. Table 2 lists materials that had no appreciable effect and did not effect a significant change in the soil parameters. Table 2 is similar to Table 1; however, no individual pages of detailed information are provided. Table 3 lists the best materials for each soil type; effective unconfined compressive strengths are listed.

Discussion

13. A wide range of materials was evaluated, both in the laboratory and in the field, during the course of this program. Basically, cement, lime, and asphalt were proven to be the better materials for strength stabilization. Research indicated that certain additives used with these materials in trace amounts either increased the strength developed or made the materials effective over a wider range of soils.

14. Also, other materials may be considered for use. These materials are effective in some soils and are economically feasible. Brief statements about these materials are listed below.

- a. Lignin or ligno sulphonate is a waste product from paper pulp manufacture. This material is an effective stabilizer and dust control agent for some silt and clay soils. The material is either free or very inexpensive, but laboratory tests should be conducted to determine its effectiveness on soils before large-scale field use is planned.
- b. Phosphoric acid and phosphorus pentoxide are effective stabilizers for some clay soils. These materials are hazardous and should be used carefully in the laboratory and the field.
- c. Aniline furfural resin is a highly effective waterproofing agent when admixed into clay soils. Permanent waterproofing

can be achieved with 1 to 3 percent of the resin. Aniline is highly toxic and should be used only after reviewing necessary precautions.

d. A number of materials were investigated for dust control for military purposes. This group of materials is listed in WES Miscellaneous Paper S-69-1, "Materials Investigated for Dust-Control Program (Southeast Asia)," by D. W. White and J. L. Decell, January 1969.

15. The documentation of materials tested is a method of providing guidance for later research. The program has been continued over a period of years. Many organizations and people have been involved. The list includes Government agencies, universities, and private firms. Ideas, concepts, and requirements were changed several times during the duration of the program, and information presented in the tables and in Appendix A is of a general nature. The appropriate referenced reports should be referred to for specific information about materials, test techniques, soils used, and results.

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Table 1

EFFECTIVE SOIL STABILIZERS

Basic Material	Additives	Soil Type	Reference	Page No.*
		CATEGORY: ACID		
Phosphoric acid (H_3PO_4)	Sodium fluosilicate	Clayey silt	40	A7-A8
↓	Refer to pages A9 and A10	Lean clay Heavy clay	18	A9-A10
↓	Curing agent - sodium fluosilicate Waterproofing agent - n-octylamine	Lean clay Clay	25	A11
↓	Refer to A12 and A13	Clayey silt	38	A12-A13
↓	Sodium fluosilicate (Na_2SiF_6) Octylamine, and Ortho-rhombic phosphoric anhydride ($O-P_2O_5$)	Clayey silt	40	A14-A15
↓	Sodium fluosilicate Rosinamine silico-fluoride Benzene phosphoric acid Butyl acid phosphate Phenyl acid phosphate Isooctyl acid phosphate	Clayey silt	37	A16-A17
↓	Water	Clayey silt Sandy clay Clay	36	A18

* The page (in Appendix A of this report) on which detailed information is presented.

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Phosphorus pentoxide		Sandy silt, clayey silt, sandy clay, loess, and clay	36	A19
↓	Sodium fluosilicate	Lean clay	15	A20
		CATEGORY: ASPHALT		
Asphalt cutback (Refer to page A23)	Phosphorus pentoxide (P_2O_5)	Clayey silt	37	A23
Asphalt cutback (50-60 pen)	Solvents (refer to pages A24-A25) Phosphorus pentoxide (P_2O_5)	Clayey silt	37	A24-A25
Asphalt cutback (Refer to pages A26 and A27)	Phosphorus pentoxide (P_2O_5)	Clayey silt	37	A26-A27
Cutback asphalt (Straight run, cracked, and blown)	Refer to A28 and A29	Clayey silt	35	A28-A29
Cutback asphalt (40-50 pen straight run asphalt)	Refer to A30	Lean clay and heavy clay	25	A30
↓	Solvent - unleaded gasoline Phosphoric acid (H_3PO_4)	Lean clay and clay	25	A31

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Cutback asphalt (40-50 pen straight run asphalt)	Solvent - unleaded gasoline Additive - phosphorus pentoxide (P_2O_5)	Lean clay and clay	25	A37
	Solvent - unleaded gasoline Additives (Refer to A38-A39)	Lean clay and clay	25	A38
	Solvent - unleaded gasoline Additives (Refer to A40-A41)	Lean clay and clay	25	A40-A41
	Solvent - unleaded gasoline Additives (Refer to A40-A41)	Lean clay and clay	25	A42-A43
	Solvent - unleaded gasoline Additives (Refer to A42-A43)	Lean clay and clay	25	A44-A45
Straight run asphalt	Refer to A46-A47	Clayey silt	36	A44-A45
Straight run asphalt (40-50 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline Additive - chromic chloride and phosphoric acid	Clayey silt	40	A48

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Straight run (40-50 pen) asphalt	Phosphorus pentoxide and anti-stripping additives and water	Sandy silt	36	A49-A51
Straight run asphalt (100-200 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline Additive - chromic chloride	Clayey silt	40	A52
Straight run asphalt (100-120 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Additive - chromic chloride, water, and phosphoric acid	Clayey silt	40	A53
Straight run asphalt (100-200 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline Additive - chromic chloride and phosphoric acid	Clayey silt	40	A54
Straight run asphalt (100-120 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline Additives - ferric chloride and phosphoric acid (H_3PO_4)	Clayey silt	40	A55

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Straight run asphalt (100-120 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline and phosphoric acid	Clayey silt	40	A57
Straight run asphalt (100-200 pen)	Emulsifying agent - nonic 218 Solvent - gasoline and phosphoric acid (H_3PO_4)	Clayey silt	40	A58
Straight run asphalt (100-120 pen)	Emulsifying agents - Duomeen T and hydrochloric acid Solvent - gasoline Additives - ferric chloride and phosphoric acid	Clay (Vicksburg)	40	A59
	CATEGORY: CEMENT			
Alumina cement	Modifiers (Refer to A62-A63)	Loess	Internal Data (1956), not published	A62-A63
Cement	Sodium hydroxide plus sodium sulfate	Clay (Texas #2)	39	A64
↓	Sodium hydroxide (NaOH)	Clay (Vicksburg)	40	A65
↓	Sodium hydroxide plus sodium sulfate	Sand (Wisconsin #1)	39	A66

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Cement	Sodium hydroxide plus sodium sulfate	Silt	39	A67
Cement (plus 1N NaOH - sodium hydroxide)	Refer to A68-A69	Clay (Vicksburg)	40	A68-A69
Fast Fix		Lean clay, heavy clay, and sand	Internal Data (1971), not published	A70
Lumnite cement		Sand, loess, and heavy clay	Internal Data (1956), not published	A72-A73
Plaster of Paris		Lean clay and heavy clay	Internal Data (1956-1957), not published	A74
Portland cement		Loess	24	A75
↓		Lean clay and clay	25	A76
	Refer to A77-A78	Clayey silt	35	A77-A78
	Arquad 2HT plus sodium hydroxide	Clay (Texas #2)	39	A79-A80
	Refer to sheets A81-A82	Clay (Vicksburg)	39	A81-A82
	Refer to sheets A83-A84	Silt	37	A83-A84
	Calcium chloride Sodium hydroxide Sodium carbonate Sodium sulfite Sodium sulfate Sodium metasilicate	Sand (Wisconsin #2)	38	A85-A86

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Portland cement	Refer to pages A87-A88	Lean clay and heavy clay	18	A87-A88
	Dispersants (Refer to pages A89-A90)	Clayey silt	35	A89-A90
	Sodium hydroxide Sodium carbonate Sodium metasilicate	Loess	38	A91-A92
	Sodium hydroxide Sodium carbonate Sodium metasilicate Sodium sulfate	Sand (Wisconsin #1)	38	A93-A94
	Sodium hydroxide, sodium carbonate, sodium metasilicate, sodium sulfate, sodium aluminate, sodium fluosilicate, sodium floride, sodium fluoborate, and sodium tetraborate	Silt	38	A95-A96
	Sodium hydroxide, sodium sulfate, sodium aluminate	Silt	39	A97-A98
	Sodium hydroxide, sodium sulfate, sodium aluminate, ferric chloride plus sodium hydroxide, octylamine plus sodium hydroxide	Clay (Texas #2)	39	A99-A100

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Portland cement	Sodium hydroxide sodium sulfate, sodium aluminate, sodium metasilicate	Clay (Texas #2)	39	A101
	Sodium hydroxide sodium sulfite, sodium carbonate	Clay (Illinois)	38	A102-A103
	Sodium hydroxide, sodium sulfite, sodium carbonate, sodium metasilicate	Clay (Texas #1)	38	A104-A105
	Sodium hydroxide, sodium hydroxide plus barium chloride, sodium sulfite, sodium carbonate, sodium metasilicate	Clay (Texas #2)	38	A106-A107
	Sodium metasilicate	Lean clay and clay	25	A108
	Sodium orthosilicate	Lean clay and clay	25	A109
↓	Sodium orthosilicate, sodium metasilicate, grade 50 silicate, grade 40 silicate, sodium oxide (Na_2O), silicon dioxide (SiO_2)	Silt	39	A110-A111

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Portland cement	Sodium sulfate (Also refer to pages A112-A113)	Loess	14	A112-A113
	Sodium sulfate, ET-224 dispersant, barium chloride, sodium fluosilicate	Loess	38	A114-A115
	Sodium sulfate and sodium metasilicate	Lean clay and clay	25	A116
	Sulfate compounds (Refer to pages A117-A118)	Sand (Wisconsin #1)	39	A117-A118
Type I normal portland cement	Chemical additives (Refer to pages A119-A121)	Loess	36	A119-A121
	Chemical additives (Refer to pages A122-A124)	Silt	36	A122-A124
	Chemical additives (Refer to pages A125-A127)	Silty clay	36	A125-A127
Type I portland cement	Sodium hydroxide (with heavy clay only)	Lean clay and heavy clay	9	A128-A129

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
		CATEGORY: LIME		
Hydrated lime	Sodium hydroxide, sodium sulfate, sodium carbonate, magnesium sulfate, calcium oxide, calcium hydroxide, portland cement	Lean clay	Internal Data (1960), not pulbished	A132
Calcium hydroxide (slaked lime)		Clay (Vicksburg)	41	A133
↓	Magnesium sulfate	Clay (Vicksburg)	41	A134
Calcium and magnesium limes (CaO and MgO)	Magnesium sulfate	Lean clay and heavy clay	Internal Data (1961), not published	A135-A136
Calcium oxide		Clay (Houston black)	41	A137
Calcium oxide (lime)		Clay (Vicksburg)	41	A138
Calcium oxide	Refer to pages A139-A140	Clay (Houston black)	41	A139-A140
↓	Refer to pages A141-A142	Clay (Vicksburg)	41	A141-A142
Calcium oxide (lime)	Magnesium sulfate	Clay (Vicksburg)	41	A143
Calcium oxide	Magnesium sulfate, potassium sulfate, magnesium chloride	Clay (Vicksburg)	40	A144-A145

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Calcium oxide plus magnesium sulfate plus cutback asphalt	Solvent - gasoline	Lean clay and clay	25	A146
Quicklime		Clayey silt, silt, clay, and loess	37	A147-A148
	Magnesium sulfate	Lean clay, heavy clay, clayey silt, silt, blue clay, sandy clay, and sand	17	A149-A150
		Lean clay	16	A151-A152
	Modifiers (Refer to pages A153-A154)	Lean clay and heavy clay	18	A153-A154
		CATEGORY: RESIN		
AM9 (water-soluble acrylamide and diacrylamide)	Catalyst - dimethylamino-propionitrile-potassium ferricyanide-ammonium persulfate Solvent - water	Sand	57	A157
Aniline-furfural		Loess	24	A158
		Lean clay and clay	51	A159

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Aropol 7110	Solvent - styrene	Sand	57	A160
Arothane 170	Solvent - butyl acetate	Sand	57	A161
Bisphenol A (Epon 828)	Catalyst - Ashland #1496 Solvent - solox	Sand	57	A162
Calcium acrylate		Loess	24	A163
↓	Refer to pages A164-A165	Sandy clay	31	A164-A165
↓	Salt additives (Refer to page A166	Sandy clay	31	A166
↓	Various salts (Refer to A167-A168	Sandy clay	32	A167-A168
Epon VIII	Curing agents - Agent A (amine) diethylenetriamine (Refer to pages A169-A170) Water	Sandy clay	34	A169-A170
Epon 562	70% diethylene triamine, 30% dimethyl aminomethyl phenol (above curing agents); solvent - acetone; potassium hydroxide (KOH)	Sandy clay	37	A171

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Epon 828	Xylene Curing agents - diethylene triamine, diethylaminomethyl phenol, mixtures of above curing agents, polyethylene	Sandy clay	35	A172
	70% diethylene triamine, 30% dimethyl aminomethyl phenol (curing agents); solvents - Refer to pages A173-A174	Sandy clay	37	A173-A174
	Curing agent - 7:1 ratio of diethylene triamine to dimethyl aminomethyl phenol	Lean clay and heavy clay	Internal Data (1956-1957), not published	A175
Epon 834	Curing agents - tetraethylenepentamine diethylenetriamine Water Refer to pages A176-A177	Sandy clay	34	A176-A177
		CATEGORY: SALT		
Arquad 2HT (Dialkyl dimethyl-ammonium chloride)		Loess	24	A180

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
		CATEGORY: SILICATE		
Sodium silicate (30% solution)		Loess	24	A183
Sodium silicate plus basic magnesium carbonate		Loess	40	A184-A185
Sodium silicate N	Solvent - water	Sand	57	A186
Sodium silicate (composed of 1.59% sodium oxide and 3.82% silicon dioxide)	Precipitating agents - magnesium oxide and magnesium carbonate	Clayey silt	40	A187-A188
Sodium silicate (49.8% solids, potassium oxide to silicon dioxide = 1:1.58)	Precipitant - calcium hydroxide, calcium sulfate, magnesium oxide, magnesium carbonate	Clayey silt	39	A189
Sodium silicate	Magnesium carbonate (precipitant)	Clayey silt	39	A190-
Sodium silicate (49.8% solids; sodium oxide to silicon dioxide = 1:1.58)	Precipitant - magnesium carbonate Waterproofing agents - octylamine and arquad 12 (lauryl trimethyl ammonium chloride)	Clayey silt	39	A191-A192

Table 1 (Cont'd)

Basic Material	Additives	Soil Type	Reference	Page No.
Sodium silicate plus calcium hydroxide, $Ca(OH)$		Clayey silt	40	A193
Sodium silicate plus basic magnesium carbonate		Silt	40	A194-A195
		CATEGORY: OTHER		
Chrome lignin		Loess	24	A197
Lignin (clarion extract)	Sodium dichromate, sulfuric acid, sodium chloride	Clay	5	A198-A199
Powder A plus powder B		Loess and heavy clay	Internal Data (1974), not published	A200
SA-1		Lean clay and heavy clay	Internal Data (1974), not published	A201-A202
Sandcrete		Lean clay and sand	Internal Data (1972), not published	A203
Sodium methylethyl propyl siliconate		Loess	24	A204
Soil-Set		Lean clay, heavy clay, and sand	Internal Data (1966), not published	A205-A206

Table 2

NONEFFECTIVE SOIL STABILIZERS

Basic Material	Additives	Soil Type	Reference
CATEGORY: ACETATE			
Amine D acetate		Lean clay and clay	25
Octadecyl amine acetate		Lean clay and clay	25
Resyn 78-1035 (polyvinyl acetate emulsion)		Clay	36
Rosin amine D acetate		Clay	36
Seycorez B-17		Lean clay	Internal Data (1972), not published
CATEGORY: ACID			
Hydrochloric acid	Water	Clay	36
Nitric acid	Water	Clay	36
Orthorhombic phosphorus pentoxide	Cure agent - sodium fluosilicate	Lean clay and clay	25
Orthorhombic phosphorus pentoxide	Curing agent - sodium fluosilicate Waterproofing agent - n-octylamine	Lean clay and clay	25
Orthorhombic phosphorus pentoxide $O\text{-}P_2O_5$	$O\text{-}P_2O_5$, Na_2SiF_6 (sodium fluosilicate), n-octylamine	Lean clay and heavy clay	18

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Phosphoric acid	Aluminum chloride	Clay (Vicksburg)	41
Phosphoric acid (H_3PO_4)	Octylamine, Armeen 16D, Armac 18D	Clayey silt	37
Phosphoric acid (H_3PO_4)	n-butylamine, n-hexylamine, n-octylamine, octadecylamine	Clay	38
Phosphoric acid	Duomeen C, Duomeen S, Duomeen T	Clay (VBC)	39
	Salts as waterproofers - ferric chloride, aluminum chloride, chromium chloride, magnesium chloride	Clay (VBC)	39
	Rosinamine D acetate, Melamine	Clay (Vicksburg)	40
Phosphoric acid (H_3PO_4)	Curing agent - sodium fluosilicate	Lean clay and clay	25
Phosphoric acid	Curing agent - sodium fluosilicate, ferric chloride	Lean clay and clay	25
Phosphoric acid (H_3PO_4)	Curing agent - sodium fluosilicate Waterproofing agent - n-octylamine, orthorhombic phosphorus pentoxide	Lean clay and clay	25

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Phosphoric acid	Sodium fluosilicate, octylamine, sulfuric acid, hydrochloric acid, ferric chloride	Clay (Vicksburg)	40
Phosphoric acid plus sulfuric acid		Clayey silt	41
↓	Aluminum sulfate	Clayey silt	41
↓	Ferric chloride	Clay (Vicksburg)	41
Sulfuric acid		Clay	36
↓	Ferric chloride	Clay (Vicksburg)	41
Acrylic acid and methylvinyl pyridine (MVP)	Methylene-bis-acrylamide (cross-linking agent)	Sandy clay	34
Maleic acid and MVP		Sandy clay	34
Maleic acid, MVP, and methylene-bis-acrylamide (MBA)		Sandy clay	34
Acrylic acid and acrylamide	Triacrylyl triazine (cross-linking agent)	Sandy clay	34
Maleic acid and acrylonitrile	MBA	Sandy clay	34

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
	CATEGORY: ASPHALT		
Asphalt cutback	Antistripping additives Water	Clayey silt	35
Asphalt emulsion PR 74	Pretreatment agents - Ferric sulfate, alum, hyamine 1622, quilon	Sandy clay	33
Asphalt, emulsion, straight run	Various emulsifiers	Clayey silt	35
Asphalt fractions		Clayey silt	37
Emulsified asphalt (SS-1, 66% asphalt)		Loess	24
MC - 0 asphalt (50% asphalt)		Loess	24
Modified MC-O asphalt	Phosphorus pentoxide and lauryl amine	Loess	24
Straight run asphalt	Ferric sulfate, ferric chloride, aluminum sulfate, alkyl ketenedimer (Aquapel 380), 2-ethylhexylamine, coconut fatty diamine (Duomeen C), soya fatty diamine (Duomeen S), tallow fatty diamine (Duomeen T), hexamethyl disiloxane, sodium methyl siliconate (SC-50)	Clayey silt and buckshot clay	36

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Straight run asphalt (Cont'd)	Partially polymerized chloropolysiloxane (SC-87), dimethylamine ethyl acrylate, quarternized (DV-559), methylated methylol melamine (accobond 3913), acrylic ester resin (acryloid 996)		
↓	Armeen 18D (octadecyl amine), Duomeen A - diamine, ethoduomeen T-15, cationic agent A, nonic 218	Clayey silt, silt, and clay (Vicksburg)	39
Straight run asphalt (100-120 pen)	Emulsifying agents - duomeen T, hydrochloric acid Solvent - gasoline Additives - chromic chloride, phosphoric acid	Clayey silt	40
Straight run asphalt (100-200 pen)	Emulsifying agents - duomeen T, hydrochloric acid Solvent - gasoline Additive - chromic chloride, phosphoric acid	Clayey silt	40
Straight run asphalt	Lauryl amine (Armeen 12D) and concentrated hydrochloric acid emulsion	Sandy silt, clayey silt, sandy clay, loess, and clay	36
↓	Sodium oleate emulsion	Sandy silt, loess, sandy clay, clayey silt, and clay	36

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Teroeas (emulsion)		Sand and clay	5
Vacuum refined asphalt	Armeen 18 acetate, Armeen 18 acetate plus glyceryl monostearate, Armeen 18 acetate plus nonic 218, ammonium N-Coco, amino butyrate, ethanolamine oleate, and ammonium oleate	Clayey silt	38
	CATEGORY: CEMENT		
Hydrated lime	Magnesium sulfate and sodium hydroxide	Lean clay and heavy clay	18
	Sodium hydroxide, sodium metasilicate, sodium sulfate	Silt	39
Portland cement	Polyvinyl alcohol, carboxymethyl cellulose, guartec SF, guartec D	Lean clay	Internal Data (1963), not published
↓	Sodium aluminate	Lean clay and clay	25
↓	Sodium hydroxide	Lean clay and clay	25
↓	Sodium hydroxide and sodium metasilicate	Lean clay and clay	25
↓	Sodium hydroxide, sodium metasilicate, sodium sulfate, octylamine plus sodium hydroxide	Clay (Vicksburg)	39
↓	Sodium hydroxide, sodium orthosilicate	Lean clay and clay	25

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Portland cement	Sodium sulfate	Lean clay and clay	25
↓	Sodium sulfate and sodium orthosilicate	Lean clay and clay	25
Portland cement plus aliquot		Lean clay and heavy clay	Internal Data (1961), not published
	CATEGORY: OTHER		
Aerospray		Lean clay	Internal Data (1960), not published
Airflex		Sand and silty clay	Internal Data (1973), not published
Ammonium hydroxide		Clay	36
Astro-Soil		Clay	Internal Data (1971), not published
Bentonite	Amides and quaternary salts	Sand	30
	Bentonite gel	Sand	30
	Bentonite gel plus potassium, lead, calcium, magnesium, and aluminum	Sand	30
↓	Potassium, lead, calcium, magnesium, and aluminum	Sand	29

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Bindarene flour (lignin)	Potassium bichromate, aluminum	Clay	5
↓	Potassium bichromate, calcium oxide, magnesium sulfate, borax, portland cement, barium chloride, Monsanto resin CRD 197, sodium phosphate, sodium formate, sodium aluminate, sodium silicate, and sodium hydroxide	Clay	5
Bindarene flour	Sodium bichromate, potassium bichromate	Sandy clay and clay	5
Calcium ($CA(OH)_2$) and magnesium hydroxide ($Mg(OH)_2$)	$MgSO_4$	Lean clay	Internal Data (1961), not published
Calcium carbide		Lean clay and heavy clay	Internal Data (1956-57), not published
Calcium hydroxide $Ca(OH)_2$	Sodium hydroxide, magnesium sulfate, potassium sulfate	Clay (Vicksburg)	40
Calcium hydroxide plus magnesium sulfate		Lean clay and clay	25
Calcium hydroxide plus sodium hydroxide		Lean clay and clay	25
Calcium oxide	Magnesium sulfate and Dustrol	Heavy clay	Internal Data (1960), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Calcium oxide	Magnesium sulfate, sodium metasilicate, zinc sulfate, nickel sulfate	Shale (Suburua soft)	41
	Polyvinyl alcohol plus carboxymethyl cellulose	Lean clay and heavy clay	Internal Data (1963), not published
Calcium oxide plus magnesium sulfate		Lean clay and clay	25
	Alkyl dimethyl benzyl ammonium chloride	Lean clay and clay	25
	Amine D acetate	Lean clay and clay	25
	n-octylamine	Lean clay and clay	25
	Octadecyl amine acetate	Lean clay and clay	25
	Octadecyl amine	Lean clay and clay	25
	Sodium orthosilicate	Lean clay and clay	25
Calcium oxide plus sodium hydroxide		Lean clay and clay	25
Carboxy methyl cellulose (CMC)		Sand, clay, and sandy clay	5
		Lean clay and heavy clay	Internal Data (1956-57), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Casein 141-V		Lean clay	Internal Data (1960), not published
Casein 1221V		Lean clay	Internal Data (1960), not published
Casein plus hydrated lime plus ferric oxide (ratio - 55:13:3)		Lean clay	Internal Data (1958), not published
Casein glue		Lean clay	Internal Data (1960), not published
Chrome lignin		Silt	22
↓		Clay	36
Cla-Pak		Lean clay and heavy clay	Internal Data (1974), not published
Cla-Set		Lean clay and heavy clay	Internal Data (1974), not published
Compact		Lean clay	Internal Data (1972), not published
Daimond Siroc		Lean clay	Internal Data (1964), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Dustmaster		Lean clay	Internal Data (1972), not published
Dustmaster "C"		Lean clay	Internal Data (1972), not published
Dustmaster "WR"		Lean clay	Internal Data (1972), not published
Dustrol (road oil)		Loess	24
Ecology Control M-Binder		Lean clay	Internal Data (1973), not published
Erode-X		Lean clay	Internal Data (1972), not published
Ferrous lignosulphonate		Silty sand	36
Florok		Clay	Internal Data (1965), not published
Formula 125		Lean clay and heavy clay	Internal Data (1974), not published
Formula 2221		Lean clay and heavy clay	Internal Data (1961), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Genaqua erosion control latex 169		Lean clay	Internal Data (1972), not published
Guartec D		Lean clay and heavy clay	Internal Data (1963), not published
Guartec SF		Lean clay and heavy clay	Internal Data (1963), not published
Huls 801		Lean clay	Internal Data (1972), not published
Iron polyphosphate	Sodium tetraphosphate, ferrous chloride, ferric chloride	Sandy clay	34
Kel-Pak		Lean clay and heavy clay	Internal Data (1974), not published
Laurylamine		Lean clay and clay	25
Lignin	Ferric chloride, phosphorus pentoxide, aluminum sulfate, sodium peroxide, stannic chloride, sodium chlorate	Clay	5
Lignin (unoxidized)		Sand, sandy clay, and clay	5
Magnesium oxychloride		Sandy clay	33

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Mortuary hardening compound		Lean clay	Internal Data (1959), not published
n-octylamine		Lean clay and clay	25
Octadecyl amine		Lean clay and clay	25
Orthorhombic phosphoric anhydride	Sodium fluosilicate, octylamine, phosphoric acid, ferric chloride	Clay (Vicksburg)	40
Orzan-50		Lean clay	Internal Data (1972), not published
Paczyme		Clayey silt	27
Pectosol		Clay	5
Pen-E-Pac		Lean clay	Internal Data (1970), not given
Pen-E-Pac plus asphalt		Lean clay	Internal Data (1970), not published
Phosphate rock	Sulfuric acid	Lean clay and heavy clay	18
Plasmofalt		Sandy clay	31
Polyvinyl alcohol (PVA) and CMC		Loess, heavy clay, and sandy clay	Internal Data (1956), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Sodium bentonite	Calcium chloride, lead acetate	Sandy clay	30
Sodium pectate	Sodium phosphate, sodium bichromate	Not given	5
Soil Master		Clay	Internal Data (1971), not given
Speed crete		Lean clay	Internal Data (1959), not published
Styrene	Emulsifying agents - methyl-vinyl pyridine, polymethyl-vinyl pyridine Catalyst - cyclohexanone peroxide Accelerator - cobalt-naphthenate	Sandy clay	35
Sylon (alkoxy amine silane)		Sand, sandy clay, and clay	5
Terra-Krete		Lean clay, heavy clay, and sand	Internal Data (1973), not published
Verdyol Super		Lean clay	Internal Data (1973), not published
Westco D-1		Lean clay	26

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Quicklime		Lean clay	13
Quilon (stearate chromic chloride)		Clay	5
RD-4516		Lean clay	Internal Data (1974), not published
RD-4518		Lean clay	Internal Data (1974), not published
Reynolds Road Packer (1 part Road Packer to 1000 parts water by volume)		Lean clay	Internal Data (1961), not published
R&I Moldit (418-2)		Lean clay and heavy clay	Internal Data (1957), not published
R&I Moldit (419-2)		Lean clay and heavy clay	Internal Data (1957), not published
Roadseal #17		Lean clay	Internal Data (1972), not published
SA-1		Silty clay	28
SC-100		Loess and heavy clay	Internal Data (1957), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Westco D-2		Lean clay	26
XB-2386		Lean clay and heavy clay	Internal Data (1972), not published
	CATEGORY: OTHER/ACID		
Calcium phosphate plus sulfuric acid		Clayey silt	39
Methyl-vinyl pyridine (MVP), methylene-bis-acrylamide (MBA), and benzene phosphoric acid	Water Catalyst - ammonium persulfate Activator - sodium thiosulfate	Sandy clay	34
MVP and sulfuric acid	Water Catalyst - ammonium persulfate Activator - sodium thiosulfate	Sandy clay	34
MVP, trisacryl, and benzene phosphoric acid	Water Activator - sodium thiosulfate Catalyst - ammonium persulfate	Sandy clay	34
Phosphate rock (71.4% by weight $CA_3(PO_4)_2$ and 3% fluorine) plus sulfuric acid	Octylamine and ferric chloride	Clay (Vicksburg)	40
Phosphate rock and sulfuric acid		Clayey silt	41

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Phosphate rock plus sulfuric acid	Additive - sodium fluosilicate Waterproofing agents - Octylamine and Armeen 8	Clayey silt and clay (Vicksburg)	41
	CATEGORY: RESIN		
Acrylonitrile	Emulsifying agents - Methyl-vinyl pyridine and polymethyl-vinyl pyridine Catalyst - potassium sulfate Accelerator - sodium bisulfite	Sandy clay	35
American resinous emulsion 382-37C	Pretreatment agents - quilon, hyamine 1622, ferric sulfate, alum, laurylamine, and primac JMA-T	Sandy clay	33
American resinous emulsion 1073-18H	Pretreatment agents - quilon, hyamine 1622, ferric sulfate, alum, laurylamine, and primac JMA-T	Sandy clay	33
American resinous emulsion 1450-15B	Pretreatment agents - quilon, hyamine 1622, ferric sulfate, alum, laurylamine, and primac JMA-T	Sandy clay	33
Aniline-furfural	Phthalic acid (catalyst)	Sand	30

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Aniline-furfural	Solox	Sand and clay	57
Arboneeld B		Sand, clay, and sandy clay	5
Arlon 110		Sand	57
Arlon 310 (air-dry alkyd)		Sand	57
Arlon 363		Sand	57
Arlon 580 (air-dry alkyd)	Solvent - water	Sand	57
Aroplaz 832	Solvent - JP-4	Sand	57
Aroplaz 6008	Solvent - JP-4	Sand	57
Aroplaz 6065	Solvent - JP-4	Sand	57
Ashland experimental emulsion	Solvent - water	Sand and clay	57
Barium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Butyl methacrylate	Polyvinyl alcohol (emulsifier) Dimethyl aniline (catalyst) Benzoyl peroxide (accelerator)	Sandy clay	36
Calcium acrylate	Zinc sulfate and sodium sulfate	Sandy clay	31

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Calcium acrylate	Catalyst - aluminum persulfate Catalyst activator - sodium thiosulfate	Sandy clay	30
	Ammonium persulfate-sodium thiosulfate system Ferrous ions (as activator for above system)	Sandy clay	31
Calcium acrylate and ammonium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	31
Calcium acrylate and calcium methacrylate	Water AP/ST - catalyst/activator (ammonium persulfate and sodium thiosulfate)	Sandy clay	31
Calcium acrylate and ethylene glycol diacrylate	Water AP/ST - catalyst/activator (ammonium persulfate and sodium thiosulfate)(See comments on page A227)	Sandy clay	31
Calcium acrylate and lithium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	31

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Calcium acrylate and manganese acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Calcium acrylate and magnesium acrylate	"	Sandy clay	32
Calcium acrylate and methylene-bis-acrylamide		Sandy clay	31
Calcium acrylate and monoamine acrylates		Sandy silt	31
Calcium acrylate and N-methylolacrylamide		Sandy clay	31
Calcium acrylate and organic nonionic monomers		Sandy soil	31
Calcium acrylate and precondensed N-methylolacrylamide		Sandy clay	31
Calcium acrylate and nickel acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Calcium acrylate and potassium acrylate	"	Sandy clay	31

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Calcium acrylate and sodium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	31
Calcium acrylate and zinc acrylate	"	Sandy clay	31
Calcium acrylate, zinc, and sodium acrylate	"	Sandy clay	32
Calcium methacrylate	Catalysts - ammonium persulfate, t-butyl, hydroperoxide, hydrogen peroxide, and urea peroxide	Sandy clay	31
Chem Rez 200	Solvent - solox	Sand	57
Coherex	Solvent - water	Sand and clay	57
Creosote bush extract		Lean clay	Internal Data (1959), not published
DC 804 silicone resin	See Reference 30	Sand	30
DC 2103 silicone resin	See Reference 30	Sand	30
Dimethyl aminoethyl acrylate		Clay	36
DRC resin	Catalyst - 2 parts of cobalt napthenate to 1 part lead napthenate	Lean clay	Internal Data (1960), not published

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Emlon E-200	Solvent - water	Sand and clay	57
EP 8908-23		Sand	57
EP 8908-122		Sand	57
EP 8908-129		Sand	57
Epiphen ER 823	Curing agents - diethylene triamine, diethylaminomethyl phenol, combination of above curing agents	Sandy clay	35
Epon VI	Curing agents - Agent A (amine), diethylenetriamine water	Sandy clay	34
Epon 562	Acetone (solvent); curing agent and waterproofers for treated samples (See Reference 37)	Sandy clay	37
Epon 828	Curing agent - diethylenetriamine Water	Sandy clay	34
	Curing agent and hydroxides	Sandy clay	37
Epon 834	Xylene Curing agent - DMP-30 (tri dimethylaminomethyl phenol)	Sandy clay	35

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Epon RL 1062	Curing agents - Diethylenetriamine, tetraethylenepentamine, water	Sandy clay	34
Epon Rn 34		Sand and clay	5
15xPF gelatin	Catalyst - chromium sulfate and formaldehyde Solvent - water	Sand	57
Hexamethylolmelamine	Catalyst "AC" Hydrochloric acid	Sand	30
Isomerized glyceryl ester of resin		Loess	24
Laminac 4116 (alkyl styrene resin)		Sand and clay	5
Laminac 4134		Sand, sandy clay, and clay	5
Manganese acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Magnesium acrylate	"	Sandy clay	32
Melamine		Sand	29

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Methoxy ethyl acrylate	Emulsifiers - polyvinyl alcohol and octadecyl trimethyl ammonium chloride Catalyst - dimethyl aniline Accelerator - benzoyl peroxide	Sandy clay	36
Methyl acrylate and calcium acrylate	Emulsifier - polyvinyl alcohol Catalyst - potassium persulfate Accelerator - sodium bisulfite	Sandy clay	36
Methylene-bis-acrylamide and acrylamide	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulate)	Sandy clay	32
↓	Glyoxal (reactant)	Sandy clay	33
Methylene-bis-acrylamide (MBA) and acrylamide plus ethyl acrylate	Ethanol plus water plus ethyl acrylate AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
MBA and acrylic acid	Dispersants - Quadrafos and aerosol AY Pretreatments - Volan, hyamine 1622, aluminum sulfate	Sandy clay	33
MBA and sodium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Natural shellac		Sand	30
n-methylolacrylamine	See Reference 31	Sandy clay	31
Nickel acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Parez 620 (cationic urea-formaldehyde)		Sand and clay	5
Perma-Soil		Lean clay	Internal Data (1972), not published
Petroset		Lean clay	Internal Data (1974), not published
Polycalcium acrylate	Sodium thiosulfate and ammonium persulfate	Clay (Kaolin)	30
Polylite 8000	See Reference 35	Sandy clay	35
	Arquad 12 and Armeen 12D (EA) Acrylamide (monomer) Potassium persulfate (catalyst) Sodium bisulfite (accelerator) Water added on soil EA - emulsifying agent	Sandy clay	36

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Polylite 8000	See Reference 36	Sandy clay	36
Polylite 8009	See Reference 35	Sandy clay	35
	Emulsifying agent methyl-vinyl pyridine, polymethyl-vinyl pyridine (See Reference 35 for various catalysts and accelerators used)	Sandy clay	35
Polylite 8009 and 8120	Emulsifying agent - A12-A12D Catalyst - MEKP Accelerator - CN	Sandy clay	35
Polymer emulsions (see comments on page A301)		Sand and sandy clay	31
Polyvinyl acetate	Water	Sandy clay	36
Polyvinyl acetate and acrylamide	Ammonium persulfate, sodium thiosulfate, and water (on soil)	Sandy clay	36
Resimene 815	Catalyst - "AC" 1% hydrochloric acid	Sand	30
Resinox L10060		Sand	29

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Resinox 407	Resinox 408 hardener	Sandy clay	35
Resinox 426		Sand	29
Resorsabond		Sand	29
Resorsabond R-11	See Reference 30	Sand	30
Resorsabond R-12		Sand	30
Shellac	Maleic acid	Sand	30
Strontium acrylate	Water AP/ST - catalyst-activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
Styrene emulsion	Various solvents used - Toluene, benzene, and methylene dichloride	Sandy clay	34
Trimethylolmelamine	Catalyst - "AC" 1% hydrochloric acid	Sand	30
Urea-melamine-formaldehyde (31% nonaqueous solids)	Phthalic salicylic and maleic acids (both catalysts)	Sand	30
(48.5% nonaqueous solids)	See Reference 30	Sand	30
(48.5% nonaqueous solids)	Butex, 4 C-BL, admixtures of both, catalyzed with phthalic acid	N/A	30

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Urea-melamine-formaldehyde (48% nonaqueous solids)	Catalysts - chloroacetic, maleic, succinic, tartaric, terephthalic acids, and potassium acid phthalate	Sand	30
(48.5% nonaqueous solids)	Hydrotropic agents (see Reference 30	Sand	30
	Catalyst - phthalic acid	Sandy clay	30
	Phthalic acid (pH 3.9) (cure time varied)	Sand	30
	Phthalic acid (pH 3.9)	Sand	30
	Polyvinyl alcohol, Elvanol 50-42A, Elvanol 50-42B, Elvanol 72-51A, and Elvanol 20-105A	Sand	30
	Polyvinyl acetate modification	Sand	30
	See Reference 30 for surface active agents	Sand	30
Zinc acrylate	Water	Sandy clay	31
Zinc acrylate		Lean clay and heavy clay	Internal Data (1956-57), not published
Zinc acrylate and ammonium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate and sodium thiosulfate)	Sandy clay	31

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Zinc acrylate and potassium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	31
Zinc acrylate and lithium acrylate	"	Sandy clay	31
Zinc and magnesium acrylate	Water	Sandy clay	32
Zinc-magnesium acrylate		Lean clay and heavy clay	Internal Data (1956-57), not published
Zinc acrylate and sodium acrylate	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	31
	CATEGORY: RESIN/ACID		
Butyl methacrylate, acrylic acid, and calcium acrylate	Emulsifier - polyvinyl alcohol; catalyst - potassium persulfate; accelerator - sodium bisulfite	Sandy clay	36
Calcium acrylate and acrylic acid		Sandy clay	31

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Calcium acrylate, zinc acrylate, plus acrylic acid	Water AP/ST - catalyst-activator (ammonium persulfate-sodium thiosulfate)	Sandy soil	32
Ethyl methacrylate, acrylic acid, and calcium acrylate	Emulsifier - polyvinyl alcohol; catalyst - potassium persulfate; accelerator - sodium bisulfite	Sandy clay	36
Magnesium acrylate plus acrylic acid	Water	Sandy clay	32
Methoxy ethyl acrylate, acrylonitrile, acrylic acid	Emulsifier - polyvinyl alcohol; catalyst - potassium persulfate; accelerator - sodium bisulfite	Sandy clay	36
MBA and acrylamide plus acrylic acid	Water plus acrylic acid AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
MBA, acrylamide, and acrylic acid	Complexing agents - chromium chloride and aluminum sulfate	Sandy clay	33
MBA and acrylic acid	Water Catalyst - ammonium persulfate and hydroxylamine hydrochloride (activator)	Sandy clay	32

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
MBA and acrylic acid	Water Ammonium persulfate-hydroxylamine hydrochloride (catalyst/activator)	Sandy clay	33
MBA and acrylic acid	Dimethylformamide (reactant)	Sandy clay	33
MBA and acrylic acid	Dispersants - quadrafos (sodium tetraphosphate), aerosol AY, and Triton X-100	Sandy clay	33
	Ethylene glycol (reactant)	Sandy clay	33
	Polyvinyl alcohol (esterification agent); ethylene glycol (secondary reagent)	Sandy clay	34
MBA, acrylic acid, and acrylonitrile		Sandy clay	33
MBA, acrylic acid, N,n dimethylacrylamide	Water	Sandy clay	33
MBA, acrylic acid, and methoxyethyl acrylate		Sandy clay	33
MBA, acrylic acid, and methyl vinyl ketone		Sandy clay	33
MBA and methacrylic acid	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	33

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
	CATEGORY: RESIN/OTHER		
Calcium acrylate and ethylene diamine	Water AP/ST - catalyst/activator (ammonium persulfate and sodium thiosulfate)	Sandy clay	31
Calcium acrylate and hexamethylene diamine	"	Sandy clay	31
Melamine formaldehyde and acrylamide	Catalyst - ammonium persulfate Activator - sodium thiosulfate	Sandy	35
Zinc acrylate plus acrylic acid	Water	Sandy clay	32
Calcium acrylate and acrylate salts (see comments on page A359)	Water AP/ST - catalyst/activator (ammonium persulfate-sodium thiosulfate)	Sandy clay	32
	CATEGORY: SALT		
Alkyl dimethyl, benzyl ammonium chloride		Silty sand and clay	36
↓		Lean clay and clay	25
Calcium chloride		Silty sand	36
↓		Loess	24

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Dialkyl dimethyl ammonium chloride		Silt	23
Ferric chloride		Silty sand and clay	36
Lithium chloride		Clay	36
Sodium chloride		Silty sand	36
↓		Lean clay and heavy clay	Internal Data (1961), not published
	CATEGORY: SILICATE		
Ethyl silicate	Hydrochloride acid	Sand	29
↓	Hydrogen chloride	Sand	30
Ludox (colloidal silica)		Sand, clay, and sandy clay	5
Magnesium orthosilicate	Magnesium oxide	Lean and heavy clay	18
Sodium metasilicate		Lean clay and clay	25
↓		Lean and heavy clay	18
	Magnesium carbonate	Lean and heavy clay	18
	Magnesium oxide	Lean and heavy clay	18

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Sodium orthosilicate		Lean clay and clay	25
		Lean and heavy clay	18
	Magnesium carbonate	Lean and heavy clay	18
Sodium silicate	Lead, calcium, aluminum, magnesium, nickel, zinc, and zirconium	Sand	29
	Calcium, lead, aluminum, magnesium, nickel, and zinc	Sand	30
Sodium silicate (32% solution)	Calcium chloride, lead acetate	Sandy clay	30
Sodium silicate solution (in aqueous solution of 38% concentration of sodium silicate) ($Na_2O.SiO_2$)	Magnesium carbonate	Lean and heavy clay	18
	Magnesium oxide	Lean and heavy clay	18
	CATEGORY: SILICATE/OTHER		
Sodium metasilicate plus magnesium carbonate		Lean clay and clay	25
Sodium metasilicate plus magnesium oxide		Lean clay and clay	25

Table 2 (Cont'd)

Basic Material	Additives	Soil Type	Reference
Sodium orthosilicate plus magnesium carbonate		Lean clay and clay	25
Sodium orthosilicate plus magnesium oxide		Lean clay and clay	25
Sodium silicate plus basic magnesium carbonate		Clay (Vicksburg)	40
Sodium silicate solution plus magnesium carbonate		Lean clay and clay	25
Sodium silicate solution plus magnesium oxide		Lean clay and clay	25

Table 3

MOST EFFECTIVE MATERIALS FOR EACH SOIL TYPE

Soil Type	Unconfined Compressive Strengths, psi				
	Untreated	Cement	Lime	Asphalt	Other Best Material
Silt	20	80-280	230-860	225	Sodium silicate - 650
Loess	20	100	160-970	--	Powders A and B - 389
Clay	20	76-300	100-340	104-389	Calcium oxide - 315
Sand	20	150-425	--	--	Aropol 7110 - 1170-1890

Appendix A: Documentation of Materials Evaluated

1. The information contained in this appendix covers the materials subjected to investigation and tests. These materials are grouped by category (material categories listed below), secondary materials, and date of report. Information listed as "not given" was not listed in the referenced report and not available from other sources at WES. When the "rate of material" is listed as "varied," several different rates were used in the testing program. The "mixing capability" is listed as "good" when no reference to this item is given in the reports. Definitions of terms and tests used in this appendix are presented below:

a. MIT. Massachusetts Institute of Technology.

b. WES. U. S. Army Engineer Waterways Experiment Station.

c. Effectiveness categories. Excellent, moderate, slight, none, or detrimental.

d. Material categories. Resin, asphalt, cement, salt, lime, acetate, acid, silicate, or other ("other" includes materials not in one of the given categories or material for which the proper category was not known).

e. Mixing capabilities. Excellent, good, difficult, or impossible.

f. Test types and categories of stabilization:

(1) MIT unconfined compression test (Reference 29). Test specimens are prepared in cylindrical molds about 1-1/2 in.* in diameter and about 3 in. tall. The specimen is put in the mold and then tamped by means of a light piston about 1 in. in diameter. No standard compaction procedure is used, but it is believed that all specimens receive similar compaction. This light tamping is not believed to have much effect on the compressive strength of the specimen except for the effect caused by air pockets being eliminated. The strength of the specimen is determined in simple compression; this method is a rapid, reliable method of determining the shearing strength. For indication of absorption or capillary rise of water, the specimen is immersed in water either

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

completely or to a depth of about 1 cm. The specimen is observed visually and then subjected to unconfined compression tests when wet and when redried.

(2) MIT tensile test (Reference 30). Soil specimens are prepared with the chemical material. These specimens are 3 in. long with a 1-in.-long by 1/2-in.-wide portion at the mid-section. The applied load is measured by a proving ring.

(3) MIT compression test (Reference 35). The Harvard Miniature Compaction Apparatus is used in specimen preparation. The dimensions of the mold are 2.82 in. in length and 1.312 in. in diameter. The specimens are prepared in three layers and compacted by 25 tamps per layer of a 40-lb load.

(4) Category 1 stabilization* (References 13 and 37). This is obtained if the chemical additive can increase, within a 2-hr limit, the strength of the soil from a cone index of 20 (equivalent to 1 CBR or less) to 120 (equivalent to a minimum CBR of 4), with this latter value deemed adequate for light traffic.

(5) Category 2 stabilization** (References 14 and 16). This condition occurs when a stabilizer is capable of increasing the compressive strength of the soil from about 25 psi (4 CBR) to about 100 psi (20 CBR) or greater after 24 hr curing without benefit of drying.

(6) Test procedures for unconfined compression tests for soil stabilizers and waterproofers; permeation method (Reference 24):

(a) Untreated soil and treated soil are compacted in a Harvard miniature mold (1.312 in. in diameter by 2.82 in. long). Compaction is achieved by applying 20 tamps with a 40-lb spring to each of five equal layers. The specimens are then extruded from the mold and permitted to cure under ambient laboratory conditions for a period of at least 4 days.

(b) The compacted, air-dried, treated specimens are placed in a rubber membrane, and water is permitted to enter the top and flow downward through it. Duplicate untreated specimens are also subjected to water. After 4 days of permeation, the specimens are subjected to unconfined compression tests.

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* Also referred to as "emergency requirements."
** Also referred to as "routine requirements."

(7) Test procedures for unconfined compression tests for soil stabilizers and waterproofers; capillary method (Reference 51):

(a) Untreated soil and treated soil are compacted in a Harvard miniature mold (1.312 in. in diameter by 2.82 in. long). Compaction is achieved by applying 20 tamps with a 40-lb spring to each of five equal layers. The specimens are then extruded from the mold and permitted to cure under ambient laboratory conditions for a period of at least 4 days.

(b) The air-dried specimens are then put in a membrane that is open at both ends and placed in an upright position on a 3/8-in.-thick porous stone in an evaporating dish. Water is placed in the bottom of the dish, the level of the water being maintained approximately 1/8 in. below the bottom of the specimens for a period of 4 days. This 4-day period is considered to be a cycle. After the specified number of cycles has been completed, unconfined compression tests are then conducted on the specimens.

(8) Emergency requirements. See Category 1 stabilization.

(9) Routine requirements. See Category 2 stabilization.

(10) Traffic tests. Details are given in the referenced reports.

Category: Acid

Category*

Acid

Basic Material	Rate of Material	Cost
Phosphoric acid (H_3PO_4)	0.5, 1.0, 1.5, 2.0, 3.0%	Not given

Secondary Material		
Sodium fluosilicate	0.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with 0.5% sodium fluosilicate and various rates of phosphoric acid not compared to untreated samples. Tests were conducted after a 24 hours water immersion.

H_3PO_4 (%)	Strength (psi)
0.5	85
1.0	-
1.5	170
2.0	325
3.0	630

(Continued on next page)

* Basic material

Effectiveness: As seen from the data above, once the amount of H_3PO_4 reaches 1.5 percent, the strength of the samples is very good and with a small amount of increase in the acid, a significant increase in strength is achieved.

Category*
Acid

Basic Material	Rate of Material	Cost
Phosphoric acid (H_3PO_4)	2 and 3%	Not given

Secondary Material

See comments

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 18

Comments:

Samples were molded in a Harvard Miniature Compaction Apparatus in five layers (each layer compacted with ten tamps with a 40-lb spring tamper). Samples were tested after a 24-hour cure at 100 percent relative humidity and after a 24-hour cure at 100 percent relative humidity followed by a 24-hour water immersion. The strength of the untreated soils was 20 psi. Materials added to the soils were considered to have potential as stabilizers if they increased the strength from 20 to 100 psi or greater.

Each of the following additives were used:

(Continued on next page)

* Basic material

2 percent phosphoric acid plus 0.5 percent sodium fluosilicate (Na_2SiF_6); 0.5 percent Na_2SiF_6 and 0.5 percent n-octylamine; and 0.5 percent O-P_2O_5 and 0.5 percent Na_2SiF_6 and 0.5 percent n-octylamine.

3 percent phosphoric acid plus 0.5 percent sodium fluosilicate (Na_2SiF_6); 1.0 percent Na_2SiF_6 and 1 percent n-octylamine; and 1 percent Na_2SiF_6 and 1.5 percent ferric chloride.

Effectiveness: Lean clay - The 3 percent H_3PO_4 with 1 percent sodium fluosilicate and 1.5 percent ferric choride gave the best results (81 psi dry cure and 72 psi after soak); however, these values were below 100 psi.

Heavy clay - Same comments as for lean clay; however, strength values were 74 psi dry cure and 70 psi after soak.

Category*

Acid

Basic Material	Rate of Material	Cost
Phosphoric acid (H_3PO_4)	2.0 and 3.0%	Not given

Secondary Material		
Curing agent-sodium fluosilicate	0.5%	Not given
Waterproofing agent - n-octylamine	0.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See Comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

The untreated samples were not suitable for compression tests after 4 days cure followed by 4 days wetting by capillary action. The 3 percent phosphoric acid with the secondary materials was very effective as a stabilizer and waterproofing agent (300 psi unconfined compression strength) on the lean clay soil. There was a big improvement with the clay soil; however, the materials were not effective as a stabilizer and waterproofer.

* Basic material

Category*

Acid

Basic Material	Rate of Material	Cost
Phosphoric acid (H_3PO_4)	Varied (1 to 5%)	Not given

Secondary Material

Additives (see comments)

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

The basic material plus sodium fluosilicate was for stabilizing soil and octylamine and 2-ethyl hexylamine were added to check their water-proofing ability.

Additives

Sodium fluosilicate. 0.5 percent rate - the strength of soil treated only with this material is not effective.

When this material (0.5 percent) is used with 5 percent phosphoric acid, the strength of the 24-hour cure is approximately triple the strength where only H_3PO_4 is used. The strength after 24 hours and 24 hours water immersion closely parallels the 24-hour strength.

* Basic material

Octylamine. (Rate varied from 0.05 to 2.0 percent). It was found that as little as 0.05 percent was adequate to waterproof the soil when used with 2 percent H_3PO_4 and sodium fluosilicate.

2-ethyl hexylamine. 0.2 percent was the most effective rate with 2 percent phosphoric acid and 0.5 percent sodium fluosilicate; 28 psi after 24 hours immersion, 198 psi after 24 hours humid cure, and 98 psi after 24 hours humid cure followed by 24 hours immersion and tests. However, this combination of materials was not as effective as that mentioned in Octylamine above. As the amount of the 2-ethyl hexylamine was increased, the strength decreased.

Effectiveness:

Sodium fluosilicate is very effective when used with phosphoric acid in increasing the strength of the treated samples.

Octylamine is more effective than 2-ethyl hexylamine in waterproofing soil treated with phosphoric acid and sodium fluosilicate.

Category*
Acid

Basic Material	Rate of Material	Cost
Phosphoric acid (H_3PO_4)	2%	Not given

Secondary Material		
Sodium fluosilicate (Na_2SiF_6)	0.5%	Not given
Octylamine	0.05%	Not given
Ortho-rhombic phosphoric	0.05, 0.10, 0.25%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:
The samples treated with the additives were compared to samples treated with only phosphoric acid. Tests were conducted after a 24 hour humid cure followed by an immersion in water for 24 hours. The combinations of additives which showed the most promise are given below.

(Continued on next page)
* Basic material

Na_2SiF_6 (0.5%)	Octylamine (0.05%)	$O-P_2O_5$ (%)	Strength psi	Strength Change Based on Soil Treated with only H_3PO_4, %
0	0	0	200	--
Yes	0	0	325	+63
0	0	0.05	340	+70
Yes	Yes	0.05	295	+48
0	Yes	0.05	425	+113
Yes	0	0.05	375	+88
Yes	Yes	0	350	+75

* The Na_2SiF_6 was mixed with the soil after the $O-P_2O_5$

<u>Effectiveness:</u> The most effective combination of additives was 0.05 percent octylamine plus 0.05 ortho-rhombic phosphoric anhydride (without sodium fluosilicate).

Category*
Acid

Basic Material	Rate of Material	Cost
Phosphoric acid	5%	Not given

Secondary Material		
Chemical additives		
Sodium fluosilicate	0.50%	Not given
Rosinamine silicofluoride	0.50%	Not given
Benzene phosphoric acid	0.5 and 3.0%	Not given
Butyl acid phosphate	0.25%	Not given
Phenyl acid phosphate	0.50%	Not given
Isooctyl acid phosphate	0.33%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:

See next page:

(Continued on next page)

* Basic material

	Compressive Strength After 24-hour Cure 100% Relative Humidity and 24-hour Immersion, psi	Percent Increase Over Control	Compressive Strength after Immediate Immersion, psi
Control (no additive)	175	-	0
Sodium fluosilicate	510	191	0
Rosinamine silicofluoride	No test	-	55
Benzene phosphoric acid (3 percent rate)	250	43	135
Butyl acid phosphate	210	20	0
Phenyl acid phosphate	135	Negative (-23)	0
Isooctyl acid phosphate	185	6	0

Effectiveness: Sodium fluosilicate is an effective additive for improving phosphoric acid soil stabilization.

Benzene phosphoric acid when added to phosphoric acid was effective from the standpoint of strength and water resistance.

Category*

Acid

Basic Material	Rate of Material	Cost
Phosphoric acid	2, 5, and 10% on clayey silt 2% on sandy clay 2 and 10% on clay	Not given

Secondary Material	
Water	11-30%

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt Sandy clay Clay	Good Good Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined Compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

Several methods or curing conditions were used; however, one week curing at room temperature and at 100 percent relative humidity followed by one week water immersion and then subjecting the samples to compressive tests was considered the most severe.

The treated samples were not compared to untreated samples.

The clayey silt treated samples at the 5 and 10 percent rate of phosphoric acid on dry soil and with a molding water content of 11 percent on dry soil were the only ones which showed promise as a stabilizer. After the curing conditions mentioned above, the 5 percent rate treated samples had a strength of 383 psi and the 10 percent rate treated samples had a strength of 605 psi.

* Basic material

Category*

Acid

Basic Material	Rate of Material	Cost
Phosphorus pentoxide	3% (on dry soil)	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sandy silt, clayey silt, sandy clay, loess, and clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent for silt

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

Tests were conducted on treated samples of 14 days cure and 7 days water immersion. Treated samples were not compared to untreated samples.

Sandy silt and clayey silt soil samples treated with phosphorus pentoxide were the only samples which were considered to have retained any significant compressive strengths (282 and 153 psi, respectively) after tests.

* Basic material

Category*

Acid Basic Material	Rate of Material	Cost
Phosphorus pentoxide	3, 5, and 7%	Not given

Secondary Material		
Sodium fluosilicate	0.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent (in laboratory) None (in field tests)

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 15

Comments:

Treated samples were compared to untreated samples (20 psi). Samples were prepared using the Harvard Miniature Compaction Apparatus in five layers (each layer was compacted with ten tamps of a 40-lb spring tamper). The samples were then cured for 24 hours under 100 percent relative humidity.

Each rate of basic material was used with the additive. The 5 percent rate gave the greatest (588 percent) strength increase and met the Category 2 requirements for stabilization.

Field traffic tests: A traffic test section (lean clay) was prepared and treated with 5 percent treatment of pentoxide and 0.5 percent sodium fluosilicate. However, the section failed before meeting stated requirements.

* Basic material

Category: Asphalt

Category*

Asphalt

Basic Material	Rate of Material	Cost
Asphalt cutback (see comments for various ratios of asphalt to solvent)	5%	Not given

Secondary Material		
Phosphorus pentoxide (P_2O_5) (additive)	3%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:

Asphalt- 50-60 penetration was used at four degrees of cutback: 3:1, 2:1, 1:1, and 0.5:1 asphalt to gasoline. Cure conditions were 24 hours at 100 percent relative humidity and then samples were immersed in water for 24 hours. After immersion, the samples were subjected to compression tests.

Effectiveness: The samples without the additive did not have any significant strength. Asphalt cutback at the ratio of 3:1 (asphalt to gasoline) gave the best results with the additive, P_2O_5, when used to treat soil samples. As the amount of solvent increased, the strength values decreased. Also, the samples were harder to mix. The values for the cutback ratios (3:1, 2:1, 1:1, and 0.5:1) were 225, 177, 170, and 143 psi, respectively.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Asphalt cutback (50-60 pen)	5%	Not given

Secondary Material		
Solvents (see comments) Phosphorus pentoxide (P_2O_5) - additive	3%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined Compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:
Asphalt cutback composition =1.43:1, asphalt to solvent (by volume).

Cure conditions - 24 hours cure at 100 percent relative humidity and then 24 hours immersion in water. Compressive tests then conducted.

Solvents used were: carbon disulfide, n-hexane, carbon tetrachloride, gasoline, and kerosene.

Effectiveness: The samples treated with asphalt and the various solvents without the additive had very little compressive strength. All samples treated with the various solvents plus the additive had good compressive strengths as follows:

(Continued on next page)

* Basic material

n-hexine - 233 psi

Carbon disulfide - 194 psi

Gasoline - 177 psi

Carbon tetrachloride - 159 psi

Kerosene - 76 psi

Category*

Asphalt

Basic Material	Rate of Material	Cost
Asphalt cutback (see comments for various penetration numbers)	5%	Not given

Secondary Material		
Phosphorus pentoxide (P_2O_5) (additive)	3%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compressive	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:

Cure conditions - 24 hours at 100 percent relative humidity followed by 24 hours immersion.

Asphalt cutback composition = 2:1 asphalt to gasoline cutback asphalt with various penetration numbers: 100-120, 85-100, 65-70, and 50-60 were tested with samples without additives and with additives (P_2O_5).

Effectiveness: The samples without additive when subject to the compressive tests had no significatn compressive strength, whereas the strength of all treated samples with the additive, P_2O_5, was 124 to 177 psi. The lower the penetration number, the higher the strength was for these samples. The samples tested with 100-120 pen asphalt had asphalt strength of 124 psi, and those treated with 50-60 pen asphalt had strength of 177 psi.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt Straight run, cracked, and blown	5%	Not given

Secondary Material

Additives (see below)

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compressive	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 35

Comments:

The following additives were tested with cutback asphalts. Cure time was 14 days and rewet strength was checked after 7 days water immersion.

(Continued on next page)

* Basic material

Straight Run	Cracked	Blown
Epon 828 (10 percent) plus diethylene triamine (2 percent)	Toluene diisocyanate (10 percent)	Toluene diisocyanate (10 percent)
Toluene diisocyanate (5 percent) plus ethylene glycol (5 percent)	BF_3 (2 and 5 percent)	BF_3 (2 and 5 percent)
Toluene diisoycanate (5 percent) plus diethylene triamine (5 percent)	H_2SO_4 (Conc) (5 percent)	H_2SO_4 (Conc) (5 percent)
Epon 828 (10 percent) plus BF_3 (2 percent plus diethylene triamine (2 percent0	Styrene (10 percent) plus BF_3 (5 percent)	Styrene (10 percent) plus BF_3 (5 percent)
Toluene diisocyanate (5 percent) plus ethylene glycol (5 percent) plus BF_3 (2 percent)	Acrylonitrile (10 percent) plus BF_3 (5 percent)	Acrylonitrile (10 percent)
Styrene (20 percent) plus BF_3 (10 percent)	Acrylonitrile (10 percent) plus H_2SO_4 (Conc) (5 percent)	Triphenyl methane triisocyanate (2 percent)
Styrene (20 percent plus BF_3 (10 percent) plus Benzoyl peroxide plus dimethylaniline (2 percent)	Triphenyl methane triisocyanate (2 percent)	Toluene diisocyanate (10 percent)
BF_3 (5, 10, and 20 percent)	Toluene diisocyanate (10 percent)	Diphenyl methane diisocyanate (10 percent)
BF_3 (10 percent) plus acrylonitrile (10 percent)	Diphenyl methane diisocyanate (10 percent)	Epon 828 (10 percent) plus diethylene triamine (2 percent)
	Diethylene triamine (10 percent)	Methyl sulfate (10 percent)
	Epon 828 (10 percent) plus diethylene triamine (2 percent)	
	Methyle sulfate (10 percent)	

It was concluded in the report that any additive capable of increasing the rewet compressive strength to a value of 150 psi or greater would merit further study.

Several of the additives fall into this category. Given below are the additives which appeared beneficial to asphalt cutback stabiliation (and in order of effectiveness).

Straight Run	Cracked	
Toluene diisocyanate (10 percent)	Diphenyl methane diisocyanate (10 percent)	Diphenyl methane diisocyanate (10 percent)
P_2O_5 (20 percent)	Toluene diisocyanate (10 percent)	Epon 828 (10 percent plus diethylent triamine (2 percent)
Diphenyl methand Diisocyanate (10 percent)	Triphenyl methane triisocyanate (2 percent)	Toluene diisocyanate (10 percent)
Epon 828 (10 percent plus diethylene triamine (2 percent)	Epon 828 (10 percent) plus diethylene triamine (2 percent)	
Methyl sulfate (10 percent)		
Triphenyl methane Triisocyanate (2 percent)		

Further work was conducted with the asphalts and various additives as mentioned above. The results of the work led to the following conclusions:

a. Modification of asphalt cutbacks with reactive chemical compounds such as P_2O_5 or toluene or diphenyl methane diisocyanate (at concentrations of 10 percent on the asphalt or below) significantly improves cutback stabilization of fine-graned soils, as measured by evelation of compressive strength after seven days water immersion. P_2O_5 also markedly accelerates the development of water resistance of stabilized soil during drying and/or curing.

b. There is a general correlation between rewet strength and volatiles content of the specimen at the time of test. From this correlation, it has been deduced that asphalt, irrespective of its method of incorporation with soil or its chemical alteration, functions primarily as a waterproofing agent for soil, the various additives and improved methods if incorporation merely enhancing its characteristic waterproofing ability.

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean Clay Heavy clay	Good Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - Both rates of asphalt were effective in waterproofing and stabilizing the samples with no significant benefits with the higher rate of asphalt.

Heavy clay - Same as for lean clay.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5%	Not given

Secondary Material

Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additive - phosphoric acid (H_3PO_4)	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - The combination of materials was effective as a stabilizer and waterproofer; however, the combination was not as effective as asphalt only treatment.

Clay - The combination of materials was only slightly effective; however, the strength of asphalt only treated samples was twice that of the samples treated with the combination of materials.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	1.5%	Not given
Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additives - phosphoric acid	1.0%	Not given
plus alky dimethy benzyl ammonium chloride		Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	None	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

The samples treated with asphalt only gave much better results than those treated with the combination of materials.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additives - phosphoric acid (H_3PO_4)	1.0%	Not given
plus lauryl amine	0.10%	"

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	None	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action. Samples treated with only asphalt gave much better results.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additive: phosphoric acid	1%	Not given
plus n-octylamine	0.1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	None	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

The asphalt only treated samples gave much better results than the combination of materials.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additives -		
Phosphoric acid (H_3PO_4)	1.0%	Not given
plus octadecyl amine acetate	0.10%	"

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	None	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Asphalt only treated samples were much more effective than the combination of materials.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additive: phosphorus pentoxide	3%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean Clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - Samples treated with both rates of asphalt with additive were effective in waterproofing and stabilizing the samples. However, the 7.5 percent asphalt gave the best results of the two asphalt rates and this strength was significantly better than asphalt only treated samples.

Clay - Both rates of asphalt with additive were effective; however, greater strength values were obtained with only the basic material.

* Basic material

Category*

Asphalt Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 straight run asphalt)	7.5 and 12%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additive:		
Phosphorus pentoxide (P_2O_5)	0.25% with 7.5% asphalt 0.40% with 12% asphalt	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - Both rates of asphalt with the additive were effective in waterproofing and stabilizing the samples. However, the strengths of the samples with the 0.25 percent P_2O_5 were less than those with 7.5 percent asphalt only. The samples with 12 percent asphalt and 0.4 percent P_2O_5 had strength somewhat higher than the asphalt only treated samples.

Clay - Samples treated with both rates of asphalt with additive were effective in waterproofing and stabilizing; however, the strength values were less than those for 7.5 and 12 percent asphalt only.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given

Secondary Material		
Solvent - unleaded gasoline Additives (see comments)	2:1 (asphalt, gasoline)	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See commets	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Additives:

7.5% asphalt and 0.25% phosphorus pentoxide (P_2O_5) plus 0.10% alkyl dimethyl benzyl ammonium chloride (ADBAC)

7.5% asphalt and 3.0% P_2O_5 plus 0.2% ADBAC

(Continued on next page)
* Basic material

12% asphalt and 0.40% P_2O_5 plus 0.10% ADBAC

12% asphalt and 3.0% P_2O_5 plus 0.2% ADBAC

Effectiveness: Lean clay - Both rates of asphalt with additives (all rates) were effective in waterproofing and stabilizing samples. However, 7.5 percent asphalt with 3.0 percent P_2O_5 and 0.10 percent ADBAC was more effective than asphalt alone. The other combinations of materials were not as effective as asphalt only.

Clay - 7.5 percent asphalt with 3.0 percent P_2O_5 plus 0.10 percent ADBAC was the most effective combination as was slighly more effective than only 7.5 percent asphalt. The other combinations of materials were not as effective as asphalt only at the two different rates.

Category*
Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given

Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additives (see comments)		

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:
Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Additives:

7.5 percent asphalt and 0.25 percent phosphorus pentoxide plus 0.10 percent lauryl amine.

7.5 percent asphalt and 3.0 percent phosphorus pentoxide (p_2O_5) plus 0.2 percent laurly amine.

12 percent asphalt and 0.4 percent phosphorus pentoxide plus 0.1 percent lauryl amine.

(Continued on next page)
* Basic material

12 percent asphalt and 3.0 percent phosphorus pentoxide plus 0.2 percent lauryl amine.

Effectiveness: Lean clay - The asphalt (at both rates) with the additives (all rates) were effective in waterproofing and stabilizing the samples. The 7.5 percent asphalt with 3.0 percent P_2O_5 and 0.2 percent lauryl amine was the most effective combination of materials. This combination was also more effective that either rate of asphalt alone.

Clay - Treatment with only asphalt (both rates) was more effective than treatment with asphalt plus additives.

Category*

Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given

Secondary Material

Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Additives

7.5% asphalt and 0.25% phosphorus pentoxide (P_2O_5) plus 0.1% n-octylamine

7.5% asphalt and 3.0% P_2O_5 plus 0.20% n-octylamine

(Continued on next page)

* Basic material

12% asphalt and 0.4% P_2O_5 plus 0.1% n-octylamine

12% asphalt and 3.0% P_2O_5 plus 0.2% n-octylamine

Effectiveness: Lean clay - Both rates of asphalt with additives (all rates) were effective in waterproofing and stabilizing the samples; however, the only combination that gave any great increase over asphalt only was the following:
7.5 percent asphalt plus 3.0 percent P_2O_5 and 0.20 percent n-octylamine.

Clay - Both rates of asphalt with additives (all rates) were effective in waterproofing and stabilizing the samples; however, the only combination that gave any increase over asphalt only was the following: 7.5 percent asphalt plus 3 percent P_2O_5 and 0.2 percent n-octylamine.

Category*
Asphalt

Basic Material	Rate of Material	Cost
Cutback asphalt (40-50 pen straight run asphalt)	7.5 and 12%	Not given
Secondary Material		
Solvent - unleaded gasoline	2:1 (asphalt, gasoline)	Not given
Additives (see comments)		

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean Clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See Comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Additives:

7.5% asphalt and 0.25% phosphorus pentoxide (P_2O_5) plus 0.1% octadecyl amine acetate

7.5% asphalt and 3.0% P_2O_5 plus 0.2% ocadecyl amine acetate

(Continued on next page)

* Basic material

12% asphalt and 0.4% P_2O_5 plus 0.1% octadecyl amine acetate

12% asphalt and 3.0% P_2O_5 plus 0.2% octadecyl amine acetate

Effectiveness: Lean clay - Asphalt at both percentages with the additives (all rates) were effective in waterproofing and stabilizing the samples. The 7.5 percent asphalt with 3 percent P_2O_5 and 0.2 percent octadecyl amine acetate was the most effective combination. This combination was more effective than either rate of asphalt alone.

Clay - The 7.5 percent rate of asphalt with 3.0 percent P_2O_5 plus 0.2 percent octadecyl amine acetate was very effective in stabilizing and waterproofing the samples. Treatment with only 12 percent asphalt was more effective that treatment with 12 percent asphalt plus additives.

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt	See comments	Not given

Secondary Material

Chemical additives (see comments)

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Not given

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

The following chemical additives were each used with a 5 percent asphalt cutback (composition 2:1 asphalt to gasoline) with a mixing water content of 11 percent on dry soil.

Benzene phosphoric acid (10 percent)

PCl_3 (10 percent)

$POCl_3$ (10 percent)

85 percent H_3PO_4 (10 percent)

PCl_5 (10 percent)

Yellow P (10 percent) + Armeen 18 DAc (2 percent) + CS_2 (25 percent)

(Continued on next page)

* Basic material

PCl_5 (10 percent)

P_2O_5 (10 percent) + Armeen 18DAc (2 percent)

P_2O_5 (10 percent) + Armeen 18DAc (1 percent)

$SNCl_4$ (2.5 percent)

P_2O_5 (10 percent) + Armeen 12D (2 percent)

Ethyl orthosilicate
$(C_2H_3)_3\ PO_4$ (10 percent)

CR_2O_3 (11 percent)

MoO_3 (11 percent)

PCl_5 + Excess CaO (10 percent)

P_2S_5 (12 percent)

CrO_3 (11 percent)

$SBCl_5$ (11 percent)

Guanylurea phosphate (11 percent)
$KMnO_4$ (11 percent)

KH_2PO_4 (11 percent)

$CrPO_4$ (11 percent)

85 percnet H_2PO_4 (10 percent)

Methanitrobenzoic acid (10 percent)

Hydrochloric acid (10 percent)

Fumaric acid (10 percent)

Phthalic anhydride (10 percent)

Benzoic acid (10 percent)

Adipic acid (10 percent)

The most promising additives as an acid to asphalt stabiliztion were liquid phosphoric acid (85 percent), benzene phosphoric acid. phosphorus pentachloride, chromium trioxide, and phosphorus trichloride. They improved rewet strengths more that phosphoric acid, but their relative high cost makes them less commercially attractive.

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (40-50 pen)	5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	-
Additive - Chromic chloride	0.25%	Not given
Phosphoric acid	1.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion. Strength of these samples was 165 psi.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run (40 to 50 pen) asphalt	5 and 10% (cutback composition - 2:1 asphalt to gasoline	Not given

Secondary Material		
Phosphorus pentoxide	0.5 to 3%	Not given
Antistripping additives	0.1 to 3%	Not given
Water	14.2%	

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy soil	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

1. Phosphorus pentoxide (P_2O_5) and antistripping additives were used separately and in combination at the percentage ranges cited above with cutback asphalt at the two rates shown. The antistripping agents were A12D (lauryl amine) and A18DA, Armeen 18D acetate (octodecyl amine acetate). The samples treated with P_2O_5 and other additives with asphalt were compared to samples treated with asphalt only. The samples were cured for 14 cays and after 7 days of water immersion, they were subjected to unconfined compression tests.

(Continued on next page)

* Basic material

The results indicated that the 5 percent rate of asphalt in combination with P_2O_5 (1.5 percent) gave an increase in compressive strength of 60 percent over the asphalt only treated soil. The combination of A12D (0.1 percent) and P_2O_5 (0.5 percent) gave the best results (48 percent increase over asphalt-treated soil).

At the 10 percent asphalt rate in combination with P_2O_5, an increase of 75 percent over the asphalt only treated soil resulted. The combination of A12D (0.3 percent) and P_2O_5 (3.0 percent) gave the next best increase (54 percent).

Effectiveness: P_2O_5 is considered as the most effective additive with the basic material on sandy silt soil.

2. Phosphorus pentoxide (P_2O_5) was used separately and in combination with antistripping additives (A12D - 0.1 to 0.3 percent and A18DA - 0.1 percent) and straight run asphalt (5 and 10 percent rates) on the following additional soils. Compressive tests were conducted after 14 days dry cure and 7 days water immersion.

a. Clayey silt: Mixing water content - 11 percent; asphalt cutback composition - 2:1 asphalt to gasoline.

The P_2O_5 (1.5 percent rate) with 5 percent rate asphalt gave the best results relative to the asphalt only treated samples, an increase of 93 percent in compressive strength.

The P_2O_5 (1.5 percent rate) with 10 percent rate asphalt gave the best results relative to the asphalt only treated samples, an increase of 166 percent in compressive strength.

b. Sandy clay: Mixing water content - 16 percent; asphalt cutback composition - 2:1 asphalt to gasoline.

The A12D (0.2 percent) with 5 percent rate asphalt gave best results relative to asphalt only treated samples, an increase of 109 percent in compressive strength (23 psi asphalt only to 0.2 percent A12D additive - 48 psi).

The P_2O_5 (3 percent rate) with 10 percent rate asphalt gave the best results relative to the asphalt treated samples, an increase of 560 percent in compressive strength.

c. Vicksburg loess: Mixing water content - 18.1 percent. Asphalt cutback composition - 2:1 asphalt to gasoline.

At the 5 percent asphalt rate, no favorable results were achieved with the additives.

Asphalt rate - 10 percent. The P_2O_5 (3 percent) and A12D (0.3 percent) gave the best results relative to the asphalt only treated samples, an increase of 1090 percent in compressive strength. P_2O_5 (3 percent) gave an increase of 570 percent in compressive strength.

d. Vicksburg buckshot: Mixing water content - 22.7 percent. Asphalt cutback composition - 2:1 asphalt to gasoline.

At the 5 percent asphalt rate, no favorable results were achieved with the additives.

At the 10 percent asphalt rate, no favorable results were achieved with the additives.

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-200 pen)	5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	
Additive - chromic chloride	0.25%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure plus a 24 hour water immersion.

Effectiveness: The above combination of materials produced samples with insignificant strengths.

Other samples contained the above materials plus 1.5 percent phosphoric acid, and this conbination was effective as a soil stabilizer (190 psi strength).

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-120 pen)	5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Additive - chromic chloride	0.1%	Not given
Water	3:3 (asphalt, water)	Not given
Phosphoric acid	1.5%	-

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the treated samples was 110 psi.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-200 pen)	7.5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:2 (asphalt, gasoline, water)	-
Additive - chromic chloride	0.1%	Not given
Phosphoric acid	1.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the treated samples was 125 psi.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-120 pen)	3, 4, and 5%	Not given

Secondary Material

Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	-
Additives: Ferric chloride	0.1%	Not given
Phosphoric acid (H_3PO_4)	1.5, 2, and 5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after 24 hours humid cure plus a 24 hour water immersion.

(Continued on next page)

* Basic material

Effectiveness: Combination of materials above where several rates are given, all give high strength (155 psi) and are considered effective as stabilizers; however, shown below are strengths in order of effectiveness:

Asphalt (%)	H_3PO_4 (%)	Strength (psi)
4	5	610
4	2	265
5	1.5	195
3	2.0	155

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-120 pen)	5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	-
Phosphoric acid	1.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the treated samples was 125 psi.

* Basic material

Category*

Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-200 pen)	5%	Not given

Secondary Material		
Emulsifying agent: Nonic 218	6.25%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	-
Phosphoric acid (H_3PO_4)	1.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after 24 hours humid cure plus 24 hours water immersion.

The addition of phosphoric acid is necessary for adquate stabilization given 24 hour humid cure plus 24 hour water immersion.

* Basic material

Category*
Asphalt

Basic Material	Rate of Material	Cost
Straight run asphalt (100-120 pen)	5, 10, and 12.5%	Not given

Secondary Material		
Emulsifying agents:		
Duomeen T	5.0%	Not given
Hydrochloric acid	4.7%	Not given
Solvent - gasoline	2:1:3 (asphalt, gasoline, water)	-
Additives - Ferric chloride	0.1%	Not given
Phosphoric acid	2.0%	

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with above materials were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The most effective rate of asphalt was the 10 percent. The strength of samples treated with this asphalt and other materials was 85 psi. This value was substantially higher than values previously obtained with this soil using asphalt cutback-phosphoric acid combinations.

* Basic material

Category: Cement

Category*

Cement

Basic Material	Rate of Material	Cost
Alumina cement	5%	Not given
Secondary Material		
Modifiers (see comments)	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined Compression	Stabilizer	See comments	Excellent N/O Modifiers

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1956), not published

Comments:

Samples treated with cement and modifiers were compared to untreated samples. Preparation of the samples was with the Harvard miniature compaction apparatus, five layers with an effort of 25 tamps per layer using a 40-lb spring tamper. Samples were cured in a humid room for 24 hours prior to testing.

(Continued on next page)

* Basic material

Modifiers:

Sodium hydroxide	Polyvinyl alcohol (grade 50-42)	Plaster of Paris
Ammonium hydroxide	Potassium permanganate	Ethyl silicate
Calcium acrylate	Potassium chloride	Nitrobenzene
Hydrated line	Sodium fluoride	Sulphuric acid
Portland cement		phosphoric acid

Modifiers (continued):

Sodium tetraphosphate
Arquad 2 HT
Carboxymethyl cellulose (grade 1800)
Chrome lignin
Glycerin

Effectiveness: Sodium hydroxide and ammonium hydroxide were used separately with the basic material in an effort to alter the pH of the treated samples. There was no increase in strength.

The alumina cement alone met the requirements of Category 2 stabilization.

The only modifiers when used with the cement which exhibited any significant advantage were: Polyvinyl alcohol (72%), carboxymethyl cellulose (69%), and carboxymethyl cellulose (one part) plus (one part) hydrated lime (40%). Numbers in parentheses are the percent increase in strength over cement only treated samples.

Category*
Cement

Basic Material	Rate of Material	Cost
Cement	10%	Not given

Secondary Material

Additives:		
Sodium hydroxide plus sodium sulfate	1:0, 2:1, 1:1, 1:3, 1:2, 0:1	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with additive and cement were compared to cement-treated samples. The cure time varied from 1 to 28 days. Prior to testing, ~~the samples~~ were immersed in water for 24 hours.

Effectiveness: The ratio of 1:0 sodium hydroxide to sodium sulfate in combination with cement gave the only significant increase in strength over the samples with only cement. (64 percent after 1 day cure and 67 percent after 28 days cure).

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Cement	3.5, 6.8, and 10%	Not given

Secondary Material		
Sodium hydroxide (NaOH)	0.5 N and 1.0 N	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

In the range of 3 to 10 percent cement, wet strength increased with the amount of cement and 1 N NaOH giving the higher increase of strength after the one day cure; however, as the length of curing time increased, the difference in using 1N NaOH and 0.5 N NaOH is insignificant.

To achieve a wet strength of 150 and 300 psi after 7 days of cure, 4 and 6 percent cement with 0.5 N NaOH is needed, respectively.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Cement	10%	Not given

Secondary Material

Additives:		
Sodium hydroxide plus sodium sulfate	1:0, 2:1, 1:1, 1:2, 0:1	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sand (Wisconsin #1)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with additives and cement were compared to cement-treated samples. The cure time ranged for 1 to 28 days. Prior to testing, the samples were immersed in water for 24 hours.

Effectiveness: The ratio of 1:0 sodium hydroxide to sodium sulfate in combination with cement gave less strength than the cement only treated samples. As the ratio of sodium hydroxide to sodium sulfate decreased, the effectiveness of the combined additive increased. The most effective combination of sodium hydroxide to sodium sulfate was 0:1 with the strength increase after 1 day cure being 720 percent and after 28 days cure being 1748 percent.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Cement	5%	Not given

Secondary Material

Additives:		
Sodium hydroxide plus sodium sulfate	1:0, 2:1, 1:1, 1:2, 0:2	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:
Samples treated with additives and cement were compared to coment-treated samples. The cure time ranged from 1 to 28 days. Prior to testing, the samples were immersed in water for 24 hours.

Effectiveness: The most effective ratio of sodium hydroxide to sodium sulfate was 1:1. The strength increase was 202 percent after 1-day cure and 292 percent after 28 days cure. However, all samples with the additives, regardless of the ratio of the two, were stronger than those treated with cement only.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Cement (plus 1N NaOH - sodium hydroxide)	5%	Not given

Secondary Material

See comments

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	None	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with 1N NaOH and cement were compared to samples treated only with cement. Tests were conducted after 1, 7, and 28 days humid cure plus 24 hours water immersion. The samples with the sodium hydroxide and cement for 1, 7, and 28 days cure had strength increases of 180, 46, and 41 percent, respectively, over samples treated with cement only.

Other individual additives tested with cement plus 1N NaOH were:

Rosinamine'D acetate - 0.025, 0.1, 0.2, and 0.7 percent
Melamine - 1.0 percent

(Continued on next page)

* Basic material

Aniline - 1.0 percent
Zinc nitrate - 0.5 and 1.0 percent
Stannous chloride - 0.1 percent
Ferric chloride - 0.1 percent
Ferrous chloride - 0.5 and 1.0 percent

None of the additives above produced any significant strength increase over that achieved with only cement plus sodium hydroxide (1N NaOH).

Category*
Cement

Basic Material	Rate of Material	Cost
Fast Fix	3, 5, 6, 7, 10, 15, and 20%	$0.035 per lb

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay, heavy clay, and sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1971), not published

Comments:

Samples treated with Fast Fix were compared to samples treated with Type I portland cement. Samples were prepared with a Harvard miniature compaction apparatus, five layers, ten tamps per layer of a 40-lb spring tamper. Prior to tests as a Category 2 stabilizer, the samples were cured at 100 percent relative humidity followed by 24 hours water immersion.

Effectiveness: To satisfy the Category 2 stabilization, approximately 15 percent and more than 15 percent Fast Fix is required on lean and heavy clay, respectively. Approximately 7.5 percent is required on sand.

(Continued on next page)

* Basic material

To satisfy the same requirements on all three soils, only approximately 6 percent portland cement is required. Cement also costs less than one third that of Fast Fix. From these two standpoints, the Fast Fix does not offer any advantages in stabilization.

Category*

Cement

Basic Material	Rate of Material	Cost
Lumnite cement	5, 10, and 15%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sand, loess, and heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1956), not published

Comments:

Samples treated with lumnite cement were compared with those treated with portland cement. Samples were prepared using the Harvard miniature compaction apparatus. For the loess and heavy clay samples, compaction was applied on each of three layers by 25 tamps of a 40-lb spring tamper. The sand samples were compacted on each of three layers by 25 tamps of a 20-lb spring tamper. Cure times were 6 hours, 24 hours, 3 days, and 7 days under humid conditions prior to testing.

Effectiveness: The rate of strength development and ultimate strengths achieved in the loess and heavy clay using the lumnite cement are less

(Continued on next page)

* Basic material

than that achieved using normal portland cement under comparable test conditions.

On sand, the lumnite cement was much more effective than portland cement. At the 10 percent rate of treatment, the strength increase of the lumnite over the portland cement was 429, 131, and 83 percent after 1, 3, and 7 days cure, respectively. Higher strength values were achieved with 15 percent lumnite cement.

Category*

Cement

Basic Material	Rate of Material	Cost
Plaster of Paris	3, 5, and 10%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay and heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal data (1956-57), not Published

Comments:

Treated samples were compared to untreated samples. Preparation of the samples was with a Harvard miniature compaction apparatus, five layers, ten tamps per layer with a 20-lb spring tamper. The samples were tested against Category 1 stabilization requirements.

Effectiveness: The strength increase of the treated samples as compared to the untreated varied 200 to 1700 percent; however, this did not satisfy the requirements.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	3%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	239%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi unconfined compression strength). Samples prior to tests were air-dried 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 78 psi which was in increase of 239 percent. The material showed promise as a waterproofer.

This material was also subjected to field investigations at WES as a dustproofer and waterproofer; however, the result did not indicate the need for additional tests of this material.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good
	clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

The untreated samples were not suitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - The treated samples possessed good compressive strength (203 psi); however, the samples were not waterproof.

Clay - The samples possessed no strength nor were they waterproof.

* Basic material

Category*
Cement

Basic Material	Rate of Material	Cost
Portland Cement	5%	Not given

Secondary Material

Additives (see comments)	0.5 and 1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clayey Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 35

Comments:
The treated samples with additives were compared to soil-cement samples. Compressive strengths were determined after 7 and 28 days of soaking. The soil-cement samples after 7 days soak had a compressive strength of 170 psi and 28- psi after 28 days soak in water.

(Continued on next page)

* Basic material

	Additive %	Strength Change Based on Soil-Cement Without Additives, Percent 7-day Soak	28-day Soak
Calcium chloride	0.5	+41	Negative
	1.0	+71	+39
Sodium tetraphosphate	0.5	+41	+38
	1.0	+147	+82
Pozzolith 2AA	0.5	+30	+9
	1.0	Negative	Negative
Aerotel	0.5	Negative	Negative
	1.0	Negative	Negative
Daxad 21	0.5	+30	+2
	1.0	Negative	Negative
Lignosol X2D	0.5	+56	+12
	1.0	Negative	Negative
Posassium permanganate	0.5	+82	+75
	1.0	+165	+136
Calcium hydroxide	0.5	+11	+23
	1.0	Negative	0
Polyvinyl alsohol	1.0	+68	+14

Potassium permanganate and sodium tetraphosphate are the most promising additives follow ed by calcium ch loride and polyvinyl alcohol

Additives with "negative" stated were detrimental to soil-cement treated samples.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Arquad 2HT plus sodium hydroxide	0.1 plus 0.99%; 0.5 plus 1.08%; and 1.0 plus 1.07%	Not given
Arquad 12	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Arquad 2HT - di-hydrogenated tallow dimethyl ammonium chloride

Arquad 12 - lauryl trimethyl ammonium chloride

Samples treated with additives and cement compared to samples treated with cement only. After cure time shown below and prior to tests, samples were immersed in water for 24 hours.

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additive %
None	0	1	172	-
		4	218	-
		7	180	-
		28	180	-
Arquad 2HT plus	0.1	1	100	Negative
sodium hydroxide	0.00	4	200	Negative
		7	250	+79
		28	390	+117
	0.5	1	208	+21
	1.08	4	291	+34
		7	372	+107
		28	423	+135
	1.0	1	293	+70
	1.07	4	280	+28
		7	365	+102
		28	364	+102
Arquad 12	1.0	1	139	Negative
		4	184	Negative
		7	208	+16
		28	262	+46

Effectiveness: Arquad 2HT (0.1 percent) plus sodium hydroxide (0.99 percent) with cement produced the highest strength increast except for the one day cure. Arquad 2 HT (1 percent) plus sodium hydroxide (1.0 percent) gave the greatest increase, 70 versus 21 percent for the first rates given. The remaining materials only gave strength increase after 7 and 28 days cure.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material

See comments for additives

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

The samples treated with cement plus each additive were compared to samples treated with only cement. The samples were cured for 1, 4, 7, and 28 days plus 24 hours water immersion and then subjected to tests.

The additives with rates (percent) are shown below:

a. Sodium hydroxide - 0.48 and 1.00 percent

b. Ferric shloride - 0.10 and 0.5 percent
plus sodium hydroxide - 1.03 and 1.00 percent

(Continued on next page)

* Basic material

c. Arquad 2HT (di-hydrogenated tallow dimethyl ammonium chloride) - 0.10 and 0.20 percent

d. Arquad 12 (laurly trimethyl ammonium chloride) - 0.50 and 1.00 percent plus sodium hydroxide - 0.98 and 0.96 percent

e. Triethylene tetramine (TTA) - 0.50 and 1.00 percent plus sodium hydroxide - 0.96 and 0.98 percent

f. Octylamine (soil pretreated with this material prior to the addition of sodium hydroxide) - 0.50 and 1.00 percent plus sodium - 1.04 and 1.00 percent

Effectiveness: All additives with cement gave some increase in strength over only cement-treated samples. Sodium hydroxide (1.00 percent) was the most effective additive and gave the greatest strength increase for all cure days. However, 10 percent cement only treated samples gave better results than 5 percent cement plus the sodium hydroxide.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5 and 10%	Not given

Secondary Material

Chemical additives (see comments)	Varied (0.5 to 2.0%)	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:

The molding moisture content varied from 20.1 to 21.7 percent. The number of curing hours varied from 4 to 168. In the tabulation below, data are given on the rates (percent) and hours that gave the most effective combination with the materials used. The Optimum rate of additive is also given. The cure condition for the optimum rate of additive is also given. The cure conditions for the samples were as follows: room temperature, 100 percent relative humidity, 24 hours immersion in water, and then samples subjected to tests.

(Continued on next page)

* Basic material

Additive	Concentration of Additive %	Molding Water Content %	Curing Time Hrs	Compressive Strength psi	Strength Change Based On Soil Cement Without Additive %
A. 5 percent cement					
None	0	20.9	168	107	--
Sodium metasilicate	1.0	20.6	168	359	+236
Sodium silicate	1.0	20.5	168	277	+159
Sodium hydroxide	1.0	20.5	168	285	+166
Potassium hydroxide	1.43	21.0	168	270	+153
Lithium hydroxide	0.59	20.8	168	198	+85
Sodium sulfite	1.0	21.2	168	322	+200
Sodium carbonate	1.0	20.5	168	375	+250
Sodium bicarbonate	1.0	21.0	168	248	+132
B. 10 percent cement					
None	0	19.6	168	312	--
Sodium metasilicate	1.0	19.1	168	515	+65
Sodium hydroxide	1.0	19.2	168	462	+48
Sodium carbonate	1.0	19.3	168	492	+58

Effectiveness:

5 percent cement. The additive, sodium carbonate, gave the most effective increase in compressive strength over the soil-cement samples. Sodium metasilicate and sodium sulfite were next in order of effectiveness. However, all chemical additives were effective in increasing the sample strength over the cement only treated samples.

10 percent cement. Sodium metasilicate was the most effective additive used with 10 percent cement. All additives, however, increased the compressive strength of the samples. The percent increase for the 10 percent cement was not as great an increase as for the 5 percent cement; however, the compressive strengths were higher when compared to the cement only treated samples.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	10%	Not given

Secondary Material		
Calcium shloride	0.6%	Not given
Sodium hydroxide	0.5 and 1.0%	Not given
Sodium carbonate	1.0%	Not given
Sodium sulfite	1.0%	Not given
Sodium sulfate	0.5%	Not given
Sodium metasilicate	1.05%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sand (Winconsin #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

Samples treated with the secondary materials were compared to samples treated with cement only. Curing time was 1, 4, and 7 days followed by 1 day of water immersion prior to tests. Each secondary material was used with 10 percent cement.

(Continued on next page)

* Basic material

Effectiveness: All materials except 1.0 percent sodium hydroxide, one day cure time, increased the strength of the cement-treated samples for all cure days. Sodium metasilicate (1 percent) was the most effective in that after one day cure the strength was increased over the cement-treated only by 734 percent and after 7 days cure the strength was increased by 95 percent. All materials accelerated the rate of cure of the samples.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material

See comments	1%	

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good
	Heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 18

Comments:

Samples were molded in a Harvard Miniature Compaction Apparatus in five layers (each layer compacted with ten tamps of a 40-lb spring tamper). Samples were tested after 24 hours cure at 100 percent relative humidity and after a 24 hour cure at 100 percent relative humidity followed by 24 hours water immersion. The strength of the untreated soils was about 20 psi. Materials which when added to the soil helped to increase the strength from 20 to 100 psi or greater were considered to have potential as stabilizers.

Portland cement (5%) was used alone with both soils and in combination with the following materials on both soils. (Each material was
(Continued on next page)

* Basic material

used at a 1 percent rate.)

Sodium hydroxide, sodium sulfate, sodium aluminate, sodium orthosilicate, sodium metasilicate, sodium hydroxide plus sodium orthosilicate, sodium hydroxide plus sodium metasilicate, sodium sulfate plus sodium orthosilicate, and sodium sulfate plus sodium metasilicate.

Effectiveness: Lean clay - Samples treated with 5 percent portland cement with no additives gave the best results (185 psi after 24 hours dry cure and 150 psi after 24 hours soak.) Sodium orthosilicate and sodium metasilicate each with cement gave somewhat higher wet strengths; however, the dry strengths were less than that for cement only treated samples.

Heavy clay - Samples treated with 5 percent portland cement and 1 percent sodium hydroxide gave the best results (165 psi dry strength and 150 psi after 24 hours soak). Treatment with only 5 percent portland cement was the next best treatment (145 psi dry strength and 106 psi after soak).

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Dispersants (see comments)	See comments	

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 35

Comments:

The concentration of dispersants was 1 percent except for the Kent wetting agent which was 5 percent. The treated samples were compared to a soil cement sample with 270 psi compressive strength.

(Continued on next page)

* Basic material

Dispersant	Strength Change Based on Soil Cement, Percent
Lignosol X2D	+41
Lignosol SF	+11
Lignosol SFX	Negative
Pozzolith 2AA	+59
Daxad 21	+ 33
Kent wetting agent	+ 22
Sodium thiosulfate	+ 52
Calcium phosphate-monobasic	Negative
Sodium fluosilicate	Negative
Trisodium phosphate	+37
Sodium tetraphosphate	+19
Tetrasodium pyrophosphate	0
Modified sodium phosphate	Negative
Trisocium phosphate (anhydrous)	+26
Sodium tripolyphosphate	+7

As seen from the data above, the most promising were pozzolith 2AA, sodium thiosulfate, lignosol X2D, and trisodium phosphate. Others which indicated some improvement were Kent wetting agent, sodium tetraphosphate, Daxad 21, and trisodium phosphate (anhydrous).

The maximum compressive strength of soil-cement using 10 percent cement and without dispersant was 390 psi. The four most promising gave a strength increase approximating that of an additional 5 percent cement over the base amount of 5 percent (about same strength as 10 percent cement only).

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide	1.0%	Not given
Sodium carbonate	1.0%	Not given
Sodium metasilicate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

The treated samples (with each additive) were compared to samples treated only with 5 percent cement. Cure time is listed below; however, before testing, the samples were also subjected to 24 hours water immersion.

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additives %
None	0	1	102	0
		4	175	0
		7	132	0
		28	232	0
Sodium hydroxide	1.0	1	98	Negative
		4	274	+57
		7	355	+169
		28	450	+94
Sodium carbonate	1.0	1	146	+43
		4	180	+3
		7	175	+33
		28	310	+34
Sodium metasilicate	1.0	1	211	+107
		4	264	+51
		7	265	+100
		28	430	+86

Effectiveness: Except for the slow curing after one day, sodium hydroxide is the most effective in increasing the strength. Sodium metasilicate and sodium carbonate are next in order of effectiveness.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	10%	Not given

Secondary Material		
Sodium hydroxide	0.25 to 1.0%	Not given
Sodium carbonate	1.0%	Not given
Sodium metasilicate	1.0%	Not given
Sodium sulfate	0.54 and 1.08%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sand (Wisconsin #1)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

Samples treated with the cement and additives were compared to samples treated only with cement. Tests were run on samples after 1, 4, 7, and 28 days of cure followed by 24 hours water immersion.

(Continued on next page)

* Basic material

Effectiveness: The following secondary materials gave no increase in strength of the cement-treated samples or the addition of these materials was detrimental to the strength of the samples: sodium hydroxide, sodium carbonate, and sodium metasilicate. Sodium sulfate was very effective in combination with 10 percent cement in improving the strength of treated samples. At0.54 percent sodium sulfate, the strength increased from 500 after one day cure to 1030 percent after 28 days cure over that for cement only treated samples. At 1.08 percent sodium sulfate, the strength increased from 720 after one day cure to 1739 percent after 28 days cure over that for cement only treated samples.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide, sodium carbonate, sodium metasilicate, sodium sulfate, sodium aluminate, sodium fluosilicate, sodium fluoride, sodium fluoborate, and sodium tetraborate	All materials were each tested with cement at 0.5, 1.0, and 2.0% rates	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:
Treated samples (with each additive) were compared to samples treated only with 5 percent cement. Cure time is listed below; however, before testing, the samples were also subjected to 24 hours water immersion. Of the three rates for each additive used, the most effective rate is shown below:

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additives %
None	0	1	80	-
		4	90	-
		7	95	-
		28	125	-
Sodium hydroxide	1.0	1	145	+80
		4	217	+141
		7	235	+148
		28	280	+124
Sodium carbonate	1.0	1	140	+75
		4	188	+109
		7	220	+132
		28	285	+128
Sodium metasilicate	1.0	1	135	+69
		4	198	+120
		7	218	+130
		28	344	+175
Sodium sulfate	1.0	1	228	+185
		4	275	+205
		7	325	+242
		28	435	+248
Sodium aluminate	0.5	1	230	+188
		4	282	+213
		7	330	+247
		28	425	+240

Effectiveness: Other additives which were used (sodium fluosilicate, sodium fluoride, sodium fluoborate, ET-218, and sodium tetraborate) were either detrimental when added to the cement or no significant strength increase resulted.

Sodium aluminate (0.5 percent) and sodium sulfate (1.0 percent) were very effective in increasing the strength of the treated samples. Sodium hydroxide, carbonate, and metasilicate were also effective in increasing the strength of the additive-cement-treated samples over the strength of the cement only treated samples.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland Cement	10%	Not given

Secondary Material		
Additives		
Sodium hydroxide	0.98, 1.93, and 2.90%	Not given
Sodium sulfate	1.71, 3.32, and 4.63%	Not given
Sodium aluminate	0.51, 1.03, and 2.08%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See coments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with cement plus each additive were compared to samples treated with cement only. All samples were tested after the cure time shown below followed by 24 hours water immersion. The combinations (percent) of materials which gave best results are shown below:

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additive
None	0	1	128	-
		4	208	-
		7	283	-
		28	360	-
Sodium hydroxide	0.98	1	192	+50
		4	331	+59
		7	362	+28
		28	478	+33
Sodium sulfate	3.32	1	315	+146
		4	426	+105
		7	410	+45
		28	640	+78

Effectiveness: The sodium sulfate (3.32 percent) was the most effective additive.

The amount of strength increase with additives and cement is less than that for 5 percent cement treatment; however, the early strength of the samples is much better.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide	1.0, 1.5, and 2.0%	Not given
Sodium sulfate	0.51, 0.99, 1.96, and 3.96%	Not given
Sodium aluminate	1.10, 2.22, and 4.31%	Not given
Ferric chloride plus sodium chdroxide	0.10 plus 1.00 and 1.00 plus 1.02%	Not given
Octylamine plus sodium hydroxide	0.50 plus 1.0 and 0.56, 1.07, and 0.99%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with each additive at various percentages were compared to samples treated only with cement. All samples were tested after cure of 1, 4, 7, 28, and 34 days followed by a 24-hour water immersion.

Effectiveness: The additives with rate of treatment (percent) are listed below in order of increase in strength over the cement only treated samples:

(Continued on next page)

* Basic material

Ferric chloride (0.10 percent) plus sodium hydroxice (1.0 percent):

- 1 day cure - 209 percent strength increase
- 4 day cure - 236 percent strength increase
- 7 day cure - 136 percent strength increase

Octylamine (0.50 percent) plus sodium hydroxide (0.56 percent):

- 1 day cure - 144 percent strength increase
- 4 day cure - 131 percent strength increase
- 7 day cure - 84 percent strength increase

Sodium aluminate (1.10 percent):

- 1 day cure - 142 percent strength increase
- 4 day cure - 123 percent strength increase
- 7 day cure - 88 percent strength increase

Sodium hydroxide (1.0 percent):

- 1 day cure - 110 percent strength increase
- 4 day cure - 80 percent strength increase
- 7 day cure - 17 percent strength increase

The sodium sulfate was detrimental to the soil-cement mixture.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	10%	Not given

Secondary Material		
Sodium hydroxide	0.57, 0.59, 1.09, 1.15, and 2.35%	Not given
Sodium sulfate	0.97, 1.99, and 3.95%	Not given
Sodium aluminate	1.13, 2.26, and 4.44%	Not given
Sodium metasilicate	0.88 and 1.88%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:
Samples treated with each additive at various percentages were compared to samples with cement only.

Sodium hydroxide (2.35 percent) was effective in improving the strength of the soil with 10 percent cement. The increase in strength was 70 percent after one day cure and 91 percent after 34 days cure. Next in the order of improvement were sodium aluminate (2.26 percent and sodium metasilicate (1.88 percent which gave improvements of 41 percent (one day cure) and 74 percent (34 days cure), and 64 percent (one day cure) and 67 percent (34 days cure), respectively.

* Basic material

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide (see note)	1.0%	Not given
Sodium sulfite	1.0%	Not given
Sodium carbonate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Illinois)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

Cure was for 1, 4, and 7 days. Each sample was then subjected to 24 hours water immersion and tested. Samples treated with 5 percent cement and additive were compared to samples treated with 5 percent cement. Each secondary material was used with cement in treating samples.

Effectiveness: The sodium hydroxide (1 percent) was slightly effective. The increase in strength over the 5 percent only treated samples for 1, 4, and 7 days cure was 72, 41, and 36 percent. The other two additives were detrimental to the strength of the samples treated with the 5 percent cement.

(Continued on next page)

* Basic material

NOTE: Further testing was conducted with sodium hydroxide (0.5, 1.0, and 1.5 percent) as an additive for 5 and 10 percent cement for stabilizing. It was found that the optimum effectiveness for both 5 and 10 percent cement was sodium hydroxide at 1.0 percent. However, samples treated with 15 percent cement only had strengths of 143 percent and 13 percent greater than that for 5 and 10 percent cement plus sodium hydroxide, respectively.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide	0.5, 1.0, and 2.0%	Not given
Sodium sulfite	1.0%	Not given
Sodium carbonate	1.0%	Not given
Sodium metasilicate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #1)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

Samples treated with cement and each additive were compared to samples treated only with cement. Tests were run on samples after 1, 4, and 7 days cure followed by 24 hours water immersion.

Effectiveness: Samples treated with the additives sodium sulfite and sodium carbonate had lower strengths than samples treated with cement alone (detrimental).

(Continued on next page)

* Basic material

The strength of cement with the additive sodium hydroxide was increased by 30 percent after one day cure and by 45 percent after seven days cure as compared to the same cure time for cement only treated samples. This material's effectiveness was slight.

Sodium metasilicate (1 percent) was next in effectiveness with somewhat lower values of strength increase.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium hydroxide	1%	Not given
Sodium hydorxide plus barium chloride	1.0 and 0.1%	Not given
Sodium sulfite	1.0%	Not given
Sodium carbonate	1.0%	Not given
Sodium metasilicate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Texas #2)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

The treated samples (with each additive) were compared to samples treated only with 5 percent cement. Cure time is listed below; however, before testing, the samples were also subjected to 24 hour water immersion.

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additive
None	0	1	76	-
		4	103	-
		7	157	-
Sodium hydroxide	1.0	1	162	+113
		4	185	+80
		7	184	+17
Sodium hydroxide	1.0	1	115	+51
plus barium chloride	0.1	4	195	+89
		7	232	+48
Sodium sulfite	1.0	1	45	Negative
		4	104	0
		7	107	Negative
Sodium carbonate	1.0	1	50	Negative
		4	87	Negative
		7	95	Negative
Sodium metasilicate	1.0	1	115	+51
		4	195	+89
		7	232	+48

Effectiveness: Sodium sulfite and sodium carbonate were detrimental to the strength of the additive-cement treated samples. Sodium hydroxide gave the highest one-day cure strength; however, sodium metasilicate and sodium hydroxide plus barium chloride were overall more effective.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium metasilicate	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	lean clay	Good
	clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:
The untreated samples were unsuitable for compression tests after 4 days dry cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - The treated samples possessed some compressive strength (115 psi); however, the samples were not waterproof.

Clay - The samples possessed no strength nor were they waterproof.

* Basic material

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium orthosilicate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comment

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	References 25

Comments:

The untreated samples were not suitable for compression tests after 4 days cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - ~~The samples possessed some~~ compressive strength (83 psi); however, they were not waterproof.

Clay - The samples possessed no strength nor were they waterproof.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium orthosilicate	0.54 and 1.03%	Not given
Sodium metasilicate	0.60 and 1.33%	Not given
Grade 50 silicate	1.00 and 1.98%	Not given
Grade 40 silicate	1.00 and 1.98%	Not given
Sodium oxide (Na_2O)		
Silicon doixide (SiO_2)		

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with each additive plus soda and silica at various percents were compared to samples treated with cement only. All semples were tested after the cure time shown below followed by a 24-hour water immersion. The additive (percent) which gave the best results is given below.

(Continued on next page)

* Basic material

Additive	Additive %	Ratio of Na_2O to SiO_2	Curing Days	Strength psi	Strength Change Based on Soil Cement Without Additive %
None	0	0	1	80	--
			4	90	--
			7	95	--
			28	125	--
Sodium orthosilicate	1.03	2:1	1	217	+171
			4	235	+161
			7	286	+201
			28	491	+293
Sodium metasilicate	1.33	1:1	1	135	+69
			4	198	+120
			7	218	+129
			28	344	+175
Grade 50 silicate	1.00	1:2	1	123	+54
			4	370	+311
			7	420	+342
			28	553	+342
Grade 40 silicate	1.00	1:3.22	1	290	+263
			4	352	+291
			7	386	+306
			28	530	+324

Effectiveness: All additives shown above were very effective in increasing the strength of the soil-cement samples.

Grade 40 silicate-treated samples developed the highest initial (one-day) strength.

Grade 50 developed the highest (28 days) strength followed closely by Grade 40 silicate.

Category*		
Cement		
Basic Material	**Rate of Material**	**Cost**
Portland cement	5, 6, 8, and 10%	1.5¢ per lb
Secondary Material		
See comments Sodium sulfate	1%	10¢ per lb
Material Form*	**Type of Soil Treated**	**Mixing Capability**
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
$1.60 (exclusive of shipping, storing, and construction)	WES	Reference 14

Comments:

Samples were molded in a Harvard Miniature Compaction Apparatus in five layers (each layer compacted with ten tamps of a 40-lb spring tamper). Samples were cured at 100 percent relative humdity for 24 hours and subjected to tests. When the strength of the treated samples as compared to untreated samples (25 psi) increased from 25 psi to 100 psi or greater, the materials were considered to warrant further consideration as stabilizers.

(Continued on next page)

* Basic material

Additive	Additive %	Unconfined Compression Strength psi	Strength Increase as Compared to Untreated Soil	Strength Increase Compared to Cement Without Additive
None	0	24	-	-
Portland cement with:	5	160	+567	-
Sodium carbonate	1	167	+596	+4
Sodium hydroxide	1	90	+275	Negative
Sodium sulfate	1	207	+763	+29
Sodium sulfite	1	127	+429	Negative
Potassium permanganate	1	112	+367	Negative
Portland cement	6	165	+588	+3
Portland cement	8	175	+629	+9
Portland cement	10	209	+771	+31

Portland cement (5 percent) with 1 percent sodium sulfate gave the best results. Portland cement (10 percent) gave a slight increase over the combination of the two materials.

Traffic tests were conducted on a lean clay soil treated with 5 percent portland cement and 1 percent sodium sulfate and the strength developed was sufficient to meet the requirements of emergency military roads.

Category*
Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium sulfate	0.5%	Not given
ET-224 dispersant	0.1%	Not given
Barium chloride	1.0%	Not given
Sodium fluosilicate	1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 38

Comments:

The treated samples with the additive were compared to samples treated with 5 percent cement. Curing time is listed below: however, before testing the samples were also subjected to 24 hours water immersion.

(Continued on next page)

* Basic material

Additive	% Additive	Curing Days	Strength psi	Strength Change Based on Soil Without Additive %
None	0	1	145	-
		4	172	-
		7	195	-
Sodium sulfate	0.5	1	217	+50
		4	247	+44
		7	275	+41
ET-224 Dispersant	0.1	1	165	+14
		4	260	+51
		7	304	+56
Barium chloride	1.0	1	100	Negative
		4	145	Negative
		7	172	Negative
Sodium fluosilicate	1.0	1	78	Negative
		4	96	Negative
		7	126	Negative

Effectiveness: Sodium sulfate (0.5 percent) and ET-224 dispersant (0.1 percent) were effective in combination with 5 percent cement for stabilizing loess soil.

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	5%	Not given

Secondary Material		
Sodium sulfate	1%	Not given
Sodium metasilicate	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good
	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	See comment

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

The untreated samples were not suitable for compression tests after 4 days cure followed by 4 days wetting by capillary action.

Effectiveness: Lean clay - The treated samples possessed some compressive strength (96 psi); however, the samples were not waterproof.

Clay - The samples possessed no strength nor were they waterproof.

* Basic material

Category*

Cement

Basic Material	Rate of Material	Cost
Portland cement	10%	Not given

Secondary Material

Sulfate compounds
(see comments)

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sand (Wisconsin #1)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with each sulfate plus cement were compared to samples treated with cement only. Cure time is shown below; however, in addition to this time, samples prior to testing were immersed in water 24 hours. Each additive was tested at several rates; however, the most effective is shown. Also, methods of adding additive were solution, slurry, and dry mix with cement. The most effective method is given.

(Continued on next page)

* Basic material

Additive	Additive %	Method of Adding Additives	Curing Days	Strength psi	Strength Change Based on Soil Cement Without Additive %
None	0	--	1	25	--
			4	20	--
			7	19	--
			28	23	--
Sodium sulfate	1.08	Solution	1	205	+720
			4	350	+1650
			7	342	+1700
			28	425	+1748
Calcium sulfate anhydrite	1.10	Slurry	1.	165	+560
			4	280	+1300
			7	363	+1810
			28	413	+1696
Calcium sulfate hydrate (gypsum)	1.10	Slurry	1	183	+632
			4	271	+1255
			7	292	+1437
			28	378	+1543
Magnesium sulfate	0.48	Solution	1	167	+568
			4	193	+865
			7	227	+1095
			28	304	+1222

Effectiveness: The additives above are listed in the order of their effectiveness. However, all additives were very effective in increasing the strength of the cement-treated samples. The lowest increase in effectiveness was 308 percent.

Category*

Cement

Basic Material	Rate of Material	Cost
Type I normal portland cement	5%	Not given

Secondary Material		
Chemical additives (see comments)	0.5 and 1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

The treated samples with additives were compared to soil-cement treated samples. Samples were cured for 7 and 28 days at room temperature in 100 percent relative humidity and then immersed in water for 24 hours. The soil-cement strength after a 7-day cure without additive was 180 psi and 260 psi after a 28-day cure.

(Continued on next page)

* Basic material

Additive	Percent	Strength Change Based on Soil-Cement Without Additive, percent 7-Day Cure	28-Day Cure
Quadrafos	0.5	+22	Negative
Lignosol X2D	0.5	+22	Negative
	1.0	+47	+6
Polyvinyl alcohol (50-42)	1.0	+25	Negative
Piccolyte S125	0.5	+3	Negative
Picco XX-100B	0.5	+25	0
	1.0	+28	Negative
Vinsol	0.5	+8	Negative
Arquad 2HT	0.5	+6	Negative
Calcium hydroxide	0.5	+14	Negative
Sodium hydroxide	0.5	+89	+49
	1.0	+87	+77
Sodium sulfite	0.5	+81	+15
	1.0	+67	+32
Sodium carbonate	0.5	+44	+11
	1.0	+72	+27

Other chemical additives used with 5 percent cement-treated soil samples were as follows:

Pozzolith 2AA	Ferric sulphate
Daxad 21	Ferric chloride
Arcolor 4465	Calcium chloride
Phosphorus pentoxide	Sodium chloride
Darex polyvinyl acetate X52L	Potassium permanganate

These materials, when used, either gave no increase in compressive strength over the 5 percent cement treated samples or gave less strength (chemicals were detrimental to strength).

(Continued on next page)

Effectiveness. As seen from the percent increase in compressive strength when the additives were used, only sodium hydroxide (1 percent rate) gave any significant increase in strength. Sodium sulfite and sodium carbonate gave the next highest increase in strength.

Samples with 10 percent of cement without additives have strength of 415 and 525 psi for 7 and 28 days cure, respectively. These values are 135 percent over the strength value for the 5 percent of cement (plus additives), 7-day cure, and 102 percent over the strength value for the 5 percent of cement (plus additives), 28-day cure.

Category*

Cement

Basic Material	Rate of Material	Cost
Type I normal portland cement	5%	Not given

Secondary Material		
Chemical additives (see comments)	0.5 and 1.0%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

The treated samples with additives were compared to soil-cement treated samples. Samples were cured for 7 and 28 days at room temperature in 100 percent relative humidity and then immersed in water for 24 hours.

(Continued on next page)

* Basic material

Additive	Percent	Strength Change Based on Soil-Cement Without Additive, Percent: 7-Day Cure	28-Day Cure
Quadrafos	0.5	+32	+79
	1.0	+48	+132
Aroclor 4465	0.5	+16	+29
	1.0	+21	+21
Vinsol	0.5	+5	+33
	1.0	+26	+33
Piccopale emulsion A-1	0.5	+11	+21
	1.0	+37	+12
Piccopale emulsion A-35	0.5	+53	+75
	1.0	+16	+46
Calcium chloride	0.5	+58	+75
	1.0	+48	+62
Sodium chloride	0.5	+69	+75
	1.0	+90	+133
Potassium chloride	0.5	+16	+29
	1.0	+53	+133
Potassium permanganate	0.5	+63	+92
	1.0	+126	+204
Potassium dichromate	0.5	+84	+113
	1.0	+95	+142
Sodium hydroxide	0.5	+74	+100
	1.0	+174	+200
Calcium hydroxide	0.5	+5	+17
	1.0	+16	+21
Potassium hydroxide	1.0	+156	+83
Sodium sulfite	0.5	+200	+126
	1.0	+137	+146
Sodium carbonate	0.5	+216	+174
	1.0	+240	+106

(Continued on next page)

Other chemical additives used with 5 percent cement-treated soil samples were as follows:

- Pozzolith 2AA
- Daxad 21
- Lignosol X2D
- Losorb
- PVA (5-88)
- PVA (5-88) + Paraformaldehyde
- PVA (65-98)
- PVA (65-98) + paraformaldehyde
- Phosphorus pentoxide
- Borax

These materials when used either gave no increase in compressive strength over the 5 percent cement treated samples or gave less strength (chemicals were detrimental to the strength).

Effectiveness. As seen from the percent increase in compressive strength when the additives were used, sodium hydroxide (1 percent rate), potassium permanganate (1 percent rate), sodium carbonate (0.5 and 1.0 percent rates), and sodium sulfite (0.5 and 1.0 percent rates) were quite effective. Potassium hydroxide (1.0 percent rate), potassium dichromate (0.5 and 1.0 percent rates), sodium chloride (1.0 percent rate), and potassium chloride (1.0 percent rate) were next in order of effectiveness.

Category*

Cement

Basic Material	Rate of Material	Cost
Type I normal portland cement	5%	Not given

Secondary Material		
Chemical additives (see comments)	0.5 and 1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Silty clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 36

Comments:

The treated samples with additives were compared to soil-cement treated samples. Samples were cured (for 7 and 28 days) at room temperature in 100 percent relative humidity and then immersed in water for 24 hours. The soil-cement strength after a 7-day cure without additive was 300 psi and 435 psi after a 28-day cure.

(Continued on next page)

* Basic material

Additive	Percent	Strength Change Based on Soil-Cement Without Additive % 7-Day Cure	28-Day Cure
Aroclor 4465	0.5	+12	+23
	1.0	+31	+23
Vinsol	0.5	+12	Negative
	1.0	+20	+3
Sodium chloride	0.5	+7	Negative
	1.0	+6	+10
Potassium chloride	0.5	+6	Negative
Potassium permanganate	1.0	+65	+43
Darex polyvinyl	0.5	+6	Negative
Quadrafos	0.5	+38	+38
	1.0	+105	+105
Sodium hydroxide	0.5	+169	+265
	1.0	+174	+215
Sodium sulfite	0.5	+7	+33
	1.0	+130	+174
Sodium carbonate	0.5	+93	+112
	1.0	+200	+199

Other chemical additives used with 5 percent cement soil-treated samples were as follows:

- Polyvinyl alcohol (50-42)
- Piccolyte S125
- Potassium hydroxide
- Ferric chloride
- Ferric sulfate
- Phosphorus pentoxide
- Arquad 2HT
- Acetate X52L
- Calcium chloride
- PVA (5-88)
- PVA (5-88) + paraformaldehyde

These materials, when used, either gave no increase in compressive strength over the 5 percent cement-treated samples or gave less strength (chemicals were detrimental to strength).

(Continued on next page)

Effectiveness. As seen from the percent increase in compressive strength when the additives were used, only potassium permanganate (1 percent rate), Quadrafos (1 percent rate), sodium hydroxide (0.5 and 1 percent rates), sodium sulfite (1 percent rate), and sodium carbonate (0.5 and 1 percent rates) showed any real effectiveness.

Samples with 10 percent of cement without additives had strength of 560 and 665 psi for 7- and 28-days curing, respectively. These values are 87 percent over the strength value for 5 percent of cement (7-day cure) and 53 percent over the strength value for 5 percent of cement and 28-day cure.

The chemical additives [Quadrafos (1 percent rate), sodium hydroxide (0.5 and 1 percent rates), sodium sulfite (1 percent rate), and sodium carbonate (0.5 and 1 percent rates)] are the only ones that, when used with 5 percent of cement-treated samples, exceeded the strength of samples treated only with 10 percent of cement.

Category*

Cement

Basic Material	Rate of Material	Cost
Type I portland cement	6% (on lean clay) 5% (on heavy clay)	Not given

Secondary Material		
Sodium hydroxide (with heavy clay only)	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay Heavy clay	Good Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression and traffic	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 9

Comments:

Treated samples were compared to untreated samples (18 psi). Samples were prepared using the Harvard Miniature Compaction Apparatus in five layers (each layer was compacted with ten tamps of a 40-lb spring tamper). Samples were tested after 24 hours cure under 100 percent relative humidity and after 24 hours cure under 100 percent relative humidity followed by immersion in water for 24 hours.

(Continued on next page)

* Basic material

Laboratory tests: The 6 percent portland cement treated lean clay in unconfined compression tests met the requirements of Category 2 stabilization, and 5 percent portland cement with 1 percent sodium hydroxide with heavy clay soil also met the Category 2 requirements.

Traffic tests: The materials as listed for the laboratory tests also met the requirements for emergency military operations.

Category: Lime

Category*
Lime

Basic Material	Rate of Material	Cost
Hydrated lime	2.5, 4, and 5%	Not given

Secondary Material

Additives: Sodium hydroxide	1%	Not given
Sodium sulfate, sodium carbonate,	1%	Not given
Magnesium sulfate, calcium oxide	1 and 2 %	Not given
Calcium hydroxide	2.5%	Not given
Portland cement	2.5%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1960), not published

Comments:
Samples were prepared in a Harvard miniature compaction apparatus, five layers, ten tamps per layer with a 40-lb spring tamper. Treated samples were compared to untreated samples.

Effectiveness: Even though all combinations of the treated samples had strength increases, all combinations did not meet the requirements of Catefory 2 stabilization.

The 4 percent hydrated lime plus 1 percent sodium sulfate and 2.5 percent hydrated lime plus 2.5 percent calcium oxide were the only two combinations of materials which satisfied the requirements.

* Basic material

Category*
Lime

Basic Material	Rate of Material	Cost
Calcium hydroxide (slaked lime)	6.6%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Treated samples were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the treated samples was 150 psi.

* Basic material

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium hydroxide (slaked lime)	6.6%	Not given
Secondary Material		
Magnesium sulfate	1.25%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Treated samples with additive compared to samples treated only with basic material. Tests conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the samples was 165 psi which was an increase of 10 percent over those with only the hydroxide (150 psi).

* Basic material

Category*
Lime

Basic Material	Rate of Material	Cost
Calcium and magnesium limes (DaO and MgO)	CaO - 3, 2, and 1% MgO - 1, 2, and 3%	Not given

Secondary Material		
Magnesium sulfate	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay Heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1961), not published

Comments:

Treated samples were compared to untreated samples (20 psi) and to samples treated with 4 percent calcium oxide plus 1 percent magnesium sulfate (139 psi). The samples were cured at 100 percent relative humidity for one day and then tested for Category 2 stabilization.

(Continued on next page)

* Basic material

Effectiveness: The only combination of materials on lean clay which gave an increase over the 4 percent CaO plus 1 percent $MgSO_4$ was 3 percent CaO plus 1 percent $MgSO_4$ plus 1 per cent MgO (154 psi).

On the heavy clay soil, 3 percent CaO plus 1 percent MgO plus 1 percent $MgSO_4$ was effective (162 psi).

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium oxide	1,2,5, and 7%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Houston black)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Treated samples not compared to untreated samples. Tests were conducted ater a 24 hour humid cure followed by a 24 hour water immersion.

Effectiveness: Two percent calcium oxide added to the soil gave the highest strength (315 psi). The next highest strength was 260 psi at the 5 percent rate.

* Basic material

Category*
Lime

Basic Material	Rate of Material	Cost
Calcium oxide (lime)	5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Treated samples were not compared to untreated samples. Tests conducted after a 24 hour humid cure followed by a 24 hour water immersion.

Strength of the treated samples was 125 psi.

* Basic material

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium oxide	5%	Not given

Secondary Material

Additives (see comments)

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Houston black)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Samples treated with additives compared to samples treated with 5 percent calcium oxide (260 psi strength). Tests conducted ater a 24 hour humid cure followed by a 24 hour water immersion.

(Continued on next page)

* Basic material

Additive	Additive %	Strength psi	Strength Change Based on Samples Treated with Calcium Oxide %
None	0	260	--
Magnesium sulfate	1.25	390	+50
Sodium metasilicate	1.57	345	+33
Magnesium sulfate plus sodium metasilicate	1.25 1.37	505	+94
Zinc sulfate	1.46	205	Negative
Nickel sulfate	1.34	450	+73

Effectiveness: All additives except zinc sulfate gave higher strength than samples with the calcium oxide only.

Magnesium sulfate (1.25 percent) plus sodium metasilicate (1.57 percent) were additives which gave the most improvement in strength.

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium oxide	5%	Not given

Secondary Material

See comments for additives

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Samples treated with additives compared to samples treated with calcium oxide only. Tests were conducted ater a 24 hour humid cure followed by a 24 hour water immersion.

(Continued on next page)

* Basic material

Additive	Additive %	Strength psi	Strength Change Based on Soil Treated with Calcium Oxide Without Additive %
None	0	125	--
Magnesium carbonate	0.47	115	Negative
Magnesium fluoride	0.32	125	0
Magnesium oxide	0.20	110	Negative
Ammonium chloride	2.50	140	+12
Sodium metasilicate	1.30	170	+36
Sodium metasilicate plus magnesium sulfate	1.30 1.25	265	+112
Sodium metasilicate plus magnesium sulfate	2.00 1.25	270	+116
Zinc sulfate	1.46	200	+60
Nickel sulfate	1.34	170	+36
Copper sulfate	0.81	170	+36
Aluminum sulfate	1.69	100	Negative
Zinc sulfate plus sodium metasilicate	1.46 1.54	210	+68
Nickel sulfate plus sodium metasilicate	1.34 1.54	190	+52
Copper sulfate plus sodium metasilicate	0.81 1.54	180	+44

Effectiveness: The additives and/or combination of additives with the plus percentages are more effective than samples treated with the calcium oxide only. Below are the additives which are most effective:

Sodium metasilicate (2 percent) plus magnesium sulfate (1.25 percent).
Sodium metasilicate (1.30 percent) plus magnesium sulfate (1.25 percent).

Category*
Lime

Basic Material	Rate of Material	Cost
Calcium oxide (lime)	5%	Not given

Secondary Material		
Magnesium sulfate	1.25%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 41

Comments:

Treated samples with additives were compared to samples treated with only 5 percent calcium oxide. Tests were conducted after a 24 hour humid cure followed by a 24 hour water immersion.

The strength of the samples was 235 psi. This represents an increase of 88 percent over the strength of the calcium oxide (125 psi) treated samples.

* Basic material

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium oxide	4 and 5%	Not given

Secondary Material		
Magnesium sulfate	1.0 and 1.25%	Not given
Potassium sulfate	1.25%	Not given
Magnesium chloride	1.25%	"

Material Form*	Type of Soil Treated	Mixing Capability
Solid (lumps)	Clay (Vicksburg)	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples with basic material and/or additives were not compared to untreated samples. Tests were conducted after a 24 hour humid cure followed by 24 hours water immersion.

Effectiveness: Calcium oxide (5 percent rate) alone was effective in stabilizing the soil (195 psi).

Calcium oxide (5 percent rate) with the addition of 1.25 percent magnesium sulfate treated samples had a somewhat higher strength (210 psi).

(Continued on next page)

* Basic material

Calcium oxide with the other additives gave somewhat lower strengths.

Category*

Lime

Basic Material	Rate of Material	Cost
Calcium oxide plus magnesium sulfate plus cutback asphalt	3% 0.75%	Not given
Secondary Material		
Solvent - gasoline	2:1 (asphalt, gasoline)	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Calcium oxide - powder	Lean clay	Good
Magnesium sulfate - crystals	Clay	Good
Cutback asphalt - liquid		

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 25

Comments:

Samples were subjected to 4 days dry cure followed by 4 days wetting by capillary action. Untreated samples after wetting were not suitable for compression tests.

Effectiveness: Lean clay - The samples possessed good compressive strength (191 psi) and the materials waterproofed the samples.

Clay - Same as lean clay except the strength was 188 psi.

* Basic material

Category*
Lime

Basic Material	Rate of Material	Cost
Quicklime	1-5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Solid	Clayey silt, silt, clay, and loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Cone penetrometer	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 17

Comments:

Quicklime was tested for suitability as a category I stabilizer with the four soils and percentage of treatment below:

(Continued on next page)

* Basic material

Soil	Quicklime %	Required Strength After 2 Hours Cure psi	Strength of Treated Samples 2 Hours Cure psi	Percent Strength Increase Over Required
Clayey silt	1	125	210	68
	2		460	268
	3		860	588
Silt	3	125	230	84
Clay	3	125	170	36
	5		340	172
Loess	1	125	160	28
	3		520	316
	5		970	670

Effectiveness: All four soils are effectivenly stabilized to meet the requirements of category I stabilization by using 1 to 3 percent Quicklime.

Category*

Lime

Basic Material	Rate of Material	Cost
Quicklime	3, 4, and 5%	$1.00 per 100 lb

Secondary Material		
Magnesium sulfate	0.25, 0.5, 1.0, 1.5, 2, and 3%	$5.00 per 100 lb

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay, heavy clay, clayey silt, silt, blue clay, sandy clay, and sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent except for silt and sand soils

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
See comments	WES	Reference 17

Comments:

Treated samples were compared to untreated samples. Various combinations were used of the basic material with the secondary material on lean clay. It was found that 4 percent quicklime with 1 percent magnesium sulfate was most effective. This combination was then used in preparing samples with the other soils. Samples were prepared using the Harvard Miniature Compaction Apparatus in five layers (each layer was compacted with ten tamps of a 40-lb spring tamper). After 24 hours cure under 100 percent relative humidity, the samples were tested.

(Continued on next page)

* Basic material

The strength of all untreated samples was about 20 psi. The increase in the strength of the treated soils (except silt and sand) was sufficient for the 4 percent quicklime and 1 percent magnesium sulfate to be considered as Category 2 stabilizers. Silt and sand treated samples did not meet Category 2 stabilization.

Traffic tests were also conducted on sections of heavy clay and lean clay treated soils. The sections were treated with 4 percent quicklime and 1 percent magnesium sulfate. These sections withstood traffic requirements for emergency military operations.

Costs: A 4 percent quicklime/1 percent magnesium sulfate treatment would cost about $0.85 per sq yd (12 in. deep) exclusive of construction or other costs, as the quicklime was about $1.00 per 100 lb and sulfate was about $5.00 per 100 lb.

Category*

Lime

Basic Material	Rate of Material	Cost
Quicklime	3, 5, and 8%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 16

Comments:

Treated samples were compared to untreated samples. Samples were prepared using a Harvard Miniature Compaction Apparatus in five layers (each layer was compacted using ten tamps of a 40-lb spring tamper). After curing for 24 hours under 100-percent relative humidity, the samples were subjected to unconfined compression tests using the criteria for Category 2 stabilization.

(Continued on next page)

* Basic material

The test results showed that for between 3 and 8 percent treatment with quicklime, the requirements for Category 2 stabilization were met. Additional tests were conducted with 4 and 8 percent quicklime.

Traffic tests were also conducted. It was found that both 4 and 8 percent quicklime--stabilized soil surfaces are more than adequate for traffic requirements for emergency military roads and airfield operations.

Category*

Lime

Basic Material	Rate of Material	Cost
Quicklime	4 and 5%	Not given

Secondary Material

Modifiers: See comments

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay	Good
	Heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 18

Comments:

Samples were molded in a Harvard Miniature Compaction Apparatus in five layers (each layer compacted with ten tamps of a 40-lb spring tamper). Samples were tested after a 24-hour cure at 100 percent relative humidity and after a 24-hour cure at 100 percent relative humidity followed by 24 hours water immersion. The strength of the untreated soils was 20 psi. Materials which, when added to the soils, helped to increase the strength from 20 to 100 psi or greater were considered to have potential as stabilizers.

(Continued on next page)

* Basic material

Quicklime (5 percent) and quicklime (4 percent) plus the following modifiers were tested:

Magnesium sulfate (1%)
Sodium hydroxide
Magnesium sulfate (1%) plus alkyl dimethyl benzyl ammonium chloride (0.5%)
Magnesium sulfate (1.0%) plus 0.5% amine D acetate
Magnesium sulfate (1.0%) plus 0.5% octadecyl amine acetate
Magnesium sulfate (1%) plus 0.5% octadecyl amine
Magnesium sulfate (1%) plus 0.1% n-octylamine
Magnesium sulfate (1%) plus 1% sodium orthosilicate
Magnesium sulfate (1%) plus 1% sodium metasilicate
Magnesium sulfate (1%) plus 1% sodium silicate solution
3% quicklime plus 0.75% magnesium sulfate plus 3% cutback asphalt

Effectiveness: Lean clay - The strength of the dry cured samples of 5 percent quicklime exceeded 100 psi (103); however, the strength after soaking was only 28 psi. Several of the samples treated with 4 percent quicklime plus modifier(s) had dry strength in excess of 100 psi; however, the wet strengths were much less. The combination of materials which showed the most promise was: 4 percent quicklime plus 1 percent sodium sulfate and 1 percent sodium metasilicate, with 151 psi dry strength and 69 psi after soaking. However, the wet strength did not meet the criteria of 100 psi.

Heavy clay - The strength of the dry cure samples of 4 percent quicklime plus 1 percent magnesium sulfate was 132 psi; however, the strength after soak was only 48 psi (which does not meet the required minimum of 100 psi).

Category: Resin

Category*
Resin

Basic Material	Rate of Material	Cost
AM9 (water-soluble acrylamide and diacrylamide)	2.1 lb per sq yd	Not given

Secondary Material

Catalyst - Dimethylamino-propionitrile-potassium ferricyanide-ammonium persulfate

Solvent - water — 8.8 lb per sq yd

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Ashland Chemical Co.	Reference 57

Comments:

Treated samples were not compared to untreated samples. Cure time was 3 days at room termperature. Unconfined compression strength was 1723 psi. After wet-dry (8 cycles), unconfined compression strength was 1180 psi. Wet-dry cycles consisted of water immersion of samples for 8 hours at room temperature, water drained off, and then samples were subjected to heat for 16 hours in a forced draft oven at 140°F.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Aniline-furfural	3.3% (2.1% aniline and 1.2% furfural)	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	696%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi unconfined compression strength). Samples prior to tests were air-dried for 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 183 psi which was an increase of 696 percent. This material showed potential as a waterproofer.

This material was also subjected to field investigations at the WES as a dustproofer and waterproofer. The results indicated that further investigation was warranted.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Aniline furfural	Aniline - 2% Furfural - 1%	Aniline ($0.16 per lb) Furfural ($0.18 per lb)

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression and traffic	Stabilizer Waterproofer Dustproofer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
$1.18 (1969 cost)	WES	Reference 51

Comments:

Samples for the laboratory tests were molded in a Harvard Miniature Compaction Apparatus. After the samples were taken from the molds, they were air-dried for 4 days followed by wetting cycles by capillary action for 4 days. This completed one cycle. Four cycles were completed prior to sample testing.

Analine furfural proved to be a highly effective waterproofing agent. Numerous ratios and percentages of aniline to furfural were used in determining the most effective combination. The rate given above proved to be all round the most effective.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Aropol 7110	2.6, 6.0, 6.5 and 8.7 lb per sq yd	Not given

Secondary Material		
Solvent - styrene	15, 11.8, 15.5 and 15.4 lb per sq yd	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Ashland Chemical Co.	Reference 57

Comments:
Treated samples were not compared to untreated samples. Samples were cured for three days at room temperature. Strengths for 2.6 lb per sq yd with 15 lb per sq yd solvent and 8.7 lb per sq yd solvent were 1173 and 1890 psi, respectively. After 8 wet-dry cycles, these strengths were 1412 and 2020 psi. Each wet-dry cycle consisted of immersing the samples in water for 8 hours, pouring off water, and then subjecting the samples to heat for 16 hours in a forced draft oven at 140°F.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Arothane 170	4%	Not given

Secondary Material		
Solvent - butyl acetate	3%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Ashland Chemical Co.	Reference 57

Comments:

Treated samples were not compared to untreated samples. Strength after 3 days cure at room temperature was 706 psi. After 8 wet-dry cycles, the strength was 667 psi. Each cycle consisted of immersing the samples in water for 8 hours, pouring water off, and subjecting the samples to heat for 16 hours in a forced draft oven at 140°F.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Bisphenol A (Epon 828)	1.3, 2.6, 5.2, 6.9 and 11 lb per sq yd	Not given

Secondary Material

Catalyst - Ashland #1496	Included with basic material	
Solvent - solox	5.1, 10.4, 14.6, and 16.4 lb per sq yd	

Material Form*	Type of Soil Treated	Mixing Capability
liquid	Sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Ashland Chemical Co.	Reference 57

Comments:

Treated samples not compared to untreated samples. A strength of 1079 psi was achieved as a use level of 5.2 lb per sq yd resin and 5.1 per sq yd solvent. This strength was achieved after three days cure. Wet-dry resistance was determined by immersing the specimens in water for eight hours at room temperature, draining the water, and subjecting them to heat for 16 hours in a forced draft oven at 140 °F. After eight cycles, they were subjected to unconfined compression tests. The strength of the specimens at the rate given above was 1140 psi.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Calcium acrylate	7%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Dustproofer	408%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:
Treated samples were compared to untreated samples (23 psi unconfined compression strength). Samples prior to tests were air-dried for 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 117 psi which was an increase of 408 percent. This material showed potential as a waterproofer.

This material was also subjected to field investigations at the WES as a dustproofer and waterproofer. The results did not indicate that further work with this material should be conducted.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Calcium acrylate	Varied	Not given

Secondary Material
See comments for catalysts and activators

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sandy clay	-

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 31

Comments:

Treated samples were not compared to untreated samples. A series of soil-calcium acrylate solutions with a pH range of 3.7 to 9.9 were studied. It was found that as the pH increased, the tensile strength and flexibility increased. Various inhibitors, activators, and catalysts used with calcium acrylate are shown in the following table:

(Continued on next page)

* Basic material

Inhibitors	Activators	Catalysts
Benzoquinone	Sodium theiosulfate	Ammonium pursulfate
Hydroquinone	Sodium sulfite	Potassium persulfate
Picric acid	Sodium bisulfite	Hydrogen peroxide
Methylene blue	Sodium hydrosulfite	Sodium pyrophosphate peroxide
	Sodium sulfide	Sodium carbonate peroxide
	Potassium ferrocyanide	Sodium perborsilicate
	Ferrous sulfate	Calcium peroxide
	Silver nitride	Urea peroxide
	Stannous chloride	t-butyl hydroperoxide
	Cuprous chloride	1-hydroxycyclohexyl-hydroperoxide-1
	Cupric sulfate	
	Titanium sulfatein	
	Hydrochloric acid	
	Hydroxylamine hydrochloride	
	Hydrazine hydrate	
	Hydrazine sulfate	
	Hydroquinone	
	Catechol	
	Resorcinol	
	Phloroglucinol	
	Dextrose	
	Tetramethylene pentamine	

The properties of a soil stabilized by the in-situ polymerization of calcium acrylate depend on the method of polymerization. The type of redox system used has the most influence. Three satisfactory redox systems were found: ammonium persulfate-sodium thiosulfate, potassium persulfate-sodium thiosulfate, and t-butyl hydroperoxide-sodium thiosulfate.

Category*

Resin

Basic Material	Rate of Material	Cost
Calcium acrylate	Varied	Not given

Secondary Material		
Salt additives (below)	Varied	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 31

Comments:
Treated samples not compared to untreated samples.

a. Ten of the salts tested are -- ammonium, lithium, sodium, magnesium, manganese, and nickel chlorides, and sodium, magnesium, manganese, and nickel sulfates-- had minor effects on the tensile strength.

b. Two salts, calcium chloride and aluminum chloride, increased the tensile strength at the highest ratios.

c. Three salts, zinc chloride, zinc sulfate, and chromium chloride, increased the tensile strength markedly.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Calcium acrylate	Varied	Not given

Secondary Material

Various salts (see comments)

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 32

Comments:

Various salts tested with calcium acrylate are given below. No strength values were given; however, a work description of the test results was given on each salt tested.

Ammonium chloride - No appreciable effect on the strength of samples.

Lithium chloride - No appreciable effect on the strength of samples.

Sodium chloride - No appreciable effect on the strength of samples

(Continued on next page)

* Basic material

Sodium sulfate - No effect on the tensile strength, however, the elongation was increased with increasing amounts of sulfate.

Potassium chloride - Prevented solidification of samples.

Barium chloride - Prevented solidification of samples.

Copper sulfate - Prevented solidification of samples.

Ferric chloride - Prevented solidification of samples

Lead acetate - Prevented solidification of samples.

Magnesiom chloride - No appreciable effect on strength of samples.

Magnesium sulfate - No appreciable effect on strength of samples.

Nickel chloride - No appreciable effect on strength of samples.

Nickel sulfate - No apprecialbe effect on strength of samples.

Manganous chloride - No effect on tensile strength; however, the elongation decreased.

Manganous sulfate - Slight increase in tensile strength and a slight decrease in elongation.

Zinc chloride - Slight increase in tensile strength and a great increase in elongation.

Zinc sulfate - Increased tensile strength, decreased elongation, and samples brittle.

Aluminum sulfate - Increased tensile strength, decreased elongation, and samples brittle.

Chromium chloride - Increased tensile strength, decreased elongation, and samples brittle.

Category*

Resin

Basic Material	Rate of Material	Cost
Epon VIII	20%	Not given

Secondary Material		
Curing agents		
Agent A (amine)	10%	Not given
Diethylenetriamine (see comments)	10%	Not given
Water	35 to 40%	-

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 34

Comments:

Treated samples were not compared to untreated samples.

a. Agent A (amine). After 4 hours curing time in an oven at 110°C, tensile strength of 410 psi for the dry samples was obtained. After soak tests, the strength dropped to 220 psi.

(Continued on next page)

* Basic material

b. <u>Diethylenetriamine</u>. After 4 hours curing time in an oven at 110°C, tensile strength of 400 psi for the dry samples was obtained. After soak tests, the strength dropped to 210 psi.

Samples treated with materials that have to oven cure are impractical for field use.

Category*

Resin

Basic Material	Rate of Material	Cost
Epon 562	10%	Not given

Secondary Material		
70% diethylene triamine	2%	Not given
30% dimethyl aminomethyl phenol	2%	Not given
(above 2 are curing agents)		
Acetone (solvent)	10%	Not given
Potassium hydroxide (KOH)	1%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	See comments

Comments:

The samples where acetone was used as a solvent were compared to samples treated with resin only.

Effectiveness: For the same period of cure time, the samples with the solvent had an increase in tensile strength of 46 percent. Therefore, the solvent is effective for achieving a faster cure rate.

The potassium hydroxide when used with Epon 562 caused a detrimental effect on the strength of the samples.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Epon 828	10% based on wight of dry soil	Not given

Secondary Material		
Xylene	10%	Not given
Curing agents		
Diethylene triamine	20% on weight of resin	Not given
Diethylaminomethyl phenol	20% on weight of resin	Not given
Mixtures of above curing agents	20% on weight of resin	Not given
Polyethylenimine	20% on weight of resin	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference

Comments:

Treated samples not compared to untreated samples. Curing agent, diethylene triamine, when used in preparing test samples, yielded soils with dry and rewet tensile strengths (160 to 200 psi); however, these systems do not develop high strength on curing under wet conditions. These strengths were developed only after one to six days cure time. Diethylaminomethyl phenol as a curing agent yielded soil of low dry and rewet strength (40 and 3 psi) but developed somewhat higher strength of 80 psi, rewet of 70 psi, and also 80 psi strength on curing under wet conditions. The use of polyethyleneimine gave poor results when used as a curing agent.

* Basic material

Category*

Resin

Basic Material	Rate of Material	Cost
Epon 828	10% of dry soil weight	Not given

Secondary Material		
70% diethylene triamine 30% dimethyl aminomethyl phenol (curing agents) Solvents - see comments	2% on dry soil weight	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 37

Comments:

Solvents used were acetone (1 to 3 percent) and zylene (1 percent). These were used separately with the basic material and secondary materials. The treated samples where the solvent was used were compared to samples treated with the resin only.

Effectiveness: The samples where the xylene was used had less tensile strength than those treated with only the resin.

The acetone accelerated the curing of the samples. As compared to
(Continued on next page)

* Basic material

samples treated with only the resin and after one day cure time and 24 hours water immersion, the samples treated with acetone had a strength increase of 66 percent.

Category*
Resin

Basic Material	Rate of Material	Cost
Epon 828	3, 5, and 10%	Not given

Secondary Material		
Curing agent: 7:1 ratio of diethylene triamine to dimethyl aminomethy phonel	20%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay and heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	None

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1956-57), not published

Comments:

Treated samples were compared to untreated samples. Preparation of samples was with a Harvard miniature compaction apparatus, five layers, ten tamps per layer with a 20-lb spring tamper. The samples were tested against C Category 1 stabilization requirements.

Effectiveness: The strength increase of the treated samples as compared to the untreated samples varied from 400 to 600 percent; however, this did not satisfy the requirements.

* Basic material

Category*
Resin

Basic Material	Rate of Material	Cost
Epon 828	20%	Not given

Secondary Material		
Curing agents		
Tetraethylenepentamine	10%	Not given
Diethylenetriamine	10 and 15%	Not given
Water (See comments)	35 and 40%	-

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sandy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Tensile	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 34

Comments:

These samples were cured at room temperatur.

a. Tetraethylenepentamine. Very low tensile strengths were developed after a long curing time of seven days with this curing agent. Effect-inveness - None.

b. Diethylenetriamine. Relatively high tensile strengths were developed (395 to 530 psi with the different rates of the curing agent) after long curing times of 7 to 12 days. The samples after the soak tests retained most of the dry cure strength. Effectiveness - Moderate.

(Continued on next page)

* Basic material

Other curing agents were used with Apon 834 at rates which varied from 6 to 67 percent, depending on which agent was used with 834. Long curing times from three to seven days were required on dry-cured samples and from two to seven days on wet-cured samples. The dry-cured samples had good tensile strengths; however, they were poor after the soak test. Agents used in the dry-cured samples were diethylenetriamine, monothanolamine, benzylamine, hexamethylenediamine, citric acid, polyamide 115, dimethylaminomethylphenol, and 2,4,6-tridimethylaminomethylphonel.

Agents used in the wet-cured samples were citric acid, diethylenetriamine, polyamide 115, and dimethylaminomethylphenol. The strength of the wet-cured samples was poor even after two to seven days of cure time.

Category: Salt

Category*		
Salt		
Basic Material	**Rate of Material**	**Cost**
Arquad 2HT (Dialkyl dimethyl-ammonium chloride)	0.5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Paste	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	374%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi strength). Samples prior to tests were air-dried for 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 109 psi which was an increase of 374 percent. This material showed potential as a waterproofer.

This material was also subjected to field investigations as a waterproofer and dustproofer at WES and the results indicated that further tests of this material were warranted.

* Basic material

Category: Silicate

Category*

Silicate

Basic Material	Rate of Material	Cost
Sodium silicate (30% solution)	14.5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	243%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi unconfined compression strength). Samples prior to tests were aid-dried for 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 79 psi which was a 243 percent increase. This material showed some potential as a waterproofer.

This material was also subjected to field investigations at the WES as a waterproofer and dustproofer. The results indicated that no further tests were warranted.

* Basic material

Category*

Silicate/Other

Basic Material	Rate of Material	Cost
Sodium silicate plus basic magnesium carbonate	Varied (see comments)	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder plus powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with basic materials were not compared to untreated samples. (Sodium silicate is a combination of silicon dioxide and sodium oxide.)

The effects of varying the silica and magnesium contents were studied. For each test, two of the components were held at the same rate while the rate of the third one varied.

(Continued on next page)

* Basic material

Effectiveness:

Silica content varied. 2.51, 3.82, and 5.12 percent with magnesium (1.80 percent) and sodium (1.59 percent) constant. Highest strength achieved was 140 psi at 3.82 percent silica.

Magnesium content varied. 1.20, 1.80, 2.40, and 3.00 percent with silica (5.12 percent) and sodium (1.59 percent) constant. Highest strength achieved was 105 psi at 3.00 percent magnesium.

The most effective combination for stabilization was 3.82 percent silica, 1.59 percent sodium, and 1.80 percent magnesium - 140 psi.

Category*
Silicate

Basic Material	Rate of Material	Cost
Sodium silicate N	21.6%	Not given

Secondary Material		
Solvent - water	3%	-

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Ashland Chemical Co.	Reference 57

Comments:

Treated samples were not compared to untreated samples. Initial tests were conducted after three days cure at room temperature. Strength was 650 psi, After the 8 wet-dry cycles, the strength dropped to 240 psi. Each wet-dry cycle consisted of immersion of the samples in water for 8 hours, pouring off the water, and drying for 16 hours in a forced draft oven at 140°F.

* Basic material

Category*

Silicate

Basic Material	Rate of Material	Cost
Sodium silicate (composed of two components at right)	1.59% sodium oxide 3.82% silicon dioxide	Not given
Secondary Material		
Precipitating agents:		
Magnesium oxide	0.77, 1.03, and 1.54%	Not given
Magnesium carbonate	1.2 and 1.8%	"

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with each precipitating agent were not compared to samples without treatment. Tests were conducted after one day humid cure plus one day water immersion.

(Continued on next page)

* Basic material

Effectiveness: The basic material with 1.8 percent magnesium carbonate was the most effective stabilizer (650 psi).

All rates of each agent were effective in stabilizing the soil. Magnesium oxide (1.54 percent) gave the highest strength with this agent only.

A combination of the two, 1.2 percent magnesium carbonate plus 0.26 percent magnesium oxide, gave a strength of 565 psi.

The reaction of magnesium oxide is very slow; however, it has three advantages over magnesium carbonate: (1) smaller weight must be added to the soil per equivalent of magnesium, (2) magnesium oxide is more dense and less bulky for a given weight, and (3) the carbonate ion is not present in the oxide and the problem of possible sodium carbonate crystallization is eliminated.

Category*

Silicate

Basic Material	Rate of Material	Cost
Sodium silicate (49.8% solids, potassium oxide to silicon dioxide = 1:1.58)	1 and 5%	Not given
Secondary Material		
Precipitant		
Calcium hydroxide	4.12, 2.17, 1.16, 0.46, 0.23%	Not given
Calcium sulfate	2.24%	Not given
Magnesium oxide	1.25%	Not given
Magnesium carbonate	2.63, 1.97, 1.32, 0.53, 0.27%	Not given

Material Form*	Type of Soil Treated	Mixing Capability
White lumps or powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with each precipitant were not compared to samples treated with basic material only. Samples were tested in various combinations (percent) with basic material and precipitants. The most promising based on 24 hours humid cure strength are given in order of effectiveness:

(Continued on next page)

* Basic material

Sodium Silicate %	Precipitant (%)	24 Hours Humid Cure Compressive Strength, psi
5	Magnesium carbonate - 1.97	490
5	Calcium hydroxide - 4.12	282

Category*

Silicate

Basic Material	Rate of Material	Cost
Sodium silicate	See comments	Not given

Secondary Material		
Magnesium carbonate (precipitant)	See comments	Not given

Material Form*	Type of Soil Treated	Mixing Capability
White lumps or powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Tests were run to determine the effect of varying the amount of silicon dioxide in the basic material and varying the amount of magnesium carbonate. A ratio of 1:2 and 1:1.58 sodium oxide (Na_2O) to silicon dioxide (SiO_2) was used with equivalent Mg++ per 100 gm dry soil of 0.0308, 0.0462, and 0.0615.

Effectiveness: The most effective ratio of $Na_2O:SiO_2$ was 1:2 and equivalent Mg++ was 0.0462. The compressive strength of this combination of basic material and precipitant was very high after 24 hours humid cure followed by 24 hours water immersion - 665 psi.

* Basic material

Category*

Silicate

Basic Material	Rate of Material	Cost
Sodium silicate (49.8% solids; sodium oxide to silicon dioxide= 1:1.58)	5%	Not given
Secondary Material		
Precipitant - Magnesium carbonate	1.97%	Not given
Waterproofing agents:		
Octylamine	0.1%	
Arquad 12 (lauryl trimethyl ammonium chloride)	0.1%	

Material Form*	Type of Soil Treated	Mixing Capability
White lumps or powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 39

Comments:

Samples treated with each waterproofing agent were compared to samples treated with precipitant and basic material. Samples were cured for 24 hours and immersed in water for 24 hours then tested.

(Continued on next page)

* Basic material

Precipitant (%)	Waterproofing Agent %	Strength psi	Strength Change Based on Treated Samples Without Waterproofing Agent %
Magnesium carbonate (1.97)	None (0)	380	--
Magnesium carbonate (1.97)	Octylamine (0.10)	417	+10.0
Magnesium carbonate (1.97)	Arquad 12 (0.10)	452	+19.0

Effectiveness: The 24 hours humid cure strength of the magnesium-carbonate-treated samples was 490 psi. After 24 hours water immersion, the strength was 380 psi. This is a dropoff of 22 percent without a waterproofing agent. From these data listed above, the addition of the waterproofing agents had little effect on improving the strength of the samples.

Category*

Silicate/Other

Basic Material	Rate of Material	Cost
Sodium silicate plus calcium hydroxide, Ca(OH)	Sodium oxide - 1.6% Silicon dioxide - 3.8% Calcium hydroxide - o.95, 1.4, 1.9, and 5.7%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder plus powder	Clayey silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Sodium silicate is composed of sodium oxide and silicon dioxide. Strength of samples was determined after 24 hours cure plus 24 hours water immersion. Treated samples were not compared to untreated samples.

The only effective combination of materials was with 5.7 percent calcium hydroxide. A strength value of 173 psi resulted. It was believed that the stabilization was primarily due to the sodium hydroxide rather than the silicate, since the same amount of sodium hydroxide with much smaller amounts of silicate stabilized the soil almost as effectively.

* Basic material

Category*

Silicate/Other

Basic Material	Rate of Material	Cost
Sodium silicate plus basic magnesium carbonate	Varied (see comments)	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder plus powder	Silt	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	MIT	Reference 40

Comments:

Samples treated with basic materials were not compared to untreated samples. (Sodium silicate is a combination of silicon dioxide and sodium oxide.) The effects of varying the silica, magnesium, and sodium contents were studied. For each test, two of the components were held at the same rate while the rate of the third one varied.

(Continued on next page)

* Basic material

Effectiveness: Silica content varied. 2.51, 3.82, and 5.12 percent with magnesium (1.8 percent) and sodium (1.59 percent) constant. Highest strength achieved was 180 psi at 5.12 percent silica.

Magnesium content varied. 1.20, 1.80, and 2.40 percent with silica (5.12 percent) and sodium (1.59 percent) constant. Highest strength achieved was 235 psi at 2.40 percent magnesium.

Sodium content varied. 1.59, 2.14, and 3.24 percent with silica (5.12 percent) and magnesium (1.80 percent) constant. Highest strength achieved was 350 psi at the 2.14 percent sodium.

The most effective combination for stabilization was silica (5.12 percent), magnesium (1.80 percent), and sodium (2.14 percent) - 350 psi.

Category: Other

Category*
Other

Basic Material	Rate of Material	Cost
Chrome lignin	5%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	335%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi unconfined compression strength). Samples prior to tests were air-dried for 4 days followed by 4 days wetting by permeation. The strength of the treated samples was 100 psi which was an increase of 335 percent. The material showed promise as a waterproofer.

This material was also subjected to field investigations at WES as a dustproofer and waterproofer. However, the results did not indicate the need for further tests of this material.

* Basic material

Category*

Other

Basic Material	Rate of Material	Cost
Lignin (clarion extract)	1% (5%)	Not given

Secondary Material		
Sodium dichromate	0.17% (0.82%)	Not given
Sulfuric acid	0.17% (0.82%)	Not given
Sodium chloride	0.17% (0%)	

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	See comments

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	Cornell University	Reference 5

Comments:

Treated samples were compared to untreated samples. These samples were allowed to air cure for varying amounts of time. Comparisons of strengths are given below. The numbers in parentheses give the amount of each material used in a second test.

(Continued on next page)

* Basic material

Basic Material	Basic Material %	Cure Time Days	Strength psi	Strength Change Based on Untreated Samples %
None	0	2	83	--
None	0	9	210	--
None	0	28	407	--
Lignin	1	1	25	Negative
Lignin	1	29	541	+33
Lignin	5	2	71	Negative
Lignin	5	14	404	+93

Effectiveness: After long periods of time, samples treated with 1 and 5 percent lignin have an increase in strength with the 5 percent treatment the most effective.

Category*

Other

Basic Material	Rate of Material	Cost
Powder A plus powder B	6.5 and 13%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	loess and heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Good

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1974), not published

Comments:

Treated samples were compared to untreated samples (24 psi). Samples were prepared with a Harvard miniature compaction apparatus, five layers, each layer ten tamps of a 40-lb spring tamper. Prior to tests, samples were cured at 100 percent relative humidity followed by 24 hours water immersion.

Effectiveness: Loess - the 6.5 and 13 percent rates produced strength increases of 259 and 389 percent over the untreated samples.

Heavy clay - None. Samples disintegrated when subject to water immersion.

* Basic material

Category*
Other

Basic Material	Rate of Material	Cost
SA-1	See comments	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay and heavy clay	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1974), not published

Comments:

Preparation of the samples was with a Harvard miniature compaction apparatus, ten tamps on each of five layers with a 40-lb spring tamper. The treated samples were compared to untreated samples.

Rate of material: Lean clay - 0.5 milliliter SA-1 to 99.5 milliliter of water

1 milliliter SA-1 to 999 milliliter water

1.5 milliliters SA-1 to 998.5 milliliters water

(Continued on next page)

* Basic material

2 milliliters SA-1 to 998 milliliters water

Heavy clay - 0.5 milliliters SA-1 to 999.5 milliliters water
2
2 milliliters SA-1 to 999 milliliters water

Effectiveness: Lean clay - The only rate that met the requirements of Category 2 stabilization was the third rate above.

Heavy clay - The only rate that met the requirements of Category 2 stabilization was the second rate above.

Although the rates stated met the requirements of Category 2 stabilization, portland cement at 6 percent gave higher rates and is a cheaper material.

Category*
Other

Basic Material	Rate of Material	Cost
Sundcrete	3%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Lean clay and sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent for clay

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Internal Data (1972), not published

Comments:

Preparation of samples was with a Harvard miniature compaction apparatus using ten tamps on each of five layers with a 20-lb spring tamper. Treated samples of the lean clay soil were compared to untreated samples. The untreated sand samples fell apare and could not be tested.

Effectiveness: Sand - After 24 hours humid cure, the strength of two samples was 144 and 186 psi. Two other samples were, in addition to the 24 hours humid cure, immersed in water for 24 hours. The strengths of these samples were 228 and 231 psi. Sand treated samples therefore met the requirements of Category 2 stabilization.

Lean clay - Slight increase in strength; however, not enough to satisfy Category 2 stabilization.

* Basic material

Category*
Other

Basic Material	Rate of Material	Cost
Sodium methylethyl propyl siliconate	1.0%	Not given

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Liquid	Loess	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer Waterproofer	417%	Excellent

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Not given	WES	Reference 24

Comments:

Treated samples were compared to untreated samples (23 psi unconfined compression strength.) Samples prior to tests were air-dried for 4 days wetting by permeation. The strength of the treated samples was 119 psi which was an increase of 417 percent. The material showed promise as a waterproofer.

This material was also subjected to field investigations at the WES as a dustproofer and waterproofer. The results indicated that further tests of the material were warrented.

* Basic material

Category*
Other

Basic Material	Rate of Material	Cost
Soil-Set	3, 7, 10, 20, and 30%	$0.75 per lb

Secondary Material

Material Form*	Type of Soil Treated	Mixing Capability
Powder	Lean clay, heavy clay, and sand	Good

Type of Test	Purpose of Material	Effective Strength Increase	Effectiveness
Unconfined compression	Stabilizer	See comments	Excellent for clay

Total Material Cost Per Cu Ft of Treated Soil	Test Agency	Test Report
Cost will vary from $2.50 to $7.00 per sq yd per in.	WES	Internal Data (1966), not published

Comments:

Treated samples were compared to untreated samples. Samples when tested to satisfy emergency requirements were prepared in a Harvard miniature compaction apparatus, ten tamps on each of five layers with a 20-lb spring tamper. Samples were cured for 2 hours in 100 percent relative humidity and then subjected to tests. Samples when tested to satisfy routine requirements were prepared in a Harvard miniature compaction apparatus, ten tamps on each of five layers with a 40-lb spring tamper. Tests were then conducted after a 24-hour cure of the samples under 100 percent relative humidity. Other samples were subjected to 24 hours humid cure followed by 24 hours water immersion.

(Continued on next page)

* Basic material

Effectiveness: Emergency requirements: Approximately 14 percent and 8 percent Soil-Set are required to increase the strength of the lean and heavy clay, respectively, from 1 to 2 psi to 20 psi or higher in 2 hours.

Routine requirements: Approximately 6.5 and 9.0 percent of Soil-Set are required for lean and heavy clay, respectively, to increase the strength from 20 to 100 psi in 24 hours.

The strength developing ability of Soil-Set treated fine sands is a function of water content. For water content of 5 to 10 percent, approximately 15 percent Soil-Set by dry soil weight is required to satisfy routine requirements. Excessively wet sands (water content >20 percent) do not respond to treatment by Soil-Set.